

# COMPENDIUM OF NATIONAL RESEARCH AND EDUCATION NETWORKS IN EUROPE

2017



# GÉANT COMPENDIUM OF NATIONAL RESEARCH AND EDUCATION NETWORKS IN EUROPE

2017 edition

compendium.geant.org

#### 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.

The GÉANT NREN Compendium may be found online at: https://compendium.geant.org/

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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 peculiarities such as the political situation, the history of the organisation and its relationship 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 in size and form of the early NREN communities. Each NREN was set up in a form that suited a country's needs and background. Although all survey respondents were NRENs, they are far from being a homogeneous community. It is important to recall 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, which differs between national authorities. As well as infrastructure limitations, why an NREN connects or does not connect 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 research and development firms.

An example infrastructure difference is outlined here: 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 comparison, there are networks without regional branches, which connect institutions directly and have a clear view of an NREN's connected institutions.

Such diversity, although puzzling at times, is an inherent characteristic that is vital to preserve, because the current shape into which NRENs have grown comes from their unique environments, which have fostered their scientific, educational and cultural communities.

# **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 and beyond.

National research and education network (NREN) organisations run special Internet 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, connecting over 50 million users.

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 the world's NRENs to provide detailed information about their network, equipment and users [SURVEY]. The results from this survey are highlighted here. Reports compiled from NREN data may also be generated from the online version of the Compendium [COMPENDIUM].

The diversity and complexity of the NREN community 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 that provides a base upon which NRENs can inform and build their strategic decisions.

The Compendium shows the actions NRENs are taking to meet users' requirements and help them in their research, teaching and learning activities. Unlike many other studies, it is not just a collection of desk research put together by a small editorial team. It reflects the people who carry out this work, from the executive directors, to technical officers, to service portfolio strategists and many more professionals. Almost 500 people participated in the joint effort of this edition by providing facts and figures to populate the rich and colourful picture it presents. Subject matter experts reflected on all of the NRENs' 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 GN4-2 project with its 40 partners, is the largest and most advanced R&E network in the world, connecting over 50 million users.

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. Through its integrated catalogue of connectivity, collaboration and identity services, GÉANT, together with its 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 38 NRENs, reaching over 50 million users in 10 000 institutions across Europe, and more than 100 countries worldwide through links with other regions. The core backbone is capable of supporting multiple 100Gbps wavelengths 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 is to raise European research to the next level, promoting scientific excellence, access and use of research data. It also aims to drive European-wide cost efficiencies in scientific infrastructure through the promotion of interoperability on an unprecedented scale with other e-infrastructures [GN4-2].

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 [Internet2], [ESnet], [CANARIE]. 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 reaches 66 NRENs beyond its European footprint. The projects include: AfricaConnect2, supporting pan-African connectivity and interconnections to Europe; EAPConnect, for the Eastern Partnership countries; as well as CAREN, in Central Asia, and EUMEDCONNECT3, in the eastern Mediterranean region.

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. GÉANT offers 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.

### **2.1 Key Findings**



Figure 2.1: NREN respondents to the 2017 Compendium Survey (in green)

The 2017 Compendium survey shows an ever-evolving NREN user landscape. Many more NRENs now reach beyond their traditional remit of providing connectivity to researchers and university students, with schools representing four-fifths of NRENs' user base (mainly primary schools).

The environment in which the networks operate still varies considerably. Some networks operate in a liberalised telecommunications market where access to bandwidth and technology is unconstrained by regulation or monopoly. This is generally true of the national networks. The regional networks are often much more constrained by funding and infrastructure availability.

Acceptable use policies (AUP) allow an NREN to assess its user base and identify areas for development. According to the latest Compendium survey, there are no apparent changes to these policies, with the exception of slight development on the number of commercial organisations (for-profit) able to connect.

Based on the received responses (95% of NRENs responded, as shown in Figure 2.1), the budget NRENs have for their activities posted a 2% increase since the last survey, at an average of circa EUR12 million. This is comparable to the previous year's responses. One-third of respondents observed no change to their activity budget, and one-fifth witnessed a budget decrease.

Overall, the number of personnel increased by 10%, in proportion with the increase in NRENs' activity budgets. This growth is predominantly in Southern and Western European regions.

The volume of traffic NRENs carry continues to rise. Half 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 2017. More than half of the NRENs who responded forecast average traffic growth to be circa 49% by 2020, across all organisations within the NRENs' remit. The second highest growth after universities and research institutions are schools, with 61% anticipated traffic growth.

With regards typical connectivity to universities, there has been no change from last year. The capacity ranges between 1Mbps up to 100G. Over half of respondents indicate 1G as typical capacity for connected universities and research institutions. Both of these institution types are the best connected, with the largest share of typical connectivity of 10G. In recent years, the role of NRENs has become more than just a connectivity and commodity provider. Trust and Identity (T&I), mobility and security are still important areas of development, with Distributed Denial of Service (DDoS) remaining the biggest perceived security threat. Network monitoring and support of the national deployment of GDPR is also high on NRENs' priorities for 2018.

2017 was also another year of expansion for eduroam, which saw a 17% increase in international authentications and a 14% increase in national authentications compared with the previous calendar year. In total, over 2.9 billion national authentications and more than 694 million international authentications were recorded in 2017.

Constant changes in national networks and take-up of new technologies are needed to support dynamic and growing user needs. Legislation and regulation, standardisation and scalability are common issues affecting the adoption of new services, especially cloud services, now delivered by 95% of GÉANT partner NRENs.

# **3. 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 expanded skill sets not traditionally found within NREN organisations. This expansion in activity is in contrast to national organisations coming under increased funding pressure.

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

### **3.1 Budget Dedicated to NREN Activities**

As shown in Figure 3.1, the amount of budget NRENs have for activities such as networking, trust and idenity, and security posted a 2% increase in 2017, at an average of circa EUR12 million, which is comparable to the previous year's reponses. It is important to also note that 50% of NRENs have budgets of less than than EUR10 million. One-third of respondents observed no change to their activity budget, and one-fifth witnessed a budget decrease (CYNET, EEnet, FCCN, GARR, ULAKBIM & DFN).

A decreased or flat budget has not been reported for all NRENs in 2017. Some respondents had notable budget increases. The highest growth rates were noted amongst the Eastern Partnership countries of: Belarus, BASNET (96%); Moldova, RENAM (73%); and Georgia, GRENA (20%); largely due to the funds received for participation in the EAP Connect project and a NATO infrastructure grant, which allowed the procurement of a significant amount of equipment [EAPConnect]. Increases were also noted at NIFF, LITNET & IUCC, HEAnet.

According to LITNET, the budget increase was due to funding from structural funds, for development and deployment of new services. During 2018, LITNET planned to purchase and deploy infrastructure improvements, including the upgrade of its national optical backbone deploying Open Optical Line System (OOLS) from day 1, in metro area networks of Vilnius and Kaunas, where major R&E institutions are connected. LITNET's total investment is in range of EUR2.7M, with an operational budget at EUR4.2M. These measures represent a temporary increase. The last round of the structural fund procurement is anticipated in 2019, and then funding should return to 'normal' funding levels of EUR1.5M–1.6M.



Figure 3.1: Budget available to European NRENs, 2016 vs 2017

#### **3.2 Income Sources**

It is impossible to make general assumptions on NREN funding mechanisms, due to the way NRENs are funded. Some receive all of their funding directly from the national government, some are funded entirely by their users (via the user institutions), and others have a model based on multiple sources of income.

Some NRENs receive income from the commercial services they offer (such as domain registration fees and security). The 2017 Compendium data shows a slight increase in funding from commercial services in comparison to 2016. Additional detail of source per NREN, and organisation type is shown in Table 3.1

	CLIENT INSTITUTIONS	COMMERCIAL	GEANT SUBSIDY	GOV/Public BODIES	OTHER EU	OTHER
ACOnet						
AMRES						
ARNES						
ASNET-AM						
AzScienceNet						
BASNET						
CARNet						
CESNET						
CYNET						
DFN						
EENet						
FCCN						
Funet						
GARR						
GRENA						
GRNET S.A.						
HEAnet						
IUCC						
KIFU (NIIF)						
LITNET						
MREN						
RedIRIS						
RENAM						
RENATER						
RESTENA						
RoEduNet						
SUNET						
SURFnet						
SWITCH						
URAN						

OVER 75%

Table 3.1: Estimated income sources per NREN, 2017

25% TO 75%

LESS THAN 25%

### 3.3 Staffing

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

Overall, the number of personnel increased by 10% in 2017, in proportion with the increase in NRENs' budgets covered in Section 3.1. This growth is predominantly in Southern and Western European regions.

The number of subcontracted staff members grew by 34%. This can be attributed to improvements in infrastructure, e.g. network upgrades, an expansion of activity to include other EC projects, and innovation and adaptation of new services administered by NRENs, which require more staff.



Figure 3.2: Number of staff engaged in NREN activities

Figure 3.3 provides information on the number of staff engaged in NREN activity, by function. The data shows a considerable difference in skill sets from NREN to NREN and, as expected, a high ratio of technical staff (Information Security, IT/Software development, NOC+Engineer). However, the latter did drop slightly when compared to 2016 Compendium data.

NRENs perform different tasks – some provide extensive support to individual end-users at institutional 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 3.3: NREN Staff FTE by function

#### **3.4 Policies and Service Portfolio**

Table 3.2, following, gives an overview of NRENs corporate and other policies. The 2017 Compendium survey shows that 26 NRENs already have an acceptable use policy, and out of 31 respondents, 25 have a connectivity policy in place (more details, including a link to the AUP, can be found online [AUP).

	User acceptance policy	Environmental Policy	Connectivity Policy	Updates made corporate strategy
				over the last year?
ACOnet				
AMRES				
ARNES				
ASNET-AM				
BASNET				
CARNET				
CESNET				
CYNET				
EENet				
FCCN				
Funet				
GARR				
GRENA				
GRNET S.A.				
HEAnet				
Jisc				
LITNET				
MREN				
KIFU (NIIF)				
RENAM				
RENATER				
RoEduNet				
SUNET				
SURFnet				
SWITCH				
ULAKBIM				
UNINETT				
URAN				
PIONIER				
AzScienceNet				
SANET				
Grand Total	26	7	25	6

Table 3.2: NRENs corporate and other policies, 2017

#### **3.4.1 NREN Services**

In recent years, the role of an NREN has become more than just a 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 to not only satisfy the current requirements of their user communities, but to also 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. Overall, the number of NREN services offered to end users increased by 22% since the last survey. This included increase of multimedia services doubled (+100%), network (+42%), Security-T&I (+11%), and professional service such as Web/desktop conferencing, User conferences, consultancy and training (+9%).

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



Figure 3.4: NRENs' end-user services

# **4. END USERS**

The NREN end-user landscape (namely, the 'end users' of the GÉANT network: universities, research institutes, 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, which can include 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.

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].

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.

### 4.1 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 2017 Compendium data, there are no apparent changes to last year, with the exception of a slight change to the number of commercial organisations (for-profit) connected to the network.

An overview of acceptable use for each country, including a link to the AUP, can be found online [AUP].

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

The connectivity to for-profit organisations is not usually part of an NREN's remit and, if it takes place, it often involves restrictions such as connectivity being limited to a specific research project or connectivity only allowed with the endorsement of an already connected research institution. Figure 4.1 gives an overview who can connect to NRENs.



Figure 4.1:NRENs' connectivity remit

### 4.2 The NREN User Landscape

The 2017 Compendium survey shows there has been a significant change in the NREN user landscape.

Many NRENs now go beyond their traditional remit of providing connectivity to researchers and university students, with schools representing four-fifths of NRENs' user base (mainly primary schools). See the GÉANT report, *NREN Survey Results for Access and Connectivity of Schools in Europe* for more information [SCHOOLS SURVEY].

From 34 respondents, the number of schools connected to NREN network surged by 28%, from 25 460 (2016) to 32 543 (2017). Although smaller figures, the number of government institutions grew by 75%, and not-for-profit organisations by 57%, in line with the remit of which institutions NRENs connect (as covered in Section 4.1). The range of institutions connected to NREN networks has remained similar in 2016 and 2017, as shown in Figure 4.2.



Figure 4.2: Range of institutions connected to NREN networks

### **4.3 Approximate Market Shares**

This section covers the estimated market share per institution type, per NREN. Overall market share distribution in 2017 is comparable to the 2016 Compendium results, with the exception of the previously noted increase in market share coverage for schools. Universities and research institutes represent the largest market share, with full or nearly full coverage across most NRENs, reflecting the formal remit of the NRENs.

OVEF	R 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		10	2			5	1	50	5	59
ARNES		90	10		80		90	90	90	100
ASNET-AM										
AzScienceNet										
BASNET										
CARNet	1		2		1			95	1	100
CESNET		10		10			1	95	5	95
CYNET								70		100
DFN										
EENet			6	44				16		90
FCCN										
Funet										
GARR				20	0.5	4.4	0.8	80	4.7	60
GRENA								1		
GRNET S.A.							100		100	
HEAnet		85	5	30			98	50	100	100
IUCC										50
Jisc		100								100
KIFU (NIIF)				50	5	5	90	99	90	72
LITNET	1	78	10			10				80
MARnet										20
MREN										
PIONIER										
RedIRIS			5			20		95		90
RENAM		11	5		9	7		80	0.01	72
RENATER								100		100
RESTENA			20				80	95	100	80
RoEduNet		50	10					80		90
SANET		95	5		10	5	10	70		98
SigmaNet										
SUNET		100								100
SURFnet	2	90		20	5	6	8	90	8	100
SWITCH										100
ULAKBIM		50	2							95
UNINETT		100			10			80		100
URAN	1	10	5	10	5	5		90	100	1

Table 4.1: Approximate market shares (%)

### **4.4 Typical and Highest Capacity of Connected Institutions**

Overall, there has been no change to the typical connectivity to universities from 2016 data. The common capacity ranges between 1Mbps up to 100G. Over half of respondents indicate 1G as typical capacity for connected universities and research institutions. Both of these institution types are the best connected, with the largest share of typical connectivity of 10G.



Figure 4.3 and Figure 4.4 show the typical and the highest capacity of connected institutions to those GÉANT partner NRENs who responded.

Figure 4.3: Typical capacity of connected institutions – GÉANT partner countries



Figure 4.4: Highest capacity of connected institutions – GÉANT partner countries

### 4.5 Connectivity to and for Commercial Organisations

In 2017, an increased number of NRENs connected linked commercial institutions. As mentioned in Section 6.10.2, most acceptable use policies (AUPs) do not allow such connections. 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 4.5: 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 deviate from its core function within a country. Figure 4.6 shows an overview of the different types of relationships NRENs are supporting with for-profit entities.



Figure 4.6: Connectivity policy for commercials

# **5. INVOLVEMENT IN EC PROJECTS**

In addition to the GN4-2 project, there are a number of 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 (einfrastructures). 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 5.1 gives an overview of NRENs' interaction with EC projects other than GN4-2. The data shows 54% of NRENs participating in a total of in 57 unique EC projects. See Section 6.10.2 for an overview of international research projects.



Figure 5.1: NRENs interaction with other EC projects – Total projects per NREN

# **6. NETWORK**

Network is a vast, generic term that could cover many aspects of infrastructure and communications technology in varying levels of detail. Within this section, network is defined as a snapshot of the services, infrastructure and monitoring tools that NRENs use to connect their users.

NREN networks, like the countries they reside in, are unique and 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. It also looks at respondents' views of the future, including the move towards a software-led approach offered by software-defined networking (SDN) [SDN].

### **6.1 Network Traffic**

This section considers the growth in NREN traffic and changes in traffic type and destination. Figure 6.1 and Figure 6.2 show the estimated total amount of traffic per NREN, from external networks and from NREN customers, respectively, per NREN. The data in this section has been augmented with data from GÉANT's Deepfield application to provide a better 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. Half of NRENs reported a rise in traffic, and the data highlights the wide variation in traffic from GÉANT partner NRENs: From Jisc, with more than 470 000Tbytes of data from outside the NREN to Cynet, with 15Tbytes. Overall, GÉANT recorded 43% traffic growth in 2017.



Figure 6.1: NRENs' estimated traffic from external network (sources outside an NREN's domain, such as GÉANT, general/ commercial Internet, Internet exchange, peerings, and other NRENs)



Figure 6.2: NRENs' estimated traffic from NRENs' end users (sources that are part of the NREN's remit = domains)



Figure 6.3: Traffic growth NRENs' (based on 20 respondent NRENs)

### **6.2 Traffic Growth**

New to the Compendium this year was a question about anticipated traffic growth in the next three years, by institution sector and by NREN.

More than half of the NRENs who responded forecast average traffic growth to be circa 49% by 2020, across all organisations within the NRENs' remit.

The second highest growth after universities and research institutions are schools, with 61% traffic growth, in line with the trend covered in Section 4.2 NREN User Landscape and Section 4.3 Approximate Market Shares.

Table 6.1 gives an overview of the expected traffic growth in the next three years by NREN, by institution type.

ACOnet50ASNET-AMAAzScienceNetCESNETCESNET5CYNET3	50		50	50	100	50	100	100
ASNET-AM AZSCienceNet CESNET 5 CYNET 3	5		20					
AzScienceNet CESNET 5 CYNET 3	5		20			80		80
CESNET 5 CYNET 3	5					50		30
CYNET 3		10		5	5	10	5	10
						2		23
EENet 30	15		35		30	50	40	30
FCCN	50	20				50	99	70
Funet	77		43			60		31
GARR 20	20	100	20	100	100	100	100	100
GRENA 75	30	80	40		90	60	90	70
HEAnet 30					40	30	41	30
Jisc 50 90	50	50	50	50	90	90	90	
MREN	10		10			10		50
RedIRIS	75		75	75	100	75	90	
RENAM 10								20
RoEduNet								
SigmaNet 20						20		20
SUNET								
SWITCH 35 35	35	35	35	35	35	35	35	35
ULAKBIM 75	60		49			75		50
UNINETT								1
URAN 80	90	30	20	90		20		90

LESS = 40 Table 6.1: Percentage of forecast traffic growth per NREN in three years' time

### 6.3 IPv6

OVER 40

IPv6 is the most recent version of the internet protocol (IP). 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. It should be noted that the top users vary from time to time, as this traffic tends to be bursty [IPv6].

Figure 6.4 shows the IPv6 traffic average into GÉANT from its partners during January 2018. A large part of this IPv6 traffic into the NRENs originates from CERN [CERN]. Overall, only 3.8% of GÉANT traffic is IPv6.



Figure 6.4: GÉANT IPv6: Top NREN traffic sources. [Source: GÉANT Deepfield tool]

### **6.4 Network Infrastructure: Dark Fibre**

The R&E community has substantially built up the ownership of dark fibre over recent years. In 2017, NRENs reported a total of around 130 000km of dark fibre. Dark fibre refers to fibre leased or purchased from another supplier in an unlit state, hence the name 'dark' fibre. The fibre is then lit using laser-based DWDM transmission technology by the NREN. Together with the GÉANT install base of around 11 000km of intercity dark fibre, this forms a strong community infrastructure.



Figure 6.5: Number of respondent NRENs/Length of dark fibre

The NREN community is now working together to actively pool resources through the JRA1 T1 task in the GN4-2 project. The project has identified that by interconnecting NREN fibre by purchasing Cross Border Fibre (CBF) and then making the international fibre available to GÉANT, the community can better increase the traffic fill on the fibre and reduce the cost to all members of GÉANT.

Some examples of cross-border dark fibre that are currently in use in the NREN community include:

- Amsterdam-Hamburg fibre is provided by SURFnet and lit with 500G using GÉANT Infinera equipment.
- Prague-Vienna pilot of CESNET fibre, lit using Ciena equipment carrying a GÉANT 100G IP trunk.
- London-Dublin fibre is provided by Jisc and lit with 2 x 10G Ciena equipment from Jisc.
- Madrid-Lisbon fibre is provided by RedIRIS and FCCN and lit with their transmission equipment.

Figure 6.6 shows the number of kilometres of fibre each NREN has reported in its own network.



Figure 6.6: Number of kilometres of NREN IRU

### **6.5 Alien Waves**

In the optical transport world, the term alien wavelength or alien wave (AW) is used to describe wavelengths in a dense wavelength division multiplexing (DWDM) line system that traverse the network but are not sourced/terminated by the line system vendor's equipment. This setup is in contrast to traditional DWDM systems, where the DWDM light source (transponders) is in the same management domain as the amplifiers [Transponder].

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

According to the survey results, the number of NRENs using Alien waves internally on their network is comparable to the previous year results (46%). Just over half of all European NRENs who responded (51%) are either using AWs now or plan to do so in the near future.

### **6.6 IP Trunks**

NREN fibre is being increasingly lit using 100G technology. We can see that while 11 NRENs report Internet Protocol (IP) trunks of 10Gbps, another 10 already have IP trunks of 100Gbps or above. As can be seen in Figure 6.7, from the 30 NREN respondents, 20% posted an increase on usable backbone capacity compared to the previous year.



Figure 6.7: NRENs current typical core usable backbone IP trunk (Gbps)

### **6.7 Network Peering**

Network peering refers to the direct exchange of traffic between two networks. Most NRENs are now choosing to 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, peering with non-R&E networks grew by 7% from 2084 in 2016, to 2225 in 2017. Much of this growth was due to a significant increase in peering from SWITCH, URAN, SURFnet and CARnet.





Figure 6.8: Number of non R&E network peering

### **6.8 Network Innovation: SDN and NFV**

As in previous years, NRENs are actively deploying SDN in their networks. Of the 30 NRENs that responded, half are either using, or are planning to use, SDN in their NREN. The majority are using either NETCONF or OpenFlow APIs. The preferred SDN controllers are OpenDayLight (4 NRENs) and ONOS (3 NRENs) [NETCONF], [OpenFlow], [OpenDayLight], [ONOS].

Of the 19 respondents, SDN was intended to be used as follows (note this is >100% as some NRENs are using SDN for multiple purposes):

Pilot services	32%
Production services	32%
Testbed facility for researchers	47%
To provide/support other operational services	32%
Other	16%

These responses show that there remains a strong interest in SDN in the NREN community. It should be noted that SDN seems to have found some specialised uses, in particular within testbeds, the largest single use.

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 [NFV].

When surveyed, 14 NRENs responded that they were either using or planning to deploy NFV in their network. The responses were divided up as follows: (note this is >100%, as some NRENs are using NFV for multiple purposes).

Firewalls	71%
Load balancers	36%
Routers/switches	71%
VPN Concentrator Services	57%
Other	14%

### **6.9 Network Services**

IP has historically been at the core of the services delivered to the NRENs. In 2017, this remained the case. Availability of the IPv6 service is now at 82% of NRENs. The breadth and depth of the services provided by the NRENs is a testament to the value that they offer to their users. The most ubiquitous network services are monitoring, troubleshooting tools and Net-Flow data. The next most common set of services are 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 to a lesser extent, L3 VPNs. Optical wavelengths continue to rise in popularity as a service and security and research platforms are also important services.

The over-the-top services (one or more service delivered across an IP network, which bypasses traditional distribution) being offered by NRENs include an extremely varied and rich set of services. Over-the-top services include: videoconferencing, virtual dedicated networks, Remotely Triggered Black Hole (RTBH) filtering, IPTV, cloud services, eduroam, CloudStor, hosted IP telephony, software distribution depository, cloud data storage, purchasing and admin, and digital exams [CloudStor].

End User Network Services	% of NRENs offering
Ipv4	94%
WiFi	94%
IP Connectivity	91%
DDos Mitigation	88%
Lambdas	85%
IPv6	82%
Network Monitoring	79%
Multicast	64%
LAN Extension/Virtual Network	58%
L2VPN	48%
Software Mirroring/FTP	48%
End User Monitoring/Troubleshooting Tool	45%
NetFlow	42%
Optical Wavelength	42%
Software as a Service	36%
L3VPN	33%
Managed Router Service	33%
PERT	33%
QoS	33%
Other Network Service (not named)	33%

End User Network Services	% of NRENs offering
Anti-virus Software	30%
VPN Client Access	30%
Network as a Service	21%
Disaster Recovery	18%
SDN Testbed	12%

Table 6.2: NREN end-user network services – percentage of NREN responses

# 6.10 GÉANT Network Updates

### 6.10.1 GÉANT Network and Statistics

The GÉANT network interconnects 44 networks in Europe and has: 31 active routers; 19 Infinera nodes; 727 10G and 136 100G active interfaces; 2 SDH interfaces and 206 1G active interfaces. This section presents a specific snapshot of the GÉANT network, including statistics such as IP/MPLS traffic growth.



Figure 6.9: GÉANT pan-European network topology map (January 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. 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 receives over 620Gbps of traffic at peak time, with a daily average of over 430Gbps. The year-on-year (YoY) growth rates on the IP/MPLS network slowed down for 2017 to 33% vs the 64% recorded for the 2016; science data growth was still faster than the internet service, with a 43% vs 26%. IP/MPLS YoY averaged growth rate for the three years period we have data for is still high at 48%.

The busiest part of the network is the Western Ring, where IP/MPLS links are currently at 200G with daily peaks now reaching 100Gbps, 150+ when rerouting, on the Amsterdam-Frankfurt link.

In terms of the daily average for 2017, the IP/MPLS network received 3.13PB of data, 3.13 million gigabytes, or an average daily rate of 289Gbps. The total, including lambda services, is 4.79PB, or an average daily rate of 444Gbps.

#### **Regional studies**

Network evolution is not possible without first listening to NREN requirements to gain a better understanding of user requirements, especially any specific regional needs of a network build. Regional studies provide a forum for European NRENs within a specific region to get together and set a vision for how they would like the GÉANT network to evolve in coming years. Five regional studies have been initiated in 2017 and are due to be completed mid-2018: South East Europe, Baltic region, UK/Ireland, Iberian Peninsula and the GÉANT core.

These studies investigate the capacity requirements in their regions, with growth expectations for the next 15 years. The studies collect data on the fibre infrastructure available in the region and use this information to propose an optimal regional network architecture.

While similar studies have been carried out in the past, this year the studies are particularly interesting to the community as the European Commission has made available an specific grant agreement (SGA) for fibre IRU.

The Regional Studies report will be used as an input for the design of the future GÉANT network.

#### Transmission

The GÉANT network is an IP backbone built on a dark fibre and lease circuit transmission network. At the heart of the network is the objective to achieve an uncongested capacity and high reliability network. With the projected exponential traffic growth driven by the requirements of big science projects such as LHC, SKA and others that have large, sometimes unpredictable, requirements, alongside the desire to provide a platform to integrate e-Infrastructures, GÉANT has been reviewing its transmission technology [SKA].

The current GÉANT optical network is based on the Infinera DTN-X platform and is managed by Infinera DNA. There is currently no disaggregation of the GÉANT network's optical layer; the entire transport network acts as one 'black box' network. This platform delivers fast turn-up of carrier-grade services, lambda services, and the trunks between GÉANT routers.

In 2017, GÉANT decided that while the current transmission technology was reliable and easy to use, it was no longer scalable to the match traffic growth at a sustainable cost.

At the transmission layer, the GÉANT network will take advantage of the developments of Open Line Systems (OLS) principles. The next network upgrade will be OLS-compliant, which will allow for 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 happen in 2020–21.

In the meantime, GÉANT will make use of the PRISM framework contract that is already in place to use Data Centre Interconnect (DCI) equipment to add new IP trunks to the GÉANT network. With the commoditisation of coherent DWDM optics now available in low-cost DCIs, it is possible for GÉANT to provision capacity on fibre routes, avoiding technological and cost constraints often introduced in traditional carrier-grade transmission systems. Cost analysis has shown up to 80% savings may be possible using DCIs.

The current GÉANT network has 23 European dark fibre routes. Most of the underpinning agreements will expire in 2020–21, which provides an ideal opportunity to reconsider the topology, and renew the optical platform at the same time.

#### Disaggregation

The GÉANT network's primary function is to maintain connectivity between the provider edge nodes, which deliver network connectivity services to the NRENs. As GÉANT is currently using a single vendor solution for network packet layer, GÉANT remains dependent on that vendor's innovation curve for new features in both its hardware and software. Since the vendor has to provide converged functionality on the platform, innovation cycles are slowing.

By disaggregating the network into modular architecture, GÉANT will be able to offer a service edge for big science users. The service edge enables big science users to instantiate services, such as Network Function Virtualization (NFV), locally, and only use the GÉANT and NRENs core network for connectivity to the other service edges.

The big science experiments, the exascale computing and rapidly evolving environment needs infrastructure with the ability to quickly and flexibly scale. Large, monolithic converged platforms are becoming an obstacle to GÉANT network innovation and growth and are being replaced by new disaggregated modular architectures.

In GN4-2, GÉANT has been working to develop technologies to disaggregate the technology and openly deliver a programmable, high-capacity network. This work aims to allow close interaction with applications and projects, multi-domain orchestration and virtual networks, and will allow the improved, optimal use of community resources.

#### 6.10.2 GÉANT Interaction with International Research Projects

GÉANT works closely with NREN partners to support Europe's user communities. The highly dedicated, specialised User Engagement team caters for varied and complex requirements in a structured manner.

Interactions between users, account managers, and a lead NREN 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 large part of the GÉANT User Engagement team's job is to engage with user communities, by participating in area-specific events and conferences, or involving users in NRENs-related events. Another aspect of the role/function is to look ahead to the future to anticipate change and support new demands. A range of projects around the world are supported through the following activities:

- Energy: Nuclear power, future energy research, anything to do with the science that keeps the lights and computers turned on around the world. For example, our work with ITER [ITER].
- Earth and Environmental Sciences: Earth observation, climate monitoring, water quality, volcanoes, and sustainable development are just some of the subject areas that we cover while assisting organisations, such as: Group on Earth Observation, WMO, ESA and EUMETSAT. We are the primary partner in the R&E community of the COPERNICUS project.
- Social Sciences: Music, art, languages. Working with projects, including: CLARIN, ASTRA and LOLA to cater for their specific requirements.
- Health and Food: Pharmaceutical research, EMBL-EBI, the Human Brain project, and ARES have all been assisted through our account management and support to their communities.
- Physical Science: Exploring the universe and cornerstone of human existence, we're assisting the likes of SKA, JIVE, NEXPReS, LIGO-VIRGO and CERN.
- e-infrastructures: Assist and provide services to the infrastructures who deliver complimentary services to research communities, including PRACE, EUDAT, EGI and others [PRACE], [EUDAT], [EGI].

Research users worldwide are facing a whole new set of challenges, due to the technology advancement and market trends in the ICT offerings. During an extensive requirement gathering activity, we have had conversations with international research communities in different scientific areas, collecting information about their future plans and the challenges they are facing or anticipating for the next five years. Some common trends have emerged across the users, mostly in areas such as cloud computing, storage needs and trust and identity. This intelligence will be used to drive our future strategy in the user support area, but also to inform the preparation of the white papers for the next iteration of the GÉANT project, specifically on the part regarding the future network design.

# **7. SECURITY SERVICES**

Security is a key aspect in the R&E sector and NRENs are very keen to improve security and risk management within their organisations. For example, 71% of respondent NRENs have performed or plan to perform regular risk assessments. As a result, the take-up of international security standards such as ISO 270001 (Information Security Management) and risk management frameworks (such as ISO 27005 and OCTAVE) are now established within their organisations. Approximately 96% of the respondents utilise recognised methodologies.

Security audits are increasingly performed within the NREN community, for instance, 59% of respondent NRENs carry out security management systems audits and 69% undertake technical infrastructure audits. NRENs use security audit results to ensure that management is aware of any security gaps in both project and corporate environments. There is also noticeable interest in security training as a means to better equip an NREN's members through a combination of community and private events

NRENs, research infrastructures and the GÉANT community as a whole work together to advance security in different ways, such as training, task forces and global initiatives. New international initiatives were launched to address security challenges faced by NRENs and e-infrastructures, and complement the work carried out by well-established groups. The recent new addition (2017) is the Global Security Group, championed by the Global NREN CEO Forum. The group aims to coordinate security resources globally, including people and knowledge, and promote collaboration around addressing security requirements and challenges across our Research and Science communities.

During TNC17, the Security for Collaborating Infrastructures (SCI v2) framework was officially endorsed by representatives of EGI, EUDAT, GÉANT, GridPP, PRACE, SURF, WLCG and the USA's XSEDE e-infrastructure. SCI is a framework of best practices and policy standards for security with the goal of facilitating collaboration during and after security incidents. SCI's governing principles cover incident containment, forensics, data protection and risk management and analysis of preventive measures. The SCI framework is the first output of the WISE Community, which was established in 2015 [WISE].

### 7.1 Notable Trends

As NRENs work to become a more secure community, greater adoption of well-established security frameworks is required (as reflected by responses to the survey). It is important for each NREN to identify the best framework and assess the viability of adhering to internationally recognised standards that provide a baseline set of controls and practices (52% of NRENs are doing this).

Key security trends emerged in 2017 include:

 Increased care for end-users and for bring your own device (BYOD) – to this end it is important to mention eduVPN initiative that enables users to connect to their home VPN service when using public (and potentially insecure) networks. SURFnet and GÉANT are piloting it at present, and some NRENs (AARNET, NOR-DUNET, UNINETT and DeiC) plan to pilot it in 2018.

- TF-CSIRT keeps growing: in 2017 there were 22 new teams listed, 17 accredited and 2 certified within Trusted Introducer. In line with the growth of TF-CSIRT, the demand for TRANSITS training continues to increase with the previous courses fully booked, with waiting lists.
- Distributed Denial of Service (DDoS) remains one of the biggest security threats

There are a number of simple controls that NRENs have found helpful, as per the NREN Compendium survey, to improve their approach to security training and risk management:

- Security training to understand the nature of the attack/security incident or security problem. This will help to prevent, mitigate and respond to a security incident or issue in the appropriate manner.
- Annual security reviews, including technical assessments (full audits of security environment) to identify any potential security gaps so they can be mitigated and or managed.
- Regular risk assessments to prioritise the risks and threats to the organisation, its assets and information, and enable proportional controls to the risk to be implemented.
- In spite of the threats and perceived vulnerabilities, NRENs are taking positive steps towards increasing network security.



Figure 7.1: Top security measures put in place by NRENs

#### **Key Security Stats**

- 59% of respondents provide **training** to security staff. TRANSITS,TF-CSIRT were the most popular community event options, followed by FIRST, Black Hat and others.
- Top security services on offer included NOC, security audit, incident response and security consulting (59% had regular audits of security management systems).
- 84% of respondents used or were planning to use security controls to mitigate technical threats. Firewalls were the most popular of these controls, followed by network analysers, anti-virus and integrity checkers.
- DDoS and malware remain the two most common security incidents experienced by NRENs; nearly every respondent reported at least one example of this.
  - 53% of respondents implemented or planned to implement mitigation measures against DDoS.

### 7.2 Community Groups

There are many ways in which the NREN community is trying to link with other groups to share and inform security best practice. This includes WISE, Task Forces (TF) and Special Interest Groups (SIGs), as detailed below .

Furthermore, the community is using a versatile range of security standards and best practices to ensure a better and more secure environment, including: ISKE, ISO 27001, ETSI and TS 102042 (for PKI).

**Wise Information Security for collaborating e-infrastructures (WISE)** The WISE community, set up by GÉANT and the Security for Collaborating Infrastructures (SCI) group, provides a trusted global framework for security experts to exchange experience and knowledge [<u>WISE</u>]. WISE brings together four of the largest e-infrastructures: EGI, EUDAT, GÉANT and PRACE; NREN organisations; user communities such as HEP/CERN and the Human Brain Project, and other initiatives such as XSEDE, NCSA, CTSC, to facilitate the exchange of experience and knowledge on information security management and related topics.

#### Information Security Management Special Interest Group (SIG-ISM)

SIG-ISM offers Chief Information Security Officers (CISOs) of NREN organisations the opportunity to share best practice and learn from each other's experience of safeguarding their networks against security incidents and threats.

Taking part in SIG-ISM can help equip NRENs with the skills to manage information security within their research and education community.

#### Computer Security Incident Response Team Task Force (TF-CSIRT)

TF-CSIRT provides a forum where members of the CSIRT community can exchange experiences and knowledge in a trusted environment in order to improve cooperation and coordination. It maintains a system for registering and accrediting CSIRTs, as well as certifying service standards.

The task force also develops and provides services for CSIRTs, promotes the use of common standards and procedures for handling security incidents, and coordinates joint initiatives where appropriate. This includes the training of CSIRT staff and assisting in the establishment and development of new CSIRTs.

# **8. TRUST AND IDENTITY SERVICES**

The deployment of federated access and national identity federations for research and education has enabled NRENs to explore new service delivery models. This also included areas that, until a few years ago, were not NRENs core business of NRENs. As a result, NRENs have expanded their boundaries to think about wider trust and identity strategies to make service offers more sustainable and attractive to NREN users. (Trends for these aspects are explored in Section 8.2 Identity Federations and eduGAIN.)

The trust and identity activity within GÉANT and the NRENs encompasses the following areas:

- Operations of national federated AAI.
- Operations of international infrastructures, such as eduGAIN and eduroam, and related inter-federation services and monitoring tools.
- Development of suites of services (eduTEAMS) to support research collaborations.
- Support of policy harmonisation and best practices across identity federations.
- Development of new technical and policy frameworks to make federated access accessible for eScience communities.
- Digital certificate services, such as the Trust Certificate Service (TCS) [TCS].

GÉANT supports the work in these areas in collaboration with the NRENs and via different frameworks, such as the GÉANT and AARC projects, REFEDS and task-forces [AARC].

#### The Research and Education FEDerations group (REFEDS)

REFEDS is the international body that articulates the needs of identity federations in the research and education sector. Thanks to sponsorships and many volunteers, REFEDS offers a home for several working groups, as well as manages process to agree on policy best practices. The resulting best practices are then deployed by R&E federations worldwide {REFEDS].

In order to avoid NRENs having to answer the same questions on different surveys, the following information has been collected as part of the 2017 REFEDS survey.

Key trends in T&I:

- A new Task Force on Data Protection Regulation (TF-DPR), was launched in 2017 [TF-DPR]. TF-DPR is gaining traction among federations and research infrastructures. About 20 NRENs are actively engaging in TF DPR discussions. One of the biggest topics for everyone in the trust and identity field is General Data Protection Regulation (GDPR) and how our established systems and services will support it (see below).
- Adoption of Security Incident Response Trust Framework for Federated Identity (Sirtfi) keeps increasing, 16 federations said they were supporting Sirtfi in 2017 (up from 4 in 2016). With more widespread use of digital identity, security has now grown to also encompass security incidents in identity federations and eduGAIN. This work is being addressed by the Sirtfi working group, hosted by

REFEDS and also sponsored by the AARC project. This is a clear example of a work area that touches on both the trust and identity, as well as the security areas. In December 2017:

- 16 federations supported Sirtfi and 13 planned to support it in the short term.
- 23 federations asserted R&S and 5 planned to support it in the short term.
- It emerged from the REFEDS survey that 40% (16 of 40) of R&E federations that responded already have an incident response plan in place, whilst 50% said they are planning to implement one in the near future.
- Open ID Connect continues to gain traction (see Section 8.2).
- The support for REFEDS Research and Scholarship (R&S) Entity Category, keeps increasing (although not as fast as it would be desirable). In 2017, 5 new federations supported R&S, bringing the number to 23; this translates to 338 Identity Providers (IdPs) that assert R&S, about 12% of the total number of IdPs in eduGAIN.
- There is a significant interest in assurance (the way to increase trust in identities based on the user identity vetting procedure followed by the identity provider) and in multi-factor authentication (requiring more than one method of **authentication** from independent categories of credentials). Support for multi-factor authentication is now offered by 6 federations.
- Despite the large coverage of the Trust Certificate Service (TCS), demand continues to increase: in 2017 another NREN joined the service, bringing the total up to 30.

#### GDPR

The new General Data Protection Regulation (GDPR), replaced the Data Protection Directive 95/46/EC, in May 2018. The main questions around the new GDPR concern the impact on federated authentication in relation to transferring user data to access services located in countries different than the country in which the user authenticates; and how NRENs and GÉANT established systems and services will need to change to support the new legislation.

Since 2017, GÉANT Task Force Data Protection Regulation (TF-DPR) has been actively supporting institutions and NRENs to prepare for GDPR. GÉANT and NRENs have offered webinars and blogs on this topic.

### 8.1 eduroam

eduroam (education roaming) is the secure, worldwide roaming, federated access service developed for the international research and education community. eduroam allows students, researchers and staff from participating institutions to connect to the Internet when they are at their own campus or institutions, as well as when visiting other participating institutions. This seamless access is possible via a technical architecture and a number of policy agreements that enable eduroam participating institutions to trust the result of the authentication of a user that takes place at the user's home organisation. The authorisation required to allow access to local network resources is carried out by the visited network. eduroam is built on one of the most secure encryption and authentication standards in existence today. Its security greatly exceeds that of typical commercial hotspots.

Having started in Europe, eduroam has gained momentum throughout the research and education community. Tajikistan is the latest country to join, with 85 countries now taking part in eduroam around the world.

2017 was another year of expansion for eduroam, which saw a 17% increase in international authentications and a 14% increase in national authentications compared with the previous calendar year. In total, more than 2.9 billion national authentications and more than 694 million international authentications were recorded in 2017.

The growth of eduroam usage is measured monthly by counting the number of successful user authentications, as follows:

- National authN as grand sum of all successful roaming authentications in the same country counted via f-ticks system for all European countries that provide this info.
- International authN as total number of successful international (cross-border) authentications counted in the logs of ETLRs.



Figure 8.1: National and international eduroam authentications

### **8.2 Identity Federations**

The information provided in this section is taken from the annual REFEDS survey and from the eduGAIN technical website [<u>REFEDS</u>] [<u>eduGAIN</u>].

Identity federations simplify inter-organisational access to web resources, by allowing users to access, with one login, resources offered by participating organisations in the same identity federation. These federations are increasingly seen as part of NRENs' core global service portfolio, and are an important distinguishing factor from commercial services in their approach to privacy.

Identity federations are mostly built on the standardised SAML protocol and focus primarily on providing trusted, web Single Sign-on using SAML. However, federations are evolving to also support OIDC; REFEDS survey indicated that 5 federations already offered support for





Figure 8.2: Responses by federation type



Figure 8.3: NREN use of OpenID Connect (OIDC)

In 2017, REFEDS recorded an increased number of identity federations, from 66 in 2016 to 71 in 2017 [REFEDS]. Most of the identity federations operators gather in REFEDS, the global forum to articulate the needs of identity federations managed by GÉANT.

The following areas are reported as priority for respondents during 2018:

- Keep working to refine and expand federation operator best practices.
- Work to converge global federation operations on a common set of practices and expectations.
- Help to reduce the barriers to entry of running a federation.
- Joint effort to convince commercial Service Providers of the necessity to get rid of SAML1 and make their SAML implementations more user-friendly in general.

- Service Catalogue, Operate an OIDC Federation testbed, cultivating Identity Management Talent for federations to employ.
- GDPR and GÉANT Code of Conduct v2.0.
- Operate an OIDC Federation testbed.
- Statistics of federation and portfolio of eduGAIN services.

### 8.3 eduGAIN

Research and education is becoming increasingly borderless. The purpose of the eduGAIN infrastructure and the accompanying inter-federation services is to enable users from one federation to access services from other federations and to enable services offered in one federation to be accessed by users from other federations. The eduGAIN service has now achieved critical mass, having been almost universally adopted by established research and education identity federations worldwide.

It is widely recognised that eduGAIN is the foundation to enable federated access globally, and there is strong interest among the eScience community for its widespread use.



Figure 8.4: eduGAIN footprint



Figure 8.5: eduGAIN world map

## 8.4 GÉANT T&I Service Development

Students, researchers and institute staff rely on online services for collaboration through webmail, e-learning, teaching, conferencing, analysing and sharing data and for accessing journals and libraries. Trusted digital identities underpinned with secure technologies allow end users to simply and securely access content and services. This section includes examples of GÉANT services that build trust, promote security and support the use of online identities.

# **9. CLOUD AND COLLABORATION SERVICES**

In the future, 2017 will be seen as the turning point in cloud service and cloud adoption across the NRENs and wider Research and Education community, with plans and intentions from previous years converted into offerings of concrete cloud services.

Out of the European NREN Compendium Survey respondents, 95% now deliver cloud services to users (either at an institutional or end-user level). This shows that the service portfolios of NRENs are expanding, both in terms of breadth and also by moving up the value-chain.

NRENs are becoming much more aware of the different cloud delivery models and management approaches while supporting Institutions and users. From the 2017 survey, 24% of respondent NRENs are planning to become active in the area of cloud management platforms and 57% are planning to offer (or already offer) cloud expertise and support to institutions.

This combination of expertise and support will help NRENs strengthen centres of excellence for cloud services.

### 9.1 A Hybrid Service Delivery Approach and Results

Just as there are multiple cloud service types, there are multiple cloud service delivery models, and the NRENs (with the support of GÉANT) play a key role in supporting institutions' understanding of the options and selection of the correct delivery model.

The GÉANT cloud activity established a hybrid, multi cloud approach, where the NRENs:

- Share sector-specific community clouds; scale-up national cloud efforts from NRENs and other research and education organisations to a European level.
- Jointly broker and procure public clouds from commercial suppliers, such as the pan-European laaS tender leading to framework agreements with over 20 suppliers.

This is a special combination of skills and assets. Together, using these hybrid capabilities, the NRENs established a European Digital Single Market for cloud services, the first of its kind.

#### **9.2 Cloud Service Portfolios**

Cloud storage is the most common service provided by NRENs, with 92% currently delivering and 8% planning to deliver cloud storage at some point during the next 12 months. However, Infrastructure as a Service (IaaS) (general-purpose cloud computing services) is, or will be, offered by 84% of NRENs, indicating that these two service types are and continue to be vital to the R&E sector.



Figure 9.1: laaS and cloud storage are the most popular cloud services

#### 9.2.1 Infrastructure as a Service (laaS)

Infrastructure as a Service (IaaS) has been an area that has made the most progress over the past 12 months. This field of cloud services offers the opportunities for NRENs 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.

2017 saw the completion of the GÉANT laaS framework tender, in which 36 NRENs participated, with 27 NRENs progressing to a delivery role as either referrer, reseller and/or underwriter of cloud services. In total, 11 service providers, many working through in-country value added resellers (VARs), are delivering their offering through the laaS framework. The GÉANT cloud portfolio provides real choice and flexibility in the marketplace [laaS].

### 9.2.3 Software as a Service (SaaS)

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

- Complexity The range of SaaS solutions tend 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 of NRENs offering these services to institutions.

However, with the File Storage sub-sector, the NRENs can provide a level of scalability to the offerings that can generate benefits. This can be seen by the growth in both in-house SaaS services (through organisations such as ownCloud and NextCloud) and 100% outsourced offerings [ownCloud], [NextCloud].

GÉANT has been working with NRENs to develop tailor-made offerings in the File Storage sector. Growth in this area in 2017 was significant and is expected to continue through 2018.

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 throughout 2018.

### **9.3 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 modernised in the EU and at country levels, there is a direct impact on the cloud delivery. Especially, the new EU General Data Protection Regulation (GDPR) has direct implications on:
  - · Institutions using clouds: data controllers
  - Providers offering these clouds: data processors
- These issues affect both in-house and externally sourced services, however, 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. This perception of risk is currently inhibiting migration of services from in-house to outsourced platforms but should be largely overcome by Q3 of 2018.
- **Standardisation** Data interoperability and portability between different clouds are still in the early stages of development. This lack of standards and supplier willingness lead to data islands and vendor lock-ins.
- Scalability NRENs may face scalability issues as cloud services develop from 'commodity' infrastructure platforms into more complex managed software offerings. It is likely that the need to support multiple software platforms will require substantial resources.
- Uncertainty and Risk Aversion Many institutions are adopting a 'me second' philosophy to cloud adoption waiting for other institutions to be the leaders. GÉANT will work through 2018 to share user experience and coordinate best practice examples to reduce the uncertainty of cloud adoption.

#### 9.3.1 Summary

As the service landscape and procurement models for cloud services to support Research and Education mature, we are seeing positive growth in adoption by institutions and a matching expansion in NRENs to enable such growth.

Cloud services are likely to become significant value added service propositions for many NRENs as they adapt to new delivery models for R&E services and extend the NREN further up the value chain.

It is recognised that there are 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 strategies are put in place.

Many NRENs are positioning themselves as centres of excellence for institutions seeking to migrate to cloud services. Knowledge sharing between NRENs will be crucial for the success of these initiatives.



The following list of respondents contains links to their respective websites.

<b>ACOnet</b> Vienna University Computer Centre	Austria	www.aco.net
<b>AMRES/UoB</b> Akademska mreža Republike Srbije / Univerzitet u Beogradu	Serbia	www.amres.ac.rs
<b>ANA/RASH</b> Academic Network of Albania / Rrjeti Akademik Shqiptar	Albania	<u>https://www.rash.al/</u> home-en/
ANAS Institute of Information Technology of the Azerbaijan National Academy of Sciences	Azerbaijan	http://science.gov.az/
<b>ARNES</b> Academic and Research Network of Slovenia	Slovenia	<u>www.arnes.si</u>
<b>ASNET-AM</b> Institute for Informatics and Automation Problems	Armenia	<u>www.asnet.am</u>
UIIP NASB	Belarus	www.uiip.bas-net.by
Belnet	Belgium	www.belnet.be
<b>BREN</b> Bulgarian Research and Education Network	Bulgaria	<u>www.bren.bg</u>
<b>CARNet</b> Hrvatska akademska I istrazivacka mreza	Croatia	<u>www.carnet.hr</u>
<b>CESNET</b> CESNET, zajmove sdruzeni pravnickych osob	Czech Republic	www.ces.net

<b>CyNet</b> ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ (ΚΥΡRΙΑΚΟ EREVNITIKO KAI AKADIMAIKO DIKTYO)	Cyprus	www.cynet.ac.cy
<b>DFN</b> Verein zur Förderung eines Deutschen Forschungsnetzes e.V.	Germany	www.dfn.de
<b>EENet</b> EENet of HITSA (Information Technology Foundation for Education)	Estonia	www.eenet.ee
<b>FCT   FCCN</b> Fundação para a Ciência e a Tecnologia Computação Cientifica Nacional	Portugal	<u>www.fct.pt</u>
<b>GARR</b> Consortium GARR	Italy	www.garr.it
<b>GRENA</b> Georgian Research and Educational Networking Association	Georgia	www.grena.ge
<b>GRNET</b> Greek Research and Technology Network	Greece	www.grnet.gr
<b>HEAnet</b> HEAnet Limited	Ireland	www.heanet.ie
Ministry of Education and Science	Latvia	http://www.lumii.lv
IUCC Inter University Computation Centre	Israel	www.iucc.ac.il
<b>Jisc</b> Jisc Collections and Janet Limited	UK	<u>www.ja.net</u>
<b>LITNET</b> Kauno Technologijos Universitetas	Lithuania	<u>www.litnet.lt</u>
<b>MARnet</b> Macedonian Academic and Research Network	Former Yugoslav Republic of Macedonia	www.marnet.mk

<b>MREN</b> Javna Ustanova Univerziteta Crne Gore Podgorica	Montenegro	www.mren.ac.me
<b>KIFÜ (formerly NIIFI)</b> Kormányzati Informatikai Fejlesztési ÜgynökségNemzeti	Hungary	http://kifu.gov.hu/kifu/
<b>NORDUnet</b> (Representative Member)	Denmark, Finland, Sweden, Norway, Iceland	www.nordu.net
<b>PCSS</b> Poznan Supercomputing and Networking	Poland	www.man.poznan.pl
<b>RedIRIS/RED.ES</b> Entidad pública empresarial RED.ES	Spain	www.rediris.es
<b>RENAM</b> Research and Educational Networking Association of Moldova	Moldova	www.renam.md
<b>RENATER</b> Groupement d'Intérêt Public Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche	France	www.renater.fr
<b>RESTENA</b> Réseau Téléinformatique de l'Education Nationale et de la Recherche	Luxembourg	www.restena.lu
<b>RoEduNet</b> Agentia de Administrare a Retelei Natinale de Informatica Pentru Educatie si Cercetare	Romania	www.nren.ro
<b>SANET</b> Slovak Academic Network Association	Slovakia	www.sanet.sk
SURFnet SURFnet B.V.	Netherlands	www.surfnet.nl
SWITCH	Switzerland	www.switch.ch

<b>ULAKBIM</b> Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu	Turkey	<u>www.ulakbim.gov.tr</u>
<b>UoM</b> L-Università ta' Malta	Malta	<u>http://www.um.edu.</u> <u>mt/itservices/research</u>
<b>URAN</b> Association of Users of Ukrainian Research and Academic Network	Ukraine	www.uran.net.ua

# APPENDIX B Compendium Contributors

**FEDERICA TANLONGO** holds an ICT Master's degree in New Media and Communication from the "La Sapienza" University of Rome. Since 2004, she has been with GARR, where she currently holds the position of Communication and External Relations Coordinator.

**ELIS BERTAZZON** holds a Master's degree in International Relations and in Institutional Communications. She joined GARR in 2016 as part of the communications and external relations team with international experience in advocacy and communication strategy development for both private and non-profit sectors.

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 on extraction and analysis of network data and its use in driving optimisation in network architectures. Sebastiano's study includes networking at the CISCO networking academy in the Metropolitan University in London and industry certifications, such as CCNP and MEF-CECP. **TRYFON CHIOTIS, Head of GÉANT Project Management Office** since September 2013, is responsible for the day-to-day management and administration of the GÉANT project (GN4-2). Having worked as Chief Technical Officer at GRNET, the Greek National Research and Education Network, since 1999, he has a long-standing track record in securing and managing EC-funded projects, working with GÉANT stakeholders and managing structural funded development programmes in research networking, grid, cloud and High-Performance Computing.

VINCENZO CAPONE, Senior Technical Business Development Office (GÉANT), is in charge of the user support for network solutions of pan-European and international scientific groups and collaborations and in the Science and Research engagement activities, with a background in computer science and networking. Previous positions included the Department of Physics of 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. **LICIA FLORIO, Project Development Officer (GÉANT)**. Licia joined TERENA (now GÉANT) in 2001, focussing on Identity and Trust. Licia coordinates the AARC (Authentication and Authorisation for Research and Collaboration) project. The AARC EC-funded project aims to address the integration among different Authentication and Authorisation Infrastructures (AAIs) operated by the various research collaborations and e-Infrastructures; the lack of ubiquity of federated credentials; and technical and policy challenges that are ultimately hindering global research collaborations. KARL MEYER, Product Marketing and Management Officer, (GÉANT). Karl 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 emphasis on International Enterprise Development and Knowledge Management.

# REFERENCES

#### [ALIEN\_WAVE]

Alien wavelength. Alien = data transmission laser light from third-party equipment; an alien wave system multiplexes alien light together with local signals using DWDM.

#### [AARC]

Authentication and Authorisation for Research and Collaboration (AARC) is an EC-funded project that is working with national identify federations, research infrastructures, e-infrastructures and libraries to identify building blocks and policy best practices needed to implement interoperable authentication and authorisation infrastructures (AAIs) leveraging federated access. <u>https://aarc-project.eu/</u>

[AUP]

Acceptable use policy. https://compendium.geant.org/reports/aup

[CANARIE] https://www.canarie.ca/network/

[CERN] https://home.cern/

[CloudStor]

https://www.aarnet.edu.au/network-and-services/cloud-services-applications/cloudstor

[COMPENDIUM]

The GÉANT NREN Compendium may be found online at: https://compendium.geant.org/

[DGDEVCO]

https://ec.europa.eu/europeaid/general\_en

[e-INFRA]

https://ec.europa.eu/programmes/horizon2020/en/h2020-section/e-infrastructures

[EAPConnect] https://www.eapconnect.eu/

[eduGAIN]

eduGAIN interconnects identity federations around the world, simplifying access to content, services and resources for the global research and education community. <u>https://www.geant.org/Services/Trust\_identity\_and\_security/eduGAIN</u>

[eduroam]

eduroam (education roaming) is the secure, world-wide roaming access service developed for the international research and education community. <u>https://www.eduroam.org/</u>

[eInfraCentral]

The mission of the elnfraCentral project is to ensure that, by 2020, a broader and more varied set of users (including industry) discovers and accesses the existing and developing e-infrastructure capacity.

http://einfracentral.eu/

[EGI] https://www.egi.eu/

[ESnet] https://www.es.net/

[EUDAT] https://www.eudat.eu/

[GÉANT]

GÉANT is Europe's leading collaboration on e-infrastructure and services for research and education.

https://www.geant.org/

[GN4-2] GÉANT Network 4, Phase 2 project https://www.geant.org/Projects/GEANT\_Project\_GN4

[laaS] https://clouds.geant.org/laaS

[Infinera] https://www.infinera.com/

[Internet2] http://www.internet2.edu/

[ISCED 2011]

http://www.uis.unesco.org/Education/Documents/isced-2011-en.pdf

The classification is: Level 8: Doctorate or equivalent level Level 7: Masters or equivalent level Level 6: Bachelors 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 Levels 2 and 3: Secondary education Level 1: Primary or basic education Level 0: 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] https://www.iter.org/

[IPv4]

Version 4 of the Internet Protocol (StB IETF), a connectionless protocol used on packet-switched networks. Employs 32-bit IP-addresses. <u>https://tools.ietf.org/html/rfc791</u>

[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.

[NETCONF]

The Network Configuration Protocol (NETCONF) provides mechanisms to install, manipulate, and delete the configuration of network devices. It uses an Extensible Markup Language (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). https://tools.ietf.org/html/rfc6241

[NextCloud] https://nextcloud.com/

[NFV]

Network function virtualisation network architecture that uses virtualisation to connect network and coms services

[ONOS] Open Network Operating System (ONOS) is a software-defined networking operating system for service providers. <u>http://onosproject.org/</u>

[OpenDaylight] An open source software-defined networking controller <u>https://www.opendaylight.org/</u>

[OpenFlow] A communications protocol that gives access to the forwarding plane of a network switch or router over the network <u>https://www.opennetworking.org/sdn-resources/openflow/</u>

[ownCloud] ownCloud is a self-hosted file sync and share server <u>https://owncloud.org/</u>

#### [Peering]

Network peering refers to the direct exchange of traffic between two networks.

#### [PRACE]

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. http://www.prace-ri.eu/

#### [REFEDS]

Research and Education FEDerations group represents research and education requirements for access and identity management. REFEDS participants are from a wide range of back-grounds, but all share an interest in developing access and identity management technology, policies and processes. Many participants represent national identity federations and many are NRENs.

https://refeds.org/; https://refeds.org/federations See also REFEDS sponsorship: https://refeds.org/sponsor

#### [SCHOOLS SURVEY]

https://wiki.geant.org/download/attachments/81625514/Connectivity% 20in%20the%20School%20Sector.pdf?version=1&modification-Date=1513157785971&api=v2

#### [SDN]

Software-defined networking allows network administrators to manage network components and behaviour dynamically via open interfaces and abstraction of lower-level functionality.

#### [SERVICES]

https://compendiumdatabase.geant.org/reports/nrens\_services

#### [SKA]

Square Kilometre Array project is an international effort to build the world's largest radio telescope <u>http://skatelescope.org/</u>

#### [SURVEY]

The 2018 Compendium Survey questionnaire focused on the period from January to December 2017. It requested information relating to seven areas of interest to NRENs including: network and security, 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.

#### [TCS]

Trusted Certificate Service TCS provides NRENs with cost-effective and easy to use management of digital certificates. <u>https://www.geant.org/Services/Trust\_identity\_and\_security/Pag-es/TCS.aspx</u>

#### [TF-DPR]

The Data Protection Regulation Task Force

The Data Protection Regulation Task Force offers a forum to enable NRENs and other interested parties to share experiences, best practices and tools to facilitate compliance with GDPR. [Transponder] In optical fibre networking, transponders convert electrical signals into optical ones.

#### [WISE]

WISE is a global trust community where security experts share information and work together, creating collaboration among different e-infrastructures. WISE provides a framework of standards, guidelines, and practices to promote the protection of critical infrastructure. https://wise-community.org

# **GLOSSARY**

#### AAI

Authentication and Authorisation Infrastructure

#### AARC

Authentication and Authorisation for Research and Collaboration

**API** Application Programming Interface

#### AUP

Acceptable Use Policy

**AW** Alien Wave

**BYOD** Bring Your Own Device

**CBF** Cross-Border Fibre

**CERT** Computer Emergency Response Teams

**CISO** Chief Information Security Officer

**CSIRT** Computer Security Incidents Response Teams

**DDoS** Distributed Denial of Service

**DE** Germany

#### 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

### EGI

European Grid Infrastructure

## FIRST

Forum of Incident Response and Security Teams

#### FTE Full-time equivalent

FTP File Transfer Protocol

**Gbps** Gigabits per second

**GDPR** General Data Protection Regulation

### GN4-2

(GÉANT Network 4, Phase 2) project partfunded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No.731122

laaS

Infrastructure as a Service

IdP Identity Provider

**IGTF** The Interoperable Global Trust Foundation

P Internet Protocol

**IRU** Indefeasible Rights of Use

**ISCED** International Standard Classification of Education

Information Security Management

ITER International Thermonuclear Experimental Reactor

JRA Joint Research Activity

JRA1 GN4-2 JRA1 Network Infrastructure Evolution

JRA1 T1 JRA1 Task 1 Evolving the Shared Optical Infrastructure

LHC Large Hadron Collider

MPLS Multiprotocol Label Switching

**NETCONF** Network Configuration Protocol

**NFV** Network Function Virtualisation

**NOC** Network Operations Centre NREN

National Research and Education Network

**OIDC** OpenID Connect

**ONOS** Open Network Operating System

**OpenAIRE** Open Access Infrastructure for Research in Europe

**PB** Petabyte (1015bytes of data)

PERT Performance Enhancement Response Team

**PKI** Public Key Infrastructure

**PRACE** Partnership for Advanced Computing in Europe

**Q** Quarter

**R&E** Research and Education

**R&S** Research and Scholarship

**REFEDS** Research and Education FEDerations group

**RTBH** Remotely Triggered Black Hole

**SaaS** Software as a Service

SDN Software-Defined Networking **SGA** Specific Grant Agreement

#### Sirtfi

Security Incident Response Trust Framework for Federated Identity (REFEDS working group)

#### SKA

Square Kilometre Array

#### SP

Service Provider

#### SSH

Secure Shell/Secure Socket Shell

#### T

Task

### T&I

Trust and Identity

TCS Trusted Certificate Service

**TF** Task Force

### VAR

Value-Added Reseller

### VPN

Virtual Private Network

#### WISE

Wise Information Security for collaborating e-infrastructures

### Yoy

Year-on-Year

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The GEANT Compendium provides an authoritative reference source for anyone with an interest in the development of reasearch 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.

The GÉANT NREN Compendium may be found online at: compendium. geant.org