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Networks • Services • People

GÉANT COMPENDIUM

of National Research and
Education Networks in Europe

2015 Edition

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INTRODUCTION

Welcome to the 2015 GÉANT *Compendium*! This year, the *Compendium* was written largely by experts from the research and education community itself.

Since the first *Compendium* in 2000, we have seen the research and education networking arena evolve in vast and complex ways to meet demand and continue to push boundaries. The *Compendium* has reflected this considerable progress by bringing out similarities and differences in a single reference publication, thus enabling comparison, collaboration and knowledge sharing.

The 2015 *Compendium* forms part of the GÉANT (GN4-1) project and reveals the findings from a survey to which all European NRENs, and a number further afield, were invited to contribute on the NREN's status as of January 2015. We are hopeful that this publication will also be a cornerstone for a future Global *Compendium* document. As in all years, we have endeavoured to reflect the variations we know exist in our NRENs in the *Compendium's* data findings, based upon the survey submissions. We thank all participating organisations and their staff for their contribution to the 2015 publication.

For our community

For this year's *Compendium*, we have taken a new approach. We have listened to your feedback and taken the steps to develop the *Compendium* into a more community-led publication. We have invited experts from across our community to analyse and interpret the survey results and present key findings using specialist insight.

In recent years we have seen considerable growth in areas such as Cloud services and e-Infrastructure. We have also seen increased attention to security in response to the increased complexity and frequency of cyber-attacks. This year's *Compendium* highlights these areas and the trends we are seeing.

We thank our community experts for valued author and reviewer contributions and the 2015 *Compendium* Panel for valuable insight.

Listening to NRENs

NREN feedback on the *Compendium* serving as a community resource reinforced the need to include more comparisons between NRENs and trend analysis; this is certainly the direction in which we wish to take the publication.

The *Compendium* is used in several ways. Some NRENs reported that their Board highlights the publication in discussions with Government; others mentioned managers referencing it in technical discussions on R&D and services to inform strategic decisions.

In it, together

Read on to find out how the NREN community remains at the leading edge of integrating end-to-end services, capable of meeting and advancing the needs of education and research in Europe and beyond.

A wide range of further information to complement this *Compendium* is available online at **https://compendium.geant.org/**.

Natalie Allred / Bert van Pinxteren

Quotes from NREN respondents:

'…used as a benchmark tool…'

'We use the Compendium to make comparisons with other NRENs, to see what strategies/services other NRENs are pursuing, to identify areas where we can collaborate or offer/seek help…'

'…as background to annual grant claims from Government agencies…'

'Our directors used it most frequently because the funding, connectivity and service sections are great for reference in decision making and responding to our funding agencies.'

'Management staff uses the Compendium typically to see the position of our NREN in the European landscape and to find the way other NRENs solved some issues. The section we use the most are sections about supported services, staff, budgets and so on….'

KEY FINDINGS: A BRIEF OVERVIEW

'Connected Communities'

Through the GÉANT network, more than 100 countries around the world are now interconnected with high-speed links, which are dedicated to research and education. 'Connected Communities' was the theme chosen for the 2015 TNC[1]. It reflects precisely the core business of the National Research and Education Networks (NRENs), whose work is documented in this *Compendium*.

As in 2014, this 2015 edition of the *Compendium* is the product of a global collaboration effort that has led to an NREN Common Information Model, which is now being used by regional NREN associations around the world. Policymakers, funders, NRENs and their users all need to know where the opportunities and challenges lie and what the trends are. The *Compendium* seeks to meet this need by documenting the work currently being done by NRENs, examining the different contexts in which they operate and explaining important trends in research and education networking that concern them.

The primary focus of all NRENs is to connect universities and research institutes. However, many NRENs go beyond this by also connecting institutes of further education, as well as libraries and museums. Such connections are generally of very high quality: for universities[2] within the GÉANT region, the typical connection capacity is now in the region of 10 Gb/s — again higher than last year, and a tremendous increase compared with the situation a few years ago. All other categories of users except research institutes have significantly lower capacities. Based on the data provided by NRENs themselves and our own conservative assumptions, we estimate that the NRENs in the GÉANT region provide services to approximately 86% of all university-level students in the countries involved; that is, a total of 25 million students.

NRENs offer national backbones and international connectivity of exceptional quality. In most GÉANT partner countries, the typical core capacity is now 10 Gb/s (as in 2014), though some NRENs have reached 100 Gb/s. Because many NRENs in the GÉANT region have access to dark fibre (see Section 3.3), which is potentially able to handle high capacities, they can increase capacity easily and economically whenever required. Some NRENs allow several paths in their backbone, effectively increasing the capacity even further.

Connections not only to the European academic backbone network (i.e. GÉANT) but also to the general Internet are crucial to NRENs. For some NRENs the largest connectivity is now in fact to a neighbouring NREN, using cross-border fibre connections. Most NRENs in Western and Central Europe have no problem in connecting to the Internet via Internet Exchanges or via arrangements with commercial providers. For NRENs in less-well served parts of Europe, GÉANT offers the only affordable way for the research and education sector to gain access to counterparts in other parts of Europe and the world.

Nearly all NRENs are reporting an increase in the amount of fibre in their networks. There are strong benefits for an NREN to acquiring dark fibre, including:

- rapid turn-up of new services by holding spares and installing transponders based on demand projections;
- the ability to get automated service restoration;
- integration into the NREN network operations systems;
- possibility to have new functionality developed for community requirements.

As a further development, several NRENs report that they plan to install Software Defined Networking (SDN) capabilities.

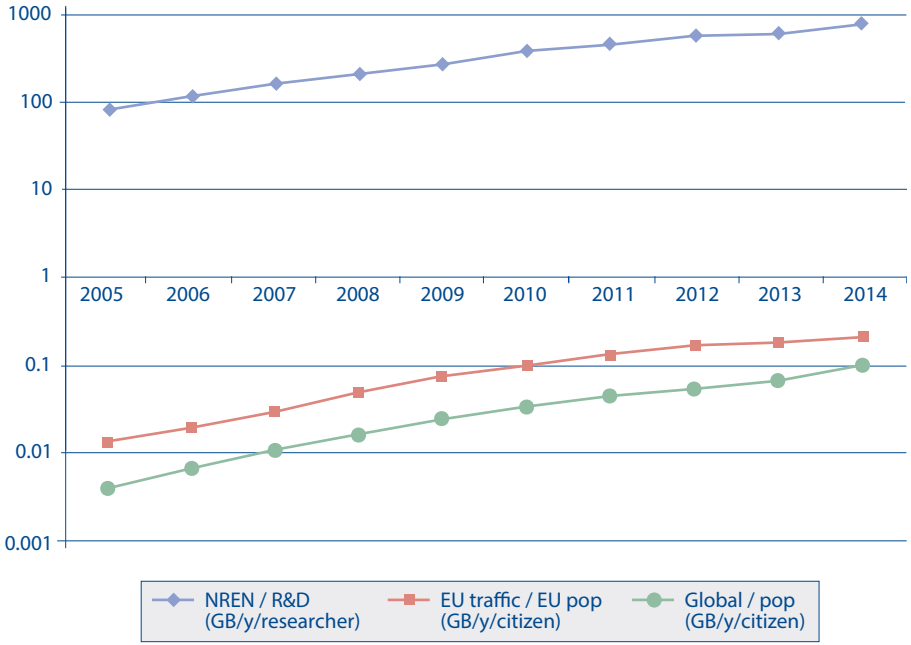
After a decrease in GÉANT traffic at the beginning of 2014, traffic increased again markedly in 2015. GÉANT provides connectivity not only via the traditional means of a routed IP network. Connectivity is also being provided, especially to larger customers, via Virtual Private Network (VPN) services and separate circuits, as for NRENs. For GÉANT, we estimated the traffic on the GÉANT Lambda service,

[1] The TNC (tnc16.geant.org) is the largest annual European research networking conference.
[2] See Appendix 2 for a definition of the term 'university'.

using conservative assumptions. This leads to the conclusion that for GÉANT, traffic on these circuits is currently at least as high as the traffic on the base routed IP network. Because of the potential traffic volumes (and associated costs) an NRENs shall try to record all traffic streams through circuits in addition to IP traffic, to the extent feasible.

Growth in traffic per researcher is similar to the growth in Internet traffic overall. However, traffic per researcher is at a much higher level than traffic per person – this trend is constant. Thus, traffic per researcher is around 10 000 times the traffic per EU citizen[3].

Average traffic in GB/y per EU researcher versus per EU and world citizen (logarithmic scale)



[3] Number of researchers and technicians per country, as published by the World Bank. World Internet traffic as documented through the annual Cisco Visual Networking Index.

Fifty NRENs answered the question about Layer 2 connectivity services: 35 of them offer such a service, with four more planning to introduce it. The number of circuits on these services vary widely from NREN to NREN, from a handful to hundreds of circuits.

Growth in services

Compendium data highlight the benefit of organised response to today's large-scale attacks: networks with mature CSIRTs suffer less disruption. However, damaging attacks on Internet naming and routing infrastructures remain a constant threat. Solutions exist, but they are challenging at a technical and organisational level to deploy. By working together, NRENs are leading improvements in Internet security.

Identity federations and eduroam use NRENs as trusted intermediaries to link service operators to the educational organisations that can vouch for their users. The approach is now being extended to research services that require a wider range of protocols and, sometimes, more information about users. Eduroam may be the most used NREN service of all, and yet the least visible. One hundred million times a month, someone opens their laptop at another university, college, museum, railway station, airport, and is silently connected to the Internet. Federations and eduroam, like research and education, are now global in scope. The eduGAIN interfederation service has now gained almost universal acceptance.

56% of the GÉANT partner NRENs are currently active in delivering cloud services and a further 22% are planning to be involved. Establishing cloud service agreements requires specialised expertise and a substantial scale. This might be an area where collaborative ventures, for example within the GÉANT framework, can bring results.

There is a clear top three in service types: Infrastructure as a Service (IaaS); file storage and backup; and Software as a Service, collaboration services and video conferencing.

Centrally-managed videoconferencing services remain strategically important for many NRENs. For the future, there is a noticeable interest in browser-based access and/or WebRTC access to services. Out of the 20 NRENs who described plans for development, 14 plan to expand desktop options and 11 specifically mention WebRTC as the technology they plan to investigate.

NRENs have a defining role in providing high performance communications networks within the **digital infrastructure**. Nearly 60% currently offer dedicated high-capacity point-to-point circuits. Almost half of NRENs have connected research organisations that provide and manage research resources and facilities to the network, such as telescopes and radio telescopes, sensor networks and lab equipment.

NRENs typically provide digital infrastructure services such as grid middleware, compute resources or storage resources, sometimes being the only provider, but often in conjunction with others. Other services NRENs offer typically include monitoring services, large data transfer services and research portals as well as e-learning resources.

In sum, we are seeing a significant move to e-Infrastructure in our community with NRENs providing more than just the underpinning network services.

Economic and organisational challenges

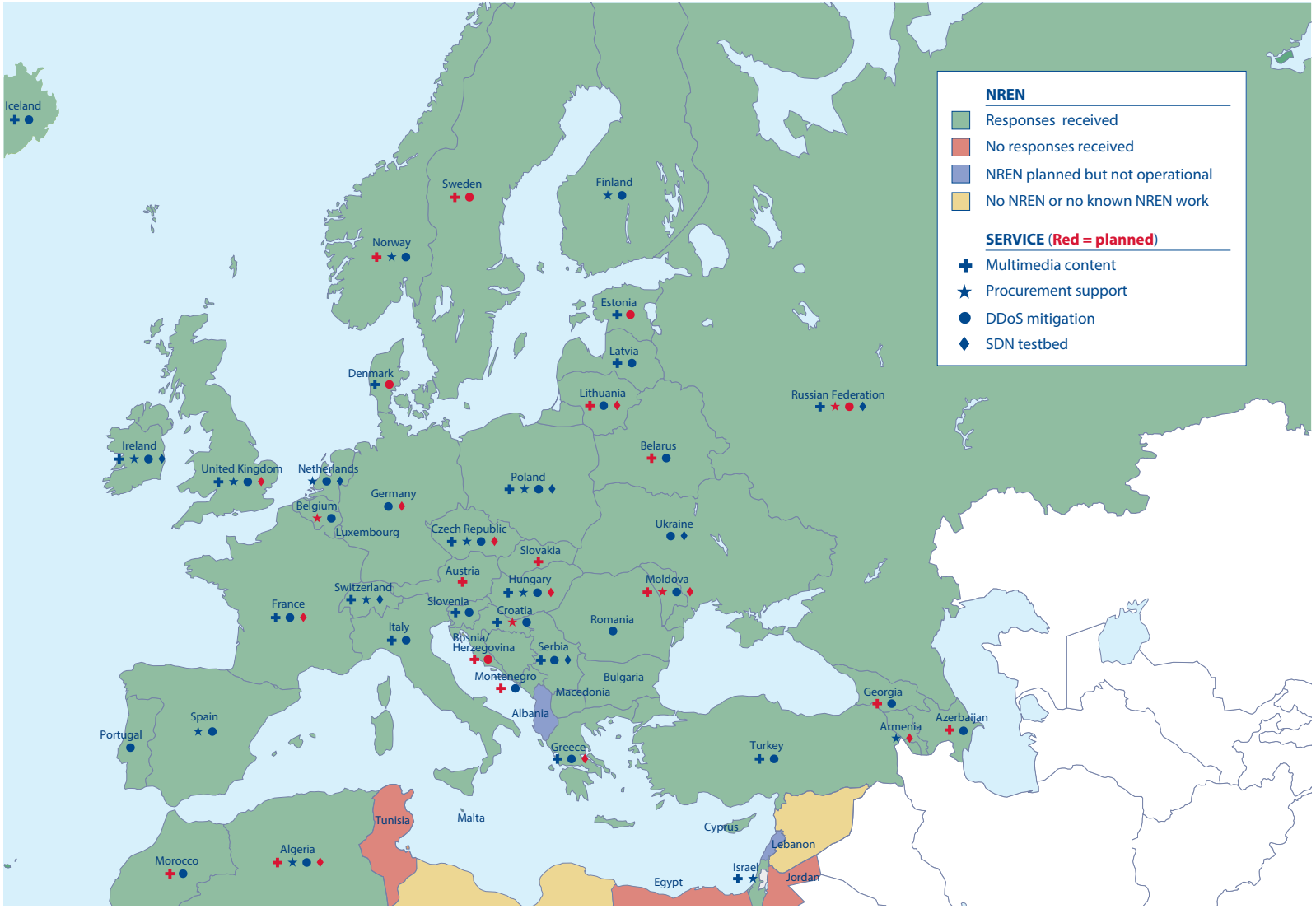
Overall, NREN budgets increased compared to 2014, though this was by no means the case for every NREN – some in fact experienced severe budget cuts. Over a longer period, we see a 10% budget decrease by comparing the three-year average of 2013-2015 with 2010-2012. The general trend is that, each year, NRENs are able to deliver more bandwidth and more services for roughly the same amount of money as in the previous year.

Over the past few years, infrastructural investments have led to savings in transmission costs. In addition, the resulting infrastructural improvements, coupled with innovations in the area of authentication and authorisation, have enabled a new generation of networked services, which have required some increases in staff size.

Although it is impossible to make general recommendations on NREN funding mechanisms, a model that in some way involves all the various stakeholders in an NREN would seem to provide the best guarantees for its continued success. In their respective fields, many NRENs are engaged in innovations, which are often steered by dedicated funding mechanisms. It is important for NRENs to use such funds to their advantage wherever they exist.

1 ORGANISATIONAL INFORMATION

Map 1.1.1 – European NRENs and selected services



The GÉANT *Compendium*, funded by the GÉANT project, is an authoritative reference on the development of research and education networking in Europe and beyond. Below, Section 1.1 presents information on the European National Research and Education Networks (NRENs) that responded to the questionnaire distributed in May 2015. Map 1.1.1 shows the European NRENs that responded and a selection of the services that they provide. Section 1.2 includes a comprehensive list of non-European NRENs, indicating which of them submitted responses to the questionnaire. Section 1.3 gives an overview of the legal status of the European NRENs and their relationship with government.

1.1 European NREN respondents

There are 54[1] countries in the main area covered by this 2015 edition of the *Compendium* (that is, Europe, as well as Mediterranean countries in the Middle East and North Africa). In three of these 54 countries (Libya, the Palestinian Territory and Syria) there is either no NREN or we have no knowledge of NREN work there. In two other countries (Albania and Lebanon) there are NREN initiatives but no operational NRENs. Replies or partial responses were received from 47 NRENs or NREN initiatives. In addition, full or partial responses were received from a further 8 NRENs in the same number of countries outside of Europe. Map 1.1.1 and Tables 1.1.1 and 1.2.2 (below) give an overview of the NRENs that submitted responses. Please note that in most of the tables and graphs included in this edition of the *Compendium*, NRENs are identified by abbreviations of their official English names.

Table 1.1.1, which lists the European and Mediterranean NRENs, is divided into two categories: GÉANT partner countries (42 in total) and other countries.

Legend for Table 1.1.1

	Responses received
	No responses received
	NREN planned but not operational
	No NREN or NREN status unknown

[1] This number does not include Andorra, Kosovo, Liechtenstein, Monaco, San Marino and the Vatican City State; these countries are not included separately in this *Compendium*.

Table 1.1.1 – European and Mediterranean NRENs included in this *Compendium*

Country	NREN	URL
GÉANT partner countries		
Armenia	**ASNET-AM**	www.asnet.am
Azerbaijan	**AzScienceNEt**	www.azsciencenet.az/en
Austria	**ACOnet**	www.aco.net/
Belgium	**Belnet**	www.belnet.be
Belarus	**BASNET**	www.basnet.by
Bulgaria	**BREN**	www.bren.bg
Croatia	**CARNet**	www.carnet.hr
Cyprus	**CYNET**	www.cynet.ac.cy
Czech Republic	**CESNET**	www.cesnet.cz, http://www.ces.net
Denmark	**DeIC**[2]	www.deic.dk
Estonia	**EENet**	www.eenet.ee/
Finland	**Funet**	www.funet.fi (http://www.csc.fi/funet)
France	**RENATER**	www.renater.fr
Georgia	**GRENA**	www.grena.ge
Germany	**DFN**	www.dfn.de
Greece	**GRNET S.A.**	www.grnet.gr/
Hungary	**NIIF/HUNGARNET**	www.niif.hu
Iceland	**RHnet**	www.rhnet.is
Ireland	**HEAnet**	www.heanet.ie
Israel	**IUCC**	www.iucc.ac.il
Italy	**GARR**	www.garr.it
Latvia	**SigmaNet**[3]	www.lumii.lv/
Lithuania	**LITNET**	www.litnet.lt
Luxembourg	**RESTENA**	www.restena.lu/
Macedonia, FYRo	**MARNet**	www.marnet.mk
Malta	**UoM/RicerkaNet**	www.um.edu.mt/itservices/about
Moldova	**RENAM**	www.renam.md
Montenegro	**MREN**	www.mren.ac.me/

[2] The five Nordic NRENs (DeIC, Funet, RHnet, SUNET and UNINETT) are represented in GÉANT through NORDUnet.

[3] In 2015, the network in Latvia changed from SigmaNet to the Ministry of Science and Education. 2015 *Compendium* data were still supplied by SigmaNet.

Table 1.1.1 - Continued

Country	NREN	URL
GÉANT partner countries		
Netherlands	**SURFnet**	www.surfnet.nl
Norway	**UNINETT**	www.uninett.no
Poland	**PIONIER**	www.pionier.net.pl
Portugal	**FCCN**	www.fccn.pt
Romania	**RoEduNet**	www.roedu.net/
Serbia	**AMRES**	www.amres.ac.rs
Slovakia	**SANET**	www.sanet.sk
Slovenia	**ARNES**	www.arnes.si/
Spain	**RedIRIS**	www.rediris.es & http://www.red.es
Sweden	**SUNET**	www.sunet.se/
Switzerland	**SWITCH**	www.switch.ch/
Turkey	**ULAKBIM**	www.ulakbim.gov.tr
Ukraine	**URAN**	www.uran.ua
United Kingdom	**Jisc**[4]	www.jisc.ac.uk/network
Other European and Mediterranean countries		
Albania	**ANA**	www.rash.al
Algeria	**ARN**	www.arn.dz
Bosnia/Herzegovina	**SARNET**[5]	jusarnet.net
Egypt	**EUN**	www.eun.eg
Jordan	**JUNet**	www.junet.edu.jo
Lebanon	**LERN**	
Libya		
Morocco	**MARWAN**	www.marwan.ma
Palestinian Territory		
Russian Federation	**e-ARENA**	www.e-arena.ru
Syria	**HIAST**	www.hiast.edu.sy/
Tunisia	**RNU**	www.cck.rnu.tn/?lg=fr&idm=1&id=2
Ukraine	**UARNet**	www.uar.net/en

[4] In the course of 2015, Janet was integrated into Jisc and also changed its name.
[5] SARNET is active only in the Republika Srpska entity of Bosnia/Herzegovina.

1.2 NRENs in other regions and continents

Table 1.2.1 lists sources of information on non-European regional and North American R&E network organisations.

Tables 1.2.1 - Information on non-European Regional and North American R&E Network organisations

Area	Organisation/project	URL
Arab states	ASREN	www.asrenorg.net
Eastern and Southern Africa	Ubuntunet Alliance	www.ubuntunet.net
West and Central Africa	WACREN	www.wacren.net
Asia/ Pacific	APAN	www.apan.net
	TEIN*CC	www.teincc.org/
Central Asia	CAREN	www.caren.geant.org/Pages/Home.aspx
Latin America	RedCLARA	www.redclara.net
Caribbean	CKLN	www.ckln.org
Canada	CANARIE	www.canarie.ca
USA	Internet2	www.internet2.edu
	ESnet	www.es.net
	National Regional Networks consortium	www.thequilt.net

Information on research and education networking communities around the globe is available at: **http://www.geant.org/Networks/Global_networking/Pages/Home.aspx**

Map 1.2.1 - NRENs known to be operating in other countries

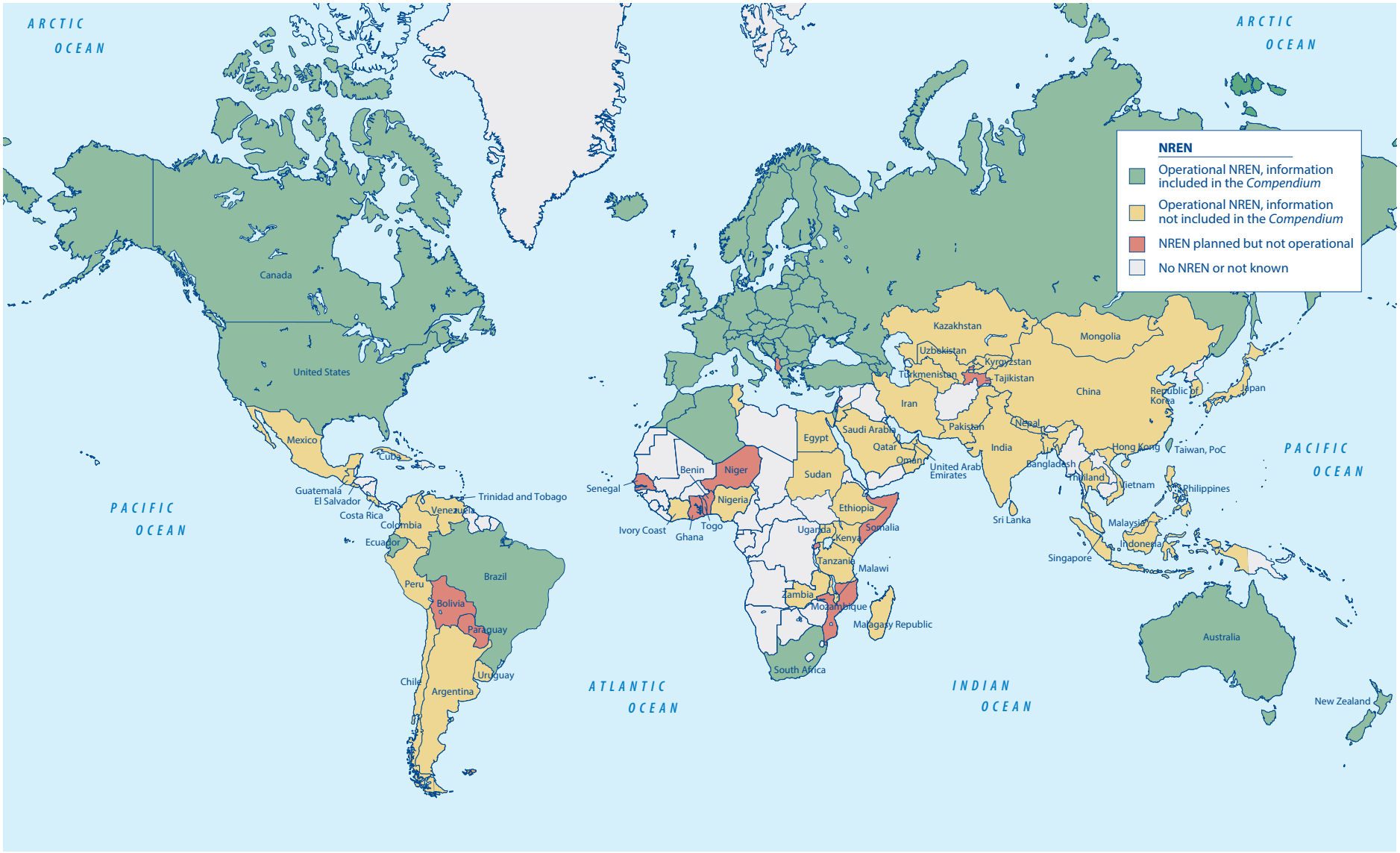


Table 1.2.2 lists those NRENs and NREN initiatives of which GÉANT is currently aware beyond the region covered by this *Compendium*. Note that this list is not comprehensive: there may be other NRENs of which we have no knowledge. Also, in some countries the situation may be subject to rapid change. A number of NRENs from non-European countries submitted data for this *Compendium*; they are highlighted in light green. Their full responses are available at **https://compendium.geant.org/**

Further information on Latin American NRENs is published in the RedCLARA *Compendium* of Latin American National Research and Education Networks, available at **http://www.redclara.net/index.php/en/noticias-y-eventos/publicaciones**

Legend for Table 1.2.2

	Operational NREN, information included in this *Compendium*
	Operational NREN, information not included in this *Compendium*
	NREN planned but not operational

Table 1.2.2 - NRENs known to be operating in other countries

Country	NREN	URL
Algeria	ARN	www.arn.dz
Argentina	INNOVA|RED	www.innova-red.net
Australia	AARNet	www.aarnet.edu.au
Bangladesh	BdREN	www.bdren.net.bd
Benin	RerBenin	www.rerbenin.net/
Bolivia	ADSIB	www.adsib.gob.bo
Brazil	RNP	www.rnp.br
Canada	CANARIE	www.canarie.ca
Chile	REUNA	www.reuna.cl

Table 1.2.2 - Continued

Country	NREN	URL
China	CERNET	www.edu.cn
China	CSTNet	www.cstnet.net.cn
China (Hong Kong)	HARNET	www.harnet.hk
Colombia	RENATA	www.renata.edu.co
Costa Rica	CONARE	www.cenat.ac.cr/computacion-avanzada/red-conare
Cuba	RedUNIV	www.reduniv.mes.edu.cu
Ecuador	CEDIA	www.cedia.org.ec
Egypt	EUN	www.portal.eun.eg
El Salvador	RAICES	www.raices.org.sv
Ethiopia	EthERNet	www.ethernet.edu.et/
Ghana	GARNET	www.garnet.edu.gh
Guatemala	RAGIE	www.ragie.org.gt
India	ERNET	www.eis.ernet.in
Indonesia	INHERENT-DIKTI	www.inherent-dikti.net
Iran	IRANET/IPM	www.iranet.ir
Ivory Coast	RITER	www.riter.ci
Japan	SINET	www.sinet.ad.jp
Japan	NICT	www.jgn.nict.go.jp/english
Jordan	JUNet	www.junet.edu.jo/
Kazakhstan	KazRENA	www.kazrena.kz
Kenya	KENET	www.kenet.or.ke
Korea, Republic Of	KOREN	www.koren.kr
Korea, Republic Of	KREONET	www.kreonet.re.kr/
Kyrgyzstan	KRENA	www.krena.kg
Lebanon	CNRS	www.cnrs.edu.lb/
Malagasy Republic	iRENALA	www.irenala.edu.mg
Malawi	MAREN	www.malico.mw/maren
Malaysia	MYREN	www.myren.net.my

Table 1.2.2 - Continued

Country	NREN	URL
Mexico	CUDI	www.cudi.edu.mx
Mongolia	ErdemNET	www.erdemnet.mn
Morocco	MARWAN	www.marwan.ma
Mozambique	MoRENet	www.ubuntunet.net/morenet
Nepal	NREN	www.nren.net.np
New Zealand	REANNZ	www.reannz.co.nz
Niger	NigerREN	www.niger-ren.ne
Nigeria	ngREN	www.ngren.edu.ng
Oman	OmREN	www.trc.gov.om
Pakistan	PERN	www.pern.edu.pk
Paraguay	Arandu	www.arandu.net.py/cms/index.php
Peru	RAAP	www.raap.org.pe
Philippines	PREGINET	www.pregi.net
Qatar	QNREN	www.qnren.qa
Rwanda	RwEdNet	www.ubuntunet.net/rwednet
Senegal	SnRER	www.snrer.edu.sn
Singapore	SingAREN	www.singaren.net.sg
Somalia	Somaliren	www.somaliren.org
South Africa	SANReN	www.sanren.ac.za
Sri Lanka	LEARN	www.learn.ac.lk
Sudan	SudREN	www.suin.edu.sd
Taiwan, PoC	NCHC/TWAREN	www.twaren.net/english
Tajikistan	TARENA	www.tarena.tj
Tanzania	TERNET	www.ternet.or.tz
Thailand	ThaiREN	www.thairen.net.th
Togo	TogoRER	www.togorer.tg
Trinidad and Tobago	TTRENT	www.ttrent.edu.tt
Tunisia	RNU	www.cck.rnu.tn/?lg=fr&idm=1&id=2
Turkmenistan	TuRENA	www.science.gov.tm/en/turena

Table 1.2.2 - Continued

Country	NREN	URL
Uganda	RENU	www.renu.ac.ug
United Arab Emirates	ANKABUT	www.ankabut.ae
USA	Internet2	www.internet2.edu
USA	ESnet	www.es.net
Uruguay	RAU	www.rau.edu.uy
Uzbekistan	UzSciNet	www.uzsci.net
Venezuela	REACCIUN	www3.reacciun.ve
Vietnam	NASATI	www.vista.gov.vn
Zambia	ZAMREN	www.zamren.zm

1.3 Legal form of NRENs

NRENs have various legal forms. NREN names and their English translations may be misleading: what is called a 'foundation' in one country may be quite different from a foundation in another country. The same is true of several other designations, including 'association'. This section distinguishes two parameters which, together, help to characterise the legal form of an NREN:

1) Its relationship with government; and
2) Whether it is a separate legal entity.

In some countries, there is a distinction between the name of the physical network (e.g. PIONIER in Poland or Funet in Finland) and the name of the organisation that runs it. Thus, Funet is run by an operational unit within CSC, an organisation that performs several other functions within Finland, such as high-performance computing. Although the two parameters cited above can usefully characterise the legal form of an NREN, the classification is not always straightforward.

Relationship with government

In this *Compendium*, we distinguish three situations:

a) An NREN that is under direct government control. Such is the case if an NREN is a government agency or parastatal, or a part thereof.
b) An NREN operating independently of government to a certain extent; for example, those that are separate legal entities with governing boards at least half of whose members are government-appointed. Also, some NRENs that are government agencies enjoy a certain degree of autonomy comparable to that of NRENs that are separate legal entities.
c) An NREN having no direct government ties, even though, typically, the majority of their client institutions are largely government-funded.

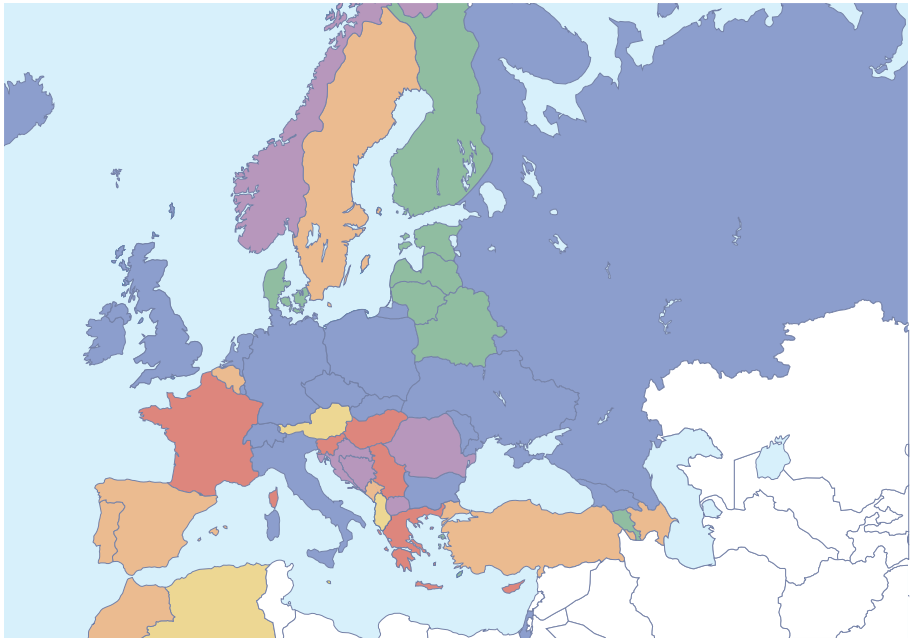
Separate legal entity

Many NRENs operate as separate legal entities.
A combination of the two parameters leads to six categories, as shown in Map 1.3.1:

Legend for Map 1.3.1

Legal entity? Level of government control	Separate legal entity	Not separate legal entity
Not under direct government control		
Some government control		
Entirely government-controlled		

Map 1.3.1 - Legal form of NRENs



It seems self-evident that for an NREN to develop, the commitment of all its major stakeholders – including funders and users – is required. A governing model that allows all such stakeholders to participate would seem to be the most appropriate; such a situation can be achieved in various ways.

NRENs that can operate with a certain degree of independence from their respective governments may have distinct advantages, such as easier decision-making processes and the ability to recruit and retain suitably qualified staff, partly by setting salaries at competitive levels. This may partially explain why this model is more common in countries where, after many years of development, research and education networking is well-established.

2 CLIENT INSTITUTIONS

Below, Section 2.1 indicates the 'market shares'; that is, how many institutions in various categories are actually connected to the NREN; Section 2.2 estimates the numbers of connected users that correspond to these market shares; Section 2.3 documents typical bandwidths. Finally, Section 2.4 examines connectivity to for-profit organisations and international (virtual) research organisations.

As indicated in previous editions of the *Compendium*, all the NRENs covered by this publication are allowed to connect universities and research institutes. Nearly all are permitted to connect institutes of further education, as well as libraries and museums.

Even if an NREN is allowed to connect a certain institution, it does not necessarily do so. In the university sector, NRENs obviously have very high market shares. Based on data provided by NRENs themselves and our own conservative assumptions, we estimate that the NRENs in the GÉANT region provide services to approximately 86% of all university-level students in the countries involved; that is, a total of 25 million university students up from 82% in 2014. The GÉANT network reaches in excess of 50 million users involved in research and education in the region.

For universities[1] within the GÉANT region, the typical connection capacity is now around 10 Gb/s – a tremendous increase compared with the situation a few years ago. In 2005 the average connection speed was in the region of 600Mb/s. The NREN connections to research institutions follow a similar pattern, although less institutions connect at very high speeds. All other categories of user institutions have significantly lower capacities. Differences in bandwidth exist not only between but also within countries.

An increasing number of NRENs connect for-profit organisations. The number of for-profit organisations connected is very limited; in most cases these connections are made specifically to access services provided by the research and education sector. In 2015, 16 GÉANT partner NRENs (40%) provide such connections, up from 10 GÉANT NRENs in 2013.

The number of connections to international (virtual) research organisations/ projects (for example, LHC, CLARIN etc) is increasing. Again, such connections are provided for collaboration with the research and education sector. 43% of GÉANT parner NRENs provide such connections.

2.1 Approximate market shares

Below, table 2.1.2 gives an overview of the number of institutions in each user-category and indicates the 'market shares' of each NREN. Note that *Compendium* respondents submitted only approximate percentages.

Many NRENs operating in a strong hierarchy of Metropolitan or Regional Area Networks (MAN/RAN) were unable to provide connection figures but did indicate that they service high percentages of their respective communities. For additional information on individual NRENs, see the *Compendium* website: **https://compendium.geant.org/**. More and more, NRENs are connecting research institutions and hospitals indirectly, in other words through an existing connection, this makes counting individual institutions somewhat difficult. In the case of Primary and Secondary Schools, most NRENs connect these indirectly but are able to account for the number of schools accurately.

[1] See Appendix 2 for a definition of the term 'university'.

As in the previous *Compendium*, we asked NRENs to use the ISCED classification of educational institutions. More clearly than the previous scheme, this new classification differentiates tertiary institutions offering courses below Bachelor level from those offering Bachelor- and higher level courses (that is, at ISCED[2] levels 6, 7 and 8). We asked NRENs to provide combined data for all tertiary education institutions in the latter category. In some countries, including Ireland, only institutions offering education up to level 8 (the doctoral level) are considered to be true universities. In the Netherlands, for example, a distinction is made between universities of applied sciences and other universities.

Table 2.1.1 – ISCED 2011 levels

8	Doctorate or equivalent level
7	Masters or equivalent level
6	Bachelors or equivalent level
5	Short-cycle tertiary education
4	Post-secondary non-tertiary education, e.g. short vocational training programmes
2-3	Secondary education
1	Primary or basic education
0	Pre-primary education

There are minor changes in the numbers of connected universities on a year to year basis, generally this in an upward trend, however local political changes may result in the amalgamation of universities resulting in a net decrease in connections. The total number of students served by the NREN may not be altered by this process.

Legend for Table 2.1.2

Legend	NREN-connected institutions
	> 80%
	60 – 80%
	40 – 60%
	20 – 40%
	< 20%
	Unknown or not applicable
	No answer provided

The chart on the following page is a combination of the percentage market share that the NREN has in the country along with the absolute number of direct connections in the various market segments. The colour shading of the cell represent the market share as outlined in the legend above.

This table can be used by NRENs to compare and contrast the levels of connectivity in their peer NRENs. In particular, NRENs can identify market opportunities by examining how comparable NRENs are performing in the various sectors. The level of "greenness" in the boxes shows the level of reported penetration in the relevant sector. Where an NREN is in a position to expand its reach, then it should look at the sectors that have lower penetration. Of course, not all NRENs have acceptable use policies that allow them serve all market sectors.

[2] http://www.uis.unesco.org/Education/Pages/international-standard-classification-of-education.aspx

Table 2.1.2 – Approximate market shares

	Share	Share	Share	Share	Share	Share	Share	Share
	Universities and other	**Institutes of further education**	**Research institutes**	**Secondary schools**	**Primary schools**	**Libraries, Museums, Archives, Cultural institutions**	**Hospitals (other than university hospitals)**	**Government departments (national, regional, local**
GÉANT partner countries								
Armenia	4		35	0	0	4	0	2
Austria	54		28			13	5	26
Azerbaijan			29			9		
Belarus	10		59			17	5	8
Belgium	57	5	41	8	0	15	13	50
Bulgaria	22		42					
Croatia	147	0	36	432	927	11	11	11
Cyprus	8	2	5					
Czech Republic	36	23	31	70	11	42	43	46
Denmark	8	7	22	0	0	5	0	0
Estonia	22	14	23	35	27	56	0	9
Finland	48		10			7		8
France	423	355	403			23	7	23
Georgia	9	19	4	3		3	1	3
Germany								
Greece	40		15				10	
Hungary	27	31	69	1610	3025	571	6	3
Iceland	7	2	8	1				0
Ireland	27	11	12	800	3200	0	0	14
Israel	12	0	4	0	0	1	0	0
Italy	150	0	374	201	21	52	44	5
Latvia	7	0	6	2	0	0	0	1
Luxembourg	7	0	24	60	229	14	0	16
Malta	1	1	3	29	69			
Moldova	10	2	36	1	0	10	10	1
Montenegro	19	1	2			2		1
Netherlands	54	40	29			11	4	

Table 2.1.2 – Continued

	Share	Share	Share	Share	Share	Share	Share	Share
	Universities and other	**Institutes of further education**	**Research institutes**	**Secondary schools**	**Primary schools**	**Libraries, Museums, Archives, Cultural institutions**	**Hospitals (other than university hospitals)**	**Government departments (national, regional, local**
GÉANT partner countries								
Norway	37	20	74	2	4	17	0	0
Poland	185	20	213	256		75	0	0
Portugal	49	0	7	0	0	0	0	10
Romania	50	10	56	350	140	40		30
Serbia	94	11	44	14	5	32	6	2
Slovakia								
Slovenia	4	17	51	153	556	209	0	24
Spain	93	6	199			48	57	32
Sweden								
Switzerland	44	2	11	2	0	1	0	6
Turkey	171	2	19			1		13
Ukraine	80	5	10			2	2	3
United Kingdom	242	551	43			8	0	11
Other countries								
Albania	12	NA	4	NA	NA	2	NA	5
Algeria	59	43	15			0		5
Australia	61	18	30	82	80	15	8	9
Bosnia / Herzegovina	30	0	20			2		
Brazil	1003	12	157	8		23	65	77
Canada	89	148			0	24	62	127
Ecuador								
Morocco	94	9	5			0	0	2
New Zealand	8	15	7	3		2		3
Russian Federation	250		140			4		2
South Africa	25	5	26		0	2	0	0
Taiwan	90	5	5	1000	1000	5	1	5
United States								
New Zealand	8	15	7	3		2		3

2.2 Numbers of university student users

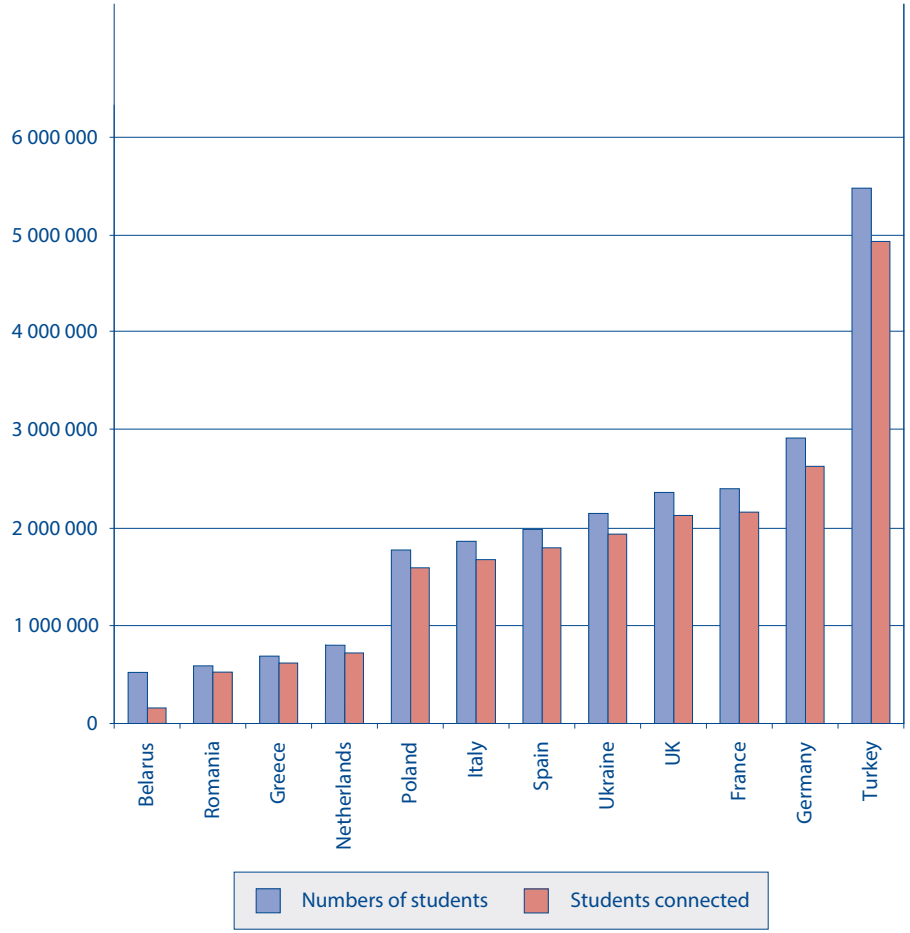
In the questionnaire for this edition of the *Compendium*, NRENs were asked to estimate the numbers of university students they serve. This information has been combined with enrolment figures derived from UNESCO statistics and Eurostat to produce Graphs 2.2.1 and 2.2.2, showing estimated numbers of university students served by GÉANT NRENs. The published counts for the students in the various categories vary as to their latest report dates and a best effort has been made to come up with a reasonable number of students in each country.

Based on the data received and the assumptions explained above, we estimate that NRENs in the GÉANT region provide services to approximately 86% of all university-level students in those 40 countries; that is, a total of 25 million university students.

The data above also suggest that approximately four million students in the GÉANT region are not serviced by an NREN. Possibly this is an area for growth by the NRENs in the countries with lower university penetration.

The graphs in this section could be used to identify where an NREN's penetration in the university market falls below their peer NRENs. So where the number of students connected falls significantly below the number of students in the country, then the NREN could consider an attempt to increase the number of students they serve.

Graph 2.2.1 – Numbers of students serviced by an NREN, GÉANT region, for countries with > 500 000 students



Graph 2.2.2 – Numbers of students serviced by an NREN, GÉANT region, for countries with < 500 000 students

2.3 Bandwidths

The 2008 edition of the *Compendium* stated that:

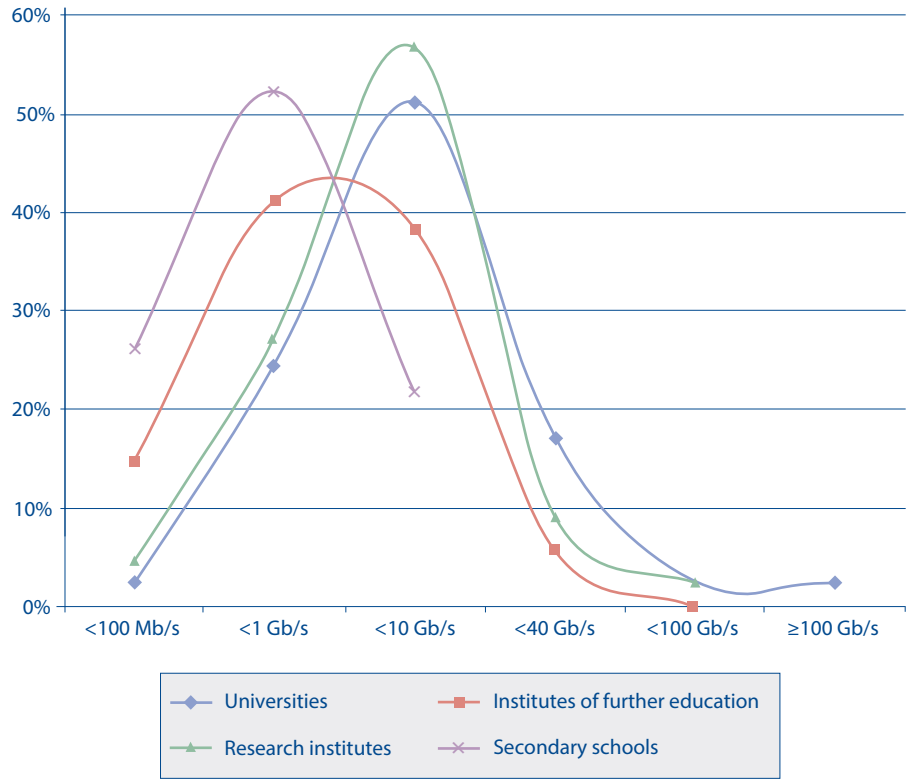
> *In 2003, the 'average' university was connected at Megabit capacity; by 2008, that had changed to Gigabit capacity.*

The typical capacity for universities in GÉANT partner countries is now in the region of 10 Gb/s. All other user-categories have lower capacities, although research institutions are similar at 10 Gb/s.

Graph 2.3.1 gives an overview of the spread of bandwidths available to NREN users. Note that not all NRENs provided information relevant to this overview, so the set of countries is not exactly the same in each user-category. In comparing the graph from 2014 it should be noted that no NREN reported typical connections below 100Mb/s and that there is a clustering effect with many institutions connecting at the 1Gb/s and 10Gb/s speeds.

We have also considered the spread within individual countries. It should be noted that in some countries all or most institutions in a particular category are connected at similar capacities, whereas in other countries there may be large capacity differences at national level.

Graph 2.3.1 – Typical bandwidth, GÉANT partner countries



Also in countries outside the GÉANT region, Gigabit connections are becoming the norm. Table 2.3.2 shows the information received from non-GÉANT countries.

Legend for Table 2.3.2

	<10 Mb/s
	<100 Mb/s
	<1 Gb/s
	<10 Gb/s
	<40 Gb/s
	<100 Gb/s
	≥100 Gb/s

A	Universities and other
B	Institutes of further education
C	Research institutes
D	Secondary schools
E	Primary schools
F	Libraries, museums, archives, cultural institutions
G	Hospitals (other than university hospitals)
H	Government departments (national, regional, local)

Table 2.3.2 – Typical bandwidth, non-GÉANT countries

Typical	A	B	C	D	E	F	G	H
Albania								
Algeria								
Australia								
Bosnia / Herzegovina								
Brazil								
Canada								
Morocco								
New Zealand								
Russian Federation								
South Africa								
Taiwan								

Table 2.3.2 is presented in a tabular form as there is a disparity in the level of development in the countries that reported their figures outside the GÉANT region.

2.4 For-profit organisations and international (virtual) research organisations (for example, LHC CLARIN etc)

We asked the NRENs whether they connect commercial, for-profit organisations. About 52%, overall, do not permit this, and the ones that do allow it, use it specifically for collaborations between the for-profit organisations and the research and education sector.

There are some differences between the GÉANT and the non-GÉANT NRENs: 40% of GÉANT NRENs allow such connections compared with 29% in the other NRENs. The number of NRENs that do not allow such connects is about 52% across all regions that reported. Table 2.4.1 outlines the percentages of NRENs that permit or disallow access to for-profit and virtual organisations.

Table 2.4.1 – Connections to for-profit and international (virtual) research organisations (for example, LHC CLARIN etc)

Country	Connects for-profit organisations?	Connects international (virtual) research organisations?	Project or Organisation	Type of connectivity	End points	Capacity
GÉANT partner countries						
Armenia	On the same basis as R&E organisations	Yes				
Austria	No	No				
Belarus	Under other circumstances					
Belgium	Under other circumstances	Yes	iMinds (involved in several European projects)	Point-to-point connections	4	1 Gb/s or less.
Bulgaria	Specifically for offering services to the research and education sector	No				
Croatia	Specifically for offering services to the research and education sector	Yes				
Cyprus	Specifically for offering services to the research and education sector					
Czech Republic	No	Yes	LHCONE	VPN	CESNET-DFN	10 Gb/s
Denmark	Specifically for offering services to the research and education sector	Yes		Capacity	1	10 Gb/s
Estonia	On the same basis as R&E organisations	No				
Finland	Specifically for offering services to the research and education sector	Yes	NDGF/LHC	lightpath	Espoo - Copenhagen	10 Gb/s
France	On the same basis as R&E organisations	Yes	LHC ONE	dedicated links	Paris, Orsay, Nantes, Marseille, Grenoble, Strasbourg, Clermont-Ferrand, Lyon	end points connected from 10 to 30 Gb/s, GÉANT is connected at 40 Gb/s
Georgia	No	Yes				
Germany	Specifically for offering services to the research and education sector	Yes		Lambda		10 Gb/s

Table 2.4.1 – Continued

Country	Connects for-profit organisations?	Connects international (virtual) research organisations?	Project or Organisation	Type of connectivity	End points	Capacity
GÉANT partner countries						
Greece	No	No				
Hungary	Under other circumstances	Yes		DWDM	Geneva-Budapest	100 Gb/s
Iceland	Specifically for offering services to the research and education sector	Yes				
Ireland	Specifically for offering services to the research and education sector	Yes				
Israel	No	Yes				
Italy	Under other circumstances	Yes	LHCOPN	L3VPN, OPN	CERN	20 Gb/s
Lithuania	Specifically for offering services to the research and education sector	No				
Luxembourg	Specifically for offering services to the research and education sector	Yes				
Macedonia	On the same basis as R&E organisations	No				
Malta	Under other circumstances	Yes				
Moldova	Specifically for offering services to the research and education sector	Yes				
Montenegro	No	No				
Netherlands	Under other circumstances	Yes	LHC	lambdas	Amsterdam - Geneva	multiple 100 Gbit/s
Norway	No	Yes	LHC	Private network	Oslo - Copenhagen	10 Gb/s
Poland	Specifically for offering services to the research and education sector	Yes	LHCONE	L3VPN	Krakow, Poznan, Warszawa	1 Gb/s
Portugal	Specifically for offering services to the research and education sector	Yes				

Table 2.4.1 – Continued

Country	Connects for-profit organisations?	Connects international (virtual) research organisations?	Project or Organisation	Type of connectivity	End points	Capacity
GÉANT partner countries						
Romania	No	Yes				
Serbia	No	Yes				
Slovakia	Specifically for offering services to the research and education sector	No				
Slovenia	No	No				
Spain	Under other circumstances	Yes	LHC	dedicated lambda	Barcelona-Geneve	10 Gb/s
Sweden	Specifically for offering services to the research and education sector	Yes				
Switzerland	Specifically for offering services to the research and education sector	Yes	BBP	P2P	EPFL, CSCS	10 Gb/s
Turkey	Under other circumstances	Yes				
UK	Specifically for offering services to the research and education sector	No				
Country	**Connects for-profit organisations?**	**Connects international (virtual) research organisations?**	**Project or Organisation**	**Type of connectivity**	**End points**	**Capacity**
Other countries						
Albania	Specifically for offering services to the research and education sector	No				
Algeria	No	Yes	EUMEDCONNECT	GEANT	GEANT-Italy	622 Mb/s
Australia	Yes	No				
Bosnia / Herzegovina	No	No				
Brazil	Yes	No				
Canada		Yes	LHCOPN/LHCONE	L2VPN		10 Gb/s
Ecuador		No				

Table 2.4.1 – Continued

Country	Connects for-profit organisations?	Connects international (virtual) research organisations?	Project or Organisation	Type of connectivity	End points	Capacity
Other countries						
Morocco	No	No				
New Zealand	No	No				
Russian Federation	Yes	Yes				
South Africa	No	Yes				
Taiwan	No	Yes	HPDMnet	Lightpath	StarLight	622M
United States	Yes					

Table 2.4.2 – NRENs that permit or disallow access to for-profit and virtual organisations

	Connections to for-profit organisations	Connections to international (virtual) research organisations
GÉANT NRENs		
Allow	40%	43%
Do not allow	53%	58%
Other NRENs		
Allow	29%	36%
Do not allow	50%	57%
All NRENs		
Allow	37%	41%
Do not allow	52%	57%

3 NETWORK AND CONNECTIVITY SERVICES

This section provides insights into several important network characteristics. Section 3.1 presents information on core capacity on the routed network. Section 3.2 examines the capacity of NREN external connections. Section 3.3 documents recent developments in dark fibre. Section 3.4 includes an overview of expected major developments in research and education networking. Sections 3.5 and 3.6 look at Software-Defined Networks (SDN) and Network Function Virtualisation, respectively.

In most GÉANT partner countries, the typical core capacity is 10 Gb/s (as in 2014) though some NRENs have reached 100 Gb/s. Because many NRENs in the GÉANT region have access to dark fibre (see Section 3.3), which is potentially able to handle high capacities, they can increase capacity easily and economically whenever required. Some NRENs allow several paths in their backbone, effectively increasing the capacity even further.

In non GÉANT countries, the trend is similar. Australia and the USA, for example, have both introduced 100 Gb/s capacities.

In general, connections not only to the European academic backbone network (i.e. GÉANT) but also to the general Internet are crucial to NRENs. For NRENs in less-well served parts of Europe, GÉANT is a key resource and offers the only affordable way for the research and education sector to gain access to counterparts in other parts of Europe and the world.

For the purposes of the *Compendium*, we have been monitoring the uptake of dark fibre by NRENs since 2005. At that time, only a few networks used dark fibre in their backbones, and GÉANT was just starting to use dark fibre and light it for transnational trunks.

This year (2015), the aggregate length of dark fibre used internally by NRENs in the GÉANT region exceeds 145 000 km, approximately 4% above the 2014 figure.

Within an NREN there are many ways to use dark fibre cost-effectively, all of which are focused on enhanced services to clients and users. NRENs, as a result of moving from managed network links to their own transmission infrastructure, have been able to develop new features and services at various levels.

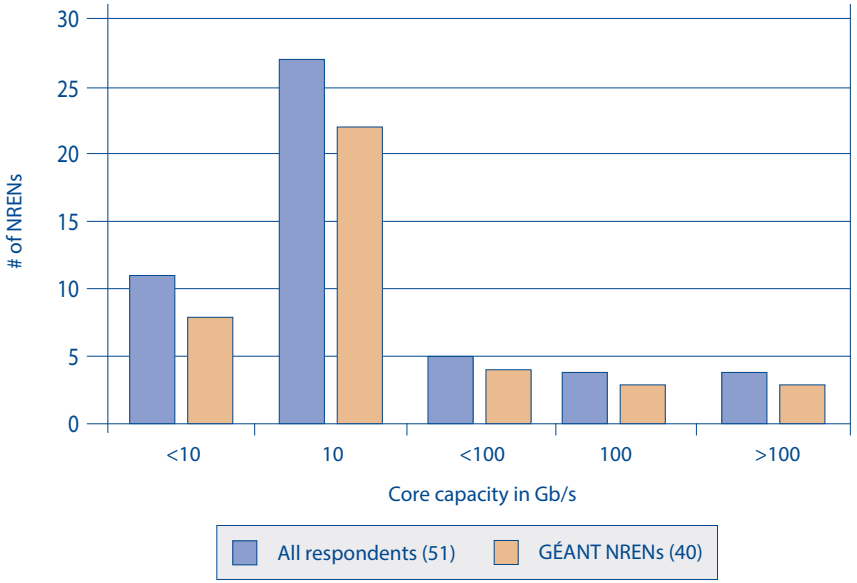
Out of the 40 responding NRENs, 20% use some type of SDN technology, with 25% planning this for the future. Three of the responding NRENs provide SDN in a production environment.
Network Function Virtualisation is not yet common in the NREN environment, even though several NRENs are planning to introduce this, mainly for internal use.

3.1 Core capacity on the routed network

The term 'core usable backbone capacity' means the typical core capacity of the linked nodes in the core. Some NRENs have dark fibre with a very high theoretical capacity; in such cases, we requested data on the usable IP capacity.

In most GÉANT partner countries, the typical core capacity is still 10 Gb/s, though some NRENs have reached 100 Gb/s. The trend is similar in non-GÉANT countries that submitted data for this year's *Compendium* survey. Graph 3.1.1 summarizes the available data.

Graph 3.1.1 – Core capacities on the routed network[1]



As many NRENs in the GÉANT region have access to dark fibre (see Section 3.3), which is potentially able to handle high capacities, they can increase capacity easily and economically whenever required. In addition, as indicated in Section 3.3, many NRENs now have several point-to-point circuits and pure optical services, which offer additional capacity that is not usually included in normal traffic statistics.

Knowing the typical capacity of the links is no longer sufficient. In several cases, the NREN's network is structured as a mesh, having redundant core and access links. SUNET finds it impossible to state a figure for its core capacity, because it has a "redundant star shaped backbone".

It should be noted that network capacity grows stepwise rather than linearly.

[1] Graph format suggested by Guy Roberts, GÉANT

3.2 External connectivity

The NRENs covered by this edition of the *Compendium* were asked to list all their external connections as of January 2015.

It should be noted that the Nordic NRENs (DeIC of Denmark, Funet of Finland, RHnet of Iceland, SUNET of Sweden and UNINETT of Norway) share their external connections through NORDUnet.

In general, connections to GÉANT and to other NRENs carry research and education traffic, whereas peerings and other connections convey traffic to and from the general Internet. Research and education traffic may consist of highly specialised data and is often transmitted in huge volumes within very short time-frames; for example, real-time observational data from a radio telescope, which must be transmitted over large distances for pre-processing and storage. As high traffic peaks can be expected on such links, they must be dimensioned to accommodate them; it is not unusual to see a flow of 1 Gb/s generated by a single high-end researcher.

In contrast, traffic to and from the general Internet tends to be aggregated and smoothly varying. It comprises a large number of small-to-medium data flows, which combine to produce a fairly predictable traffic pattern. Therefore, the required capacity of the link can be reliably related to the average flow of data.

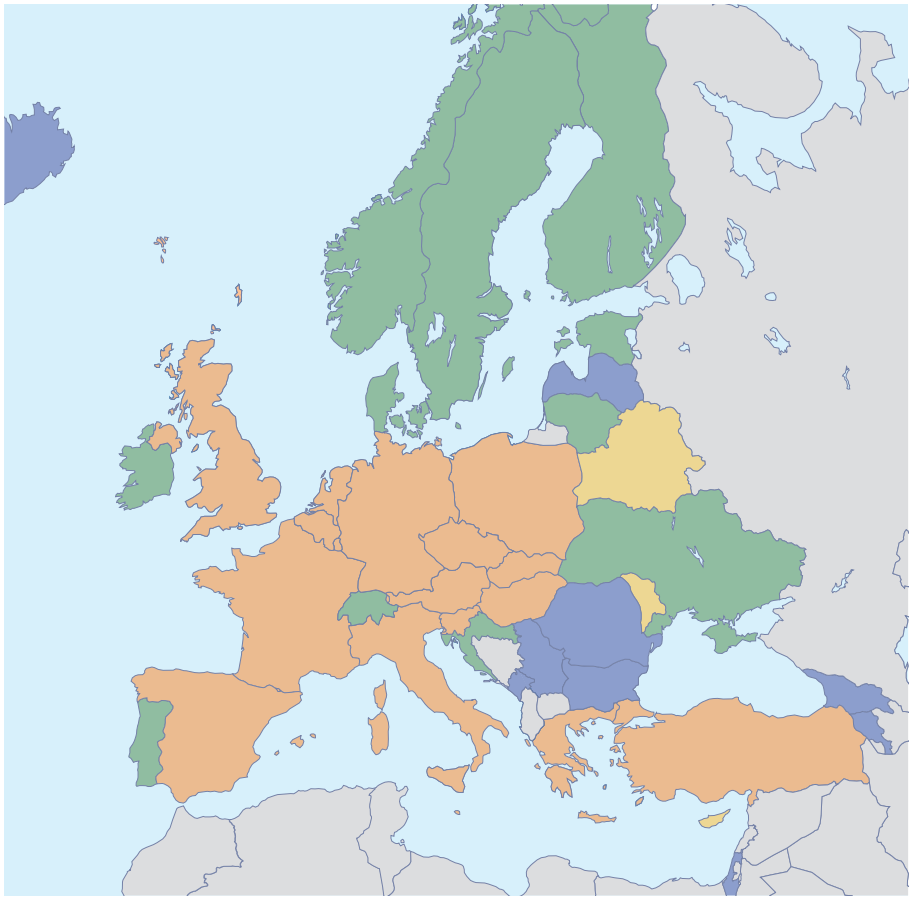
In general, connections not only to the European academic backbone network (i.e. GÉANT) but also to the general Internet are crucially important to NRENs. For certain NRENs, the connectivity to the general Internet is ensured via the GÉANT World Service (GWS). For many others, this is done either through settlement-free peerings with national internet exchanges or through contracts with commercial providers or a combination of those.

NRENs can be categorized by looking at a combination of total external connectivity and diversity in external connections, as in the scheme below:

	Combined external connectivity <= 40 Gb/s	Combined external connectivity > 40 Gb/s
GÉANT/NORDUnet provide the largest or the only external connection		
External connections are diversified, GÉANT or NORDUnet is not the largest external connection		

Map 3.2.1 (opposite) shows the division of NRENs according to this scheme. It should be noted that for some NRENs the largest connectivity is now in fact to a neighbouring NREN, using cross-border fibre connections. What is clear from the map is that most NRENs in Western and Central Europe have no problem in connecting to the Internet via Internet Exchanges or via arrangements with commercial providers. The Nordic NRENs have decided to pool their resources through NORDUnet, showing clearly on the map. For NRENs in less-well served parts of Europe, GÉANT is a key resource and offers the only affordable way for the research and education sector to gain access to counterparts in other parts of Europe and the world.

Map 3.2.1 – NREN external connectivity



3.3 Dark fibre

The NRENs covered by this edition of the *Compendium* have categorised the dark fibre they had in their network. They were asked to distinguish between fibre 'installed by the NREN' and fibre 'installed by someone else'. They were also asked to state approximately what percentage of their backbone is accounted for by dark fibre.

Fourty five of the fifty five GÉANT NRENs who responded have reported some dark fibre in their network. This reflects the continued strong commitment to deploying dark fibre in the NREN community.

The GÉANT NRENs reported that at the beginning of 2015 the total number of kilometres of dark fibre in their networks stands at 140 000km. This is up by 4% from 2014. This shows a continued commitment by NRENs to their dark fibre since the question was first asked in the 2005 *Compendium* survey. Nearly all NRENs are reporting an increase in the amount of fibre in their networks. Of the GÉANT partners, CESNET, Belnet, RESTENA have all increased their fibre footprint by between 8% and 10%.

The data also highlights a range of different motivations for NRENs. At one end are small newly emerging NRENs who have a small user-base with little or no fibre. At the other end of the spectrum are countries such as The Netherlands (SURFnet) who were early adopters of dark fibre. Of note in this category is Australia (AARNet) who increased the length of fibre in their network by 35% in 2014. This large increase is due to them putting into service their Brisbane - Longreach - Darwin fibre system. AARNet are unusual in NREN terms as they often have to dig in their own fibre. To facilitate this they have their own in-house civil works team of around 10 full time equivalents.

UNINETT finished installation of two unrepeatered subsea fibre-optic cables each of 250km each, between Longyearbyen and Ny-Ålesund in Svalbard in September 2014. In May 2015 they deployed a 100Gb/s capable coherent DWDM system on both routes. This system includes the world's most northern DWDM node which meant that the fibre had to be deployed in extreme arctic conditions. The fibre supports a strong research community in Ny-Ålesund where eleven institutions from ten countries have established permanent research stations.

The responses to the question of 'what proportion of your network is based on dark fibre?' is summarised in the table below. This table highlights that there remain considerable differences in the possibilities and approaches of NRENs to dark fibre vs leasing capacity. A number of NRENs, especially outside of the GÉANT area, have no dark fibre at all. Five GÉANT NRENs report that their entire network is dark fibre. The remaining NRENs fit somewhere in between these extremes.

For the GÉANT community, their dark fibre forms a substrate on which the services are delivered to their customers. Traditional IP and MPLS based services can be delivered on both leased circuit capacity and dark fibre infrastructure. There are, however, strong benefits for an NREN to acquiring dark fibre - these NRENs are able to offer new and more flexible services to their customers. The benefits include:

- rapid turn-up of new services by holding spares and installing transponders based on demand projections;
- the ability to build a DWDM or OTN GMPLS control plane for automated L1 service restoration;
- integration of the DWDM layer into the NRENs network operations systems;
- closer relationship with transmission equipment vendors allowing new functionality to be developed for our community requirements.

These benefits can bring substantial improvements in customer experience. When NRENs take the decision to build a dark fibre network, they have to weigh these benefits up against the cost. Typically large commercial carriers have high levels of utilization of their network and are able to sell at a low cost to the market. NRENs require sufficient demand to be able to achieve similar levels of utilization – and hence low costs - of their dark fibre infrastructure. Where demand is relatively low, NRENs are now working together to share fibre infrastructure. This allows the community to achieve utilization efficiency to make dark fibre ownership a viable finance option for the community. An example of community collaboration to share optical fibre is the Hamburg to Amsterdam fibre system. The fibre and amplifiers are owned by SURFnet and alien waves from GÉANT and NORDUnet are carried on the system. The costs of this dark fibre infrastructure is shared between SURFnet, NORDUnet and GÉANT.

Table 3.3.1 – Dark fibre on NREN backbones, 2015

GEANT partner NRENs	Km of dark fibre	% of total network	Proportion added / decommissioned (%)
Armenia	75		
Austria	4500		
Azerbaijan	43		
Belarus	5.8	6.5	0
Belgium	2264	100	9.5
Bulgaria	0	0	0
Croatia	131	0.011	-0.01
Czech Republic	6300	100	10
Denmark	2700	58	200
Estonia	1540	85	0
Finland	4340	0.92	0.01
France	13 029	92	0.8
Georgia	500	10	0

Table 3.3.1 – Continued

GEANT partner NRENs	Km of dark fibre	% of total network	Proportion added / decommissioned (%)
Germany	10 250	100	few
Greece	9000	0.999	0
Hungary	3200	95	0
Iceland	140	28	0
Ireland	2652	94	0.02
Israel	770	100	0
Italy	10 100	89	1
Latvia	0	0	0
Lithuania	1350	8	0
Luxemburg	520	0.25	0.083
Macedonia, FYRo	20	50	
Moldova	165	75	0
Montenegro	10.4	0	0
Netherlands	13 556	0.01	0.01
Poland	8944	100	0.17
Portugal	1000	0	0
Romania	5350	1	3
Serbia	4000	95	0
Slovakia	2360	60	0
Slovenia	1662	1	0.01
Spain	13 870	0.98	0.01
Sweden	8000	98	0
Switzerland	2978	100	0.003
Turkey	298	0.08	0.03
UK	9190	Not possible to calculate as we don't know the length of managed circuit components of our network	16% added (1525km)

Table 3.3.1 – Continued

GEANT partner NRENs	Km of dark fibre	% of total network	Proportion added / decommissioned (%)
Ukraine	300	10	-15% (lost MANs in Donetsk, Sevastopol, Simferopol due to Russian military occupation)
Other countries			
Albania	134	20	0
Australia	11 000	65	35% added
Bosnia/Herzegovina	724	100	0.003
Brazil	2361	0.35	0.05
Canada	5250	30	
New Zealand	2205		
Russia	650	8	0
South Africa	1500	12	0.1
Taiwan, PoC	80		
USA	25 294	86	

3.4 Major expected network developments

The NRENs covered by this edition of the *Compendium* were asked to outline major initiatives related to development of their underlying network that they expect to realise within the next two to five years.

Table 3.4.1 provides general insight into major developments in research and education networking that are expected by NRENs in the various countries of Europe and other continents, including:

- Several NRENs will upgrade their links to 10 or in some cases 100 Gb/s or even multiples thereof;
- Several NRENs report that they plan to install SDN capabilities.

Table 3.4.1 – Major expected network developments

Country	Initiative	Timeframe	Likelihood
Albania	Development of the whole ANA network	01/06/2016	Quite certain
	Connection with GEANT network	01/07/2016	Quite certain
Algeria	Upgrade GEANT Link	1 year	Quite certain
	Upgrade Commercial Internet	2 years	Likely
Belarus	Increase the capacity of the link to PIONIER (Minsk-Poznan) to 10 Gb/s	2016-2020	Likely
	New link to LITNET (Minsk-Kaunas) up to 10 Gb/s	2016-2020	Likely
Belgium	Extension of the Belnet hybrid network	Continue	Quite certain
	Efforts in automation via	Q2 2016	Quite certain
	Service extension (LAN, Wi-Fi As a Service,...)	2016	Quite certain
	Implementation of NFV functionalities towards the Belnet customers	2018	Quite certain
Brazil	Introduction of SDN pilot (Iara)	01/01/1900	Quite certain
	Deployment of some 100G links both at national and international levels	01/01/1900	Quite certain
	Extension of Performance Monitoring to include user access links	2	Quite certain
Bulgaria	5 Gb/s	07/07/1905	Quite certain
	10 Gb/s	08/07/1905	Quite certain
Canada	Developing SDN technology	08/07/1905	Likely
	L2/L3 VPN service	07/07/1905	Quite certain
Cyprus	Backbone Active equipment	9 months	Quite certain
	International Traffic upgrade	2.5 Gb/s	Uncertain
	National Dark Fibre		Uncertain

Table 3.4.1 – Continued

Country	Initiative	Timeframe	Likelihood
Czech Republic	Large Infrastructures (e-infrastructure CESNET)	2016-2022	Quite certain
Denmark	New optical equipment	2016	Quite certain
	New router equipment	2016/17	Quite certain
	CBF to Sweden	2016	Likely
	Resilience via NORDUnet	2016	Likely
Estonia	Connect K-12 schools	10/07/1905	Quite certain
France	HW upgrade	08/07/1905	Quite certain
	100Gbit/s	08/07/1905	
Georgia	EaPConnect	07/07/1905	Quite certain
Hungary	Educational Cloud	2016-18	Likely
	Schoolnet	2015-2018	Quite certain
Ireland	Replacement of layer 2 and layer 3 network	2016-2018	Quite certain
	Backbone upgrade to 100Gbit/s links		Quite certain
Italy	Currently a new project is under study, called GARR-T, aiming at guaranteeing constant evolution of access and backbone capacity in the next 15 years as well as feasibility of operational and management costs. The key elements of the project will be 15 years IRU fibre acquisition, greater capillarity of fibre PoPs and mesh topology to gain maximum reliability and resiliency	next 2 years	Likely
Lithuania	100G Kaunas - Vilnius	2 years	Likely
	DWDM system upgrade	2 years	Likely
Luxemburg	Extend 10G coverage	01/01/1900	Quite certain
	Extend WDM network	02/01/1900	Quite certain
Malta	More use of dark fibre	2016-2018	Uncertain

Table 3.4.1 – Continued

Country	Initiative	Timeframe	Likelihood
Moldova	EaPConnect	2016-2017	Quite certain
Morocco	Marwan 4 will be a Layer 2 VPN/ MPLS (Layer 3 for Marwan 3)	08/07/1905	Quite certain
	AfricaConnect	09/07/1905	Quite certain
Netherlands	SURFnet8	09/07/1905	Quite certain
	SDN	Underway	Quite certain
	Infinera Extension (South Island)	12-18 months	Likely
	Replacing Brocade with Juniper	24 months	Likely
Norway	Dark fibre Longyearbyen - Ny Alesund	07/07/1905	Quite certain
	Cross-border connection with FUNET from Finnmark for added resiliency	2016-2017	Uncertain
	Deployment of several 100G links in our backbone		Likely
Romania	Upgrade all main/core circuits to 100Gb/s	2 yr	Quite certain
Russian Federation	DWDM Moscow - Saint Petersburg	2016	Quite certain
	10Gb/s Ekaterinburg - Novosibirsk	2016	Quite certain
	SDN Testbed	2016	Quite certain
South Africa	Backbone upgrade	1-5 years	Quite certain
	International capacity upgrade	1-3 years	Quite certain
	Addition of new sites	3 years	Quite certain
	Backbone expansion	3 years	Quite certain
Spain	Submarine cable with Balearic islands	operational mid 2015	Complete
	Dark fibre link with Doñana Biological Station in Huelva	operational in October 2015	Complete
	Submarine cable with Melilla	operational in December 2015	Complete
Switzerland	Roll-Out Renewal of Optical Infrastructure	1 year	Quite certain

Table 3.4.1 – Continued

Country	Initiative	Timeframe	Likelihood
Switzerland	Deploy new 100G routers	3 years	Quite certain
Taiwan, PoC	100G backbone upgrade	2016/Jan-Dec	Likely
Turkey	Increase of fibre infrastructure	3 years	Likely
UK	Mid-term upgrade of the Janet core network infrastructure	2015/2016-2017/2018	Quite certain
	Continuation of the strategy to connect the data-intensive research organisations in the UK to the Janet transmission infrastructure by fibre	Ongoing	Quite certain
	Extending our capability to deploy Layer 2 committed rate circuits across more of the footprint of the network	Ongoing	Quite certain
	Launch of a range of Layers 2 and 3 circuit services	Start October 2015	Quite certain
	Introduction of a higher assurance networking service following a pilot activity	Start 2017	Likely
	Deployment of SDN as a provisioning mechanism		Uncertain
	Increased support to improve end-to-end network performance across Janet through training and advice, provision of tools and direct support for specific applications	Started 2015	Quite certain
Ukraine	EaPConnect	2015-2020	Uncertain

3.5 Software-Defined Networks

In this year's *Compendium*, the definition of the acronym SDN (Software Defined Networking) has been opened up. In the past SDN might have been seen as OpenFlow, but slowly SDN is seen more and more as orchestration and the ability to have APIs for automated service provisioning (zero touch). This direction is also seen by one of the SDN authors, who recognises that ISPs need other functionalities than just OpenFlow. This direction is called SDN Version 2[2]. Due to this change of direction, this edition of the *Compendium* has merged the SDN (Version 1) and Network as a Service Concepts.

As expected, one can see an increase in SDN based services. Of the 48 NRENs that responded to the SDN questions, some 20% use any kind of SDN technology, while around 25% of the NRENs are planning SDN in the future. Three of the responding NRENs provide SDN in a production environment. Of the NRENs using or planning to use SDN, all but three will use OpenFlow, while the rest will use an orchestration tool. There is not (yet) a single SDN orchestration tool that is favoured by NRENs, some mentioned are: OpenStack, OpenDayLight, OpenNaaS, NAASi, etc.

SDN is mainly (expected to be) used for: experimenting by NRENs (60%), offering to researchers (30%), or supporting operational services (10%). A majority of the NRENs (57%) is interested in multi-domain SDN facilities or is planning to start this.

Customer can request SDN type services from around one third of the NRENs that (will) provide SDN in some form. And only in a quarter of these cases, an application can activate the SDN service through an API.

[2] *Time for an SDN Sequel? Scott Shenker Preaches SDN Version 2*, https://www.sdxcentral.com/articles/news/scott-shenker-preaches-revised-sdn-sdnv2/2014/10/

3.6 Network Function Virtualisation

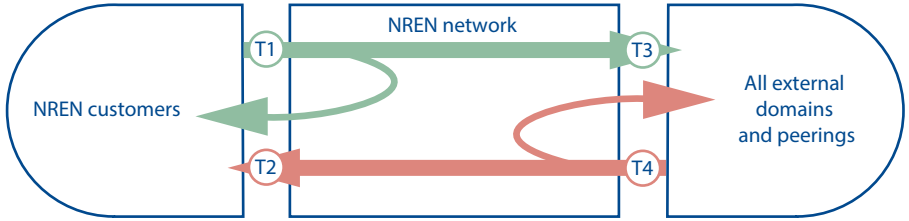
Network Function Virtualisation (NFV) as a technology is becoming more and more mainstream in the commercial ISP world. It is a logical step; similar to the standardisation of hardware and the virtualisation of hardware servers in the data centres. Extending this concept to the network allows easy provisioning of switching/routing functionality (using for instance white-label or bare-metal boxes) or allowing virtualisation of network functions such as firewalls, DDoS mitigation and load balances. Commercial ISPs provide NFV functionality in the client edge equipment at client premises.

In the NREN environment the use of NFV is still very low: at this moment two NRENs (AMRES and CARNet) are providing some form of NFV, while some eight NRENs (e-ARENA, NIIF, CESNET, HEAnet, SURFnet, GARR, LITNET and RENAM) are planning to use NFV. If using or planning, 50% of the NRENs think about router/switch functionality and the rest thinks about firewalling and load balancing functions. The offering will be mainly for internal use by the NREN (as part of providing service chaining). So customers or applications can't (yet) request NFV services.

4 TRAFFIC

As in previous years, the NRENs covered by this edition of the *Compendium* were requested to report their total annual traffic flows at the boundaries of their networks. The four flows they were asked to specify are defined in Diagram 4.0.1 (below).

Diagram 4.0.1 – Types of traffic flow



T1	all traffic[1] from customer sites and the NREN
T2	all traffic to customer sites and the NREN
T3	all traffic leaving the NREN
T4	all traffic entering the NREN

External traffic = all traffic to the NREN's regional backbone, the commercial Internet, Internet Exchanges, etc. (consisting of T3 + T4 above)

In some cases, the reported traffic may include traffic flowing between separate customers of the NREN (as in the arrow from T1 to T2 above). In other cases, such traffic may be confined to separate MANs/RANs – in that case it is not represented in the diagram above and will not show on the NREN backbone.

In certain cases, non-routed traffic within a customer network may be switched via NREN point-to-point circuits but not be reported in traffic statistics, as it does not appear as IP traffic on the NREN network.

Similar distinctions apply to external traffic. IP traffic is exchanged with external networks via peerings in neutral exchange points, via GÉANT with other NRENs in Europe and around the world. In some cases such an exchange can be a cross-border fibre (pure optical link) with neighbouring NRENs. Some NRENs provide neutral exchange points with external networks. In those cases, there is traffic as in the arrow from T4 to T3 above. Some neutral exchanges are outside the NREN – that traffic is of course not part of the T4 to T3 arrow.

Section 4.1 considers traffic in 2014, whereas Section 4.2 analyses traffic trends over the past ten years. Section 4.4 discusses traffic sent via the routed IP network versus other types of traffic. Section 4.4 gives information on traffic per researcher. Section 4.5 considers the issue of congestion. Section 4.6 examines deployment of IPv6. Finally, Section 4.7 focuses on VPN and Point-to-Point (P2P) services.

Most of the NRENs that responded to the questionnaire for this 2015 *Compendium* reported annual IP traffic flows at the points where they exchange traffic with external networks (T3 & T4); most NRENs also reported annual traffic flows between their connected sites and their backbone network (T1 & T2). Comparison with data from previous years reveals that IP traffic continues to grow. Over the past ten years, the compounded annual growth rate (CAGR) has fluctuated around an average of almost 30% (but always remained positive). After a decrease in GÉANT IP traffic at the start of 2014, traffic increased again markedly in 2015.

Many NRENs provide their customers with non-traditional connectivity services, giving them greater freedom and guaranteed quality of service. This is done either through Virtual Private Networks (VPNs) or through point-to-point (P2P) services, or both. Of the 49 responding NRENs, 17 currently offer Layer 3 VPNs, 13 more plan to do this. Fifty NRENs answered the question about Layer 2 connectivity services: 35 of them offer such a service, with four more planning to introduce it. The number of circuits on these services vary widely from NREN to NREN, from a handful to hundreds of circuits.

[1] Note that in previous years, we asked NRENs to look only at IP traffic. This year, we have asked NRENs to look at all traffic, including IP traffic. Currently, most NRENs are able to provide IP traffic data only.

GÉANT provides connectivity not only via the traditional means of a routed IP network. Connectivity is also being provided, especially to larger customers, via Virtual Private Network (VPN) services and separate circuits, as for NRENs. For GÉANT, we estimated the traffic on the GÉANT Lambda service[2], using conservative assumptions. This leads to the conclusion that for GÉANT, traffic on these circuits is currently at least as high as the traffic on the routed IP network.

It is likely that several NRENs are also transporting more traffic than reported by the IP traffic alone. We have asked NRENs to provide information about these traffic streams, but at the moment most NRENs do not measure this. Because of the potential traffic volumes (and associated costs) an NRENs shall try to record all traffic streams through circuits in addition to IP traffic, to the extent that this is feasible.

Growth in traffic per researcher is similar to the growth in Internet traffic overall. However, traffic per researcher is at a much higher level than traffic per person – this trend is constant. Thus, traffic per researcher is around 10 000 times the traffic per EU citizen.

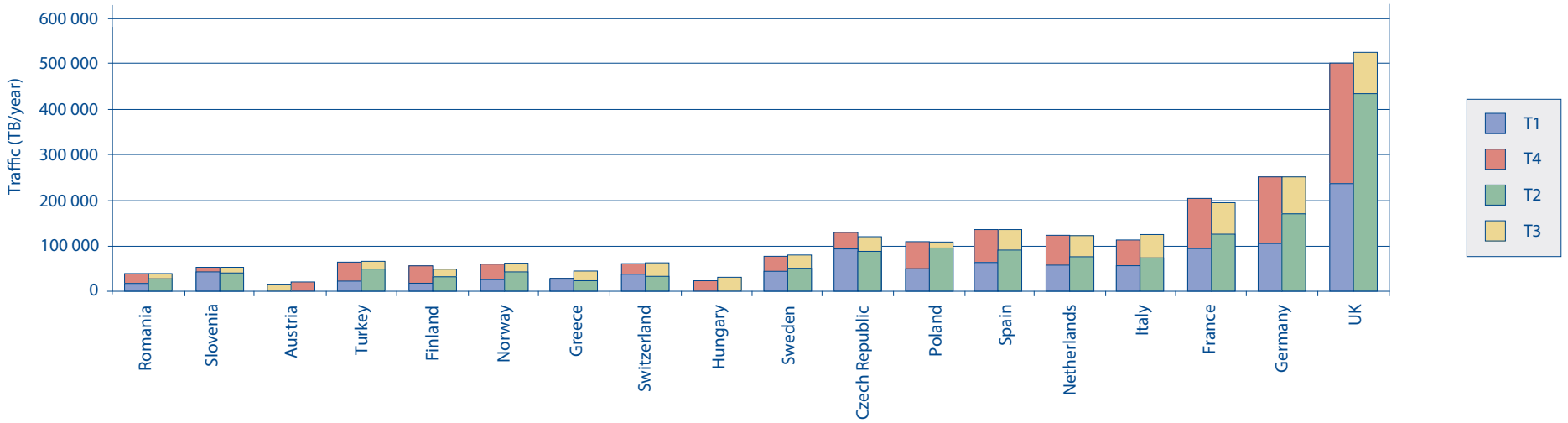
For the GÉANT partner countries, average estimated congestion levels have decreased at most levels and are now indeed very low.

The vast majority of NRENs provide some or all of their clients with both IPv4 and IPv6 connectivity, but actual take-up of IPv6 remains low.

4.1 Traffic in 2014

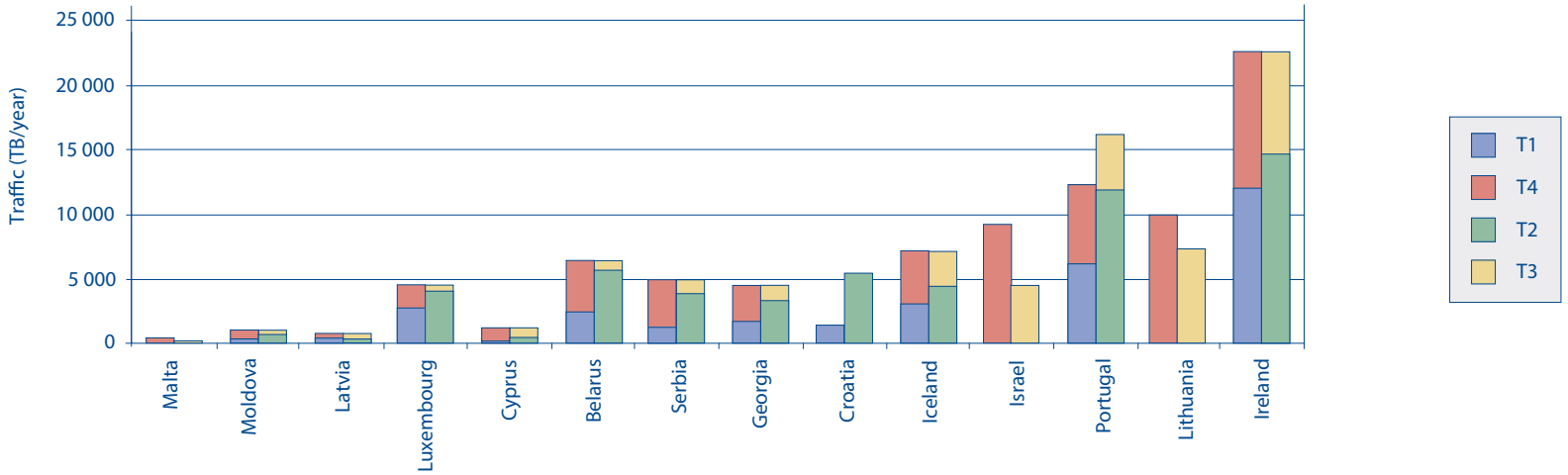
Below, Graph 4.1.1 represents the data submitted by those NRENs whose T3 traffic exceeds 10 000 terabytes per year, whereas Graph 4.2.2 represents the data submitted by NRENs with lower levels of T3 traffic. (In both graphs, the countries have been sorted on the amount of T3 traffic.) These graphs clearly show how the distribution of total traffic between the four categories (T1 to T4) differs from NREN to NREN. Note that not all respondent NRENs provided all four traffic values.

Graph 4.1.1 – 2013 traffic, T3 > 10 000 TB



[2] http://www.geant.org/Services/Connectivity_and_network/Pages/GEANT_Point-to-Point.aspx

Graph 4.1.2 – 2013 traffic, T3 < 10 000 TB

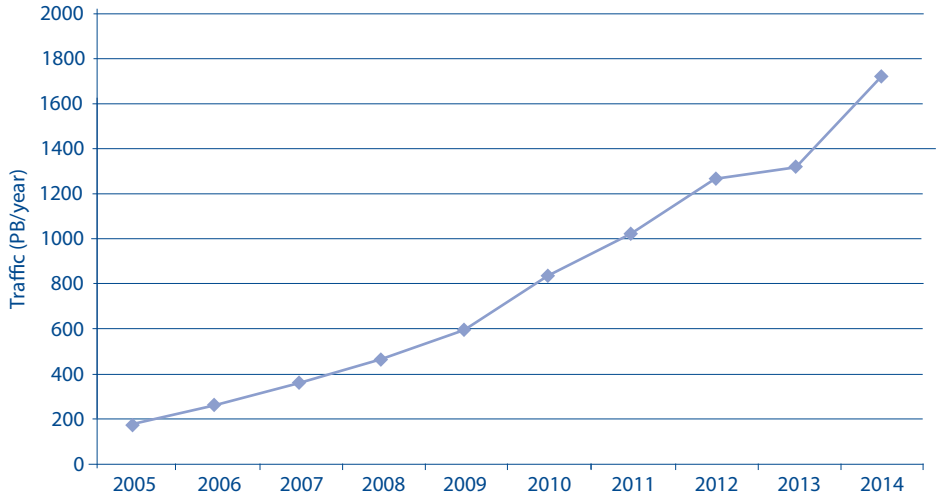


For most NRENs, the reported traffic sent into their backbone (T1+T4) is equal or nearly equal to the reported traffic sent out of their backbone (T2+T3). The few NRENs for which this is not the case cite, as main reasons for the discrepancy, hosting of Content Delivery Networks such as Akamai, and difficulties in separating out the various traffic types or not fully understanding the traffic flow model of Diagram 4.0.1. Traffic monitoring errors could be responsible for minor differences as well.

4.2 Traffic trends, 2005-2015[3]

As in the 2014 edition of the *Compendium*, Graph 4.2.1 shows T3+T4 values for a subset of 24 NRENs that have consistently submitted complete data.

Graph 4.2.1 – NREN annual IP traffic flows (T3+T4), 2005-2014, n = 24 NRENs



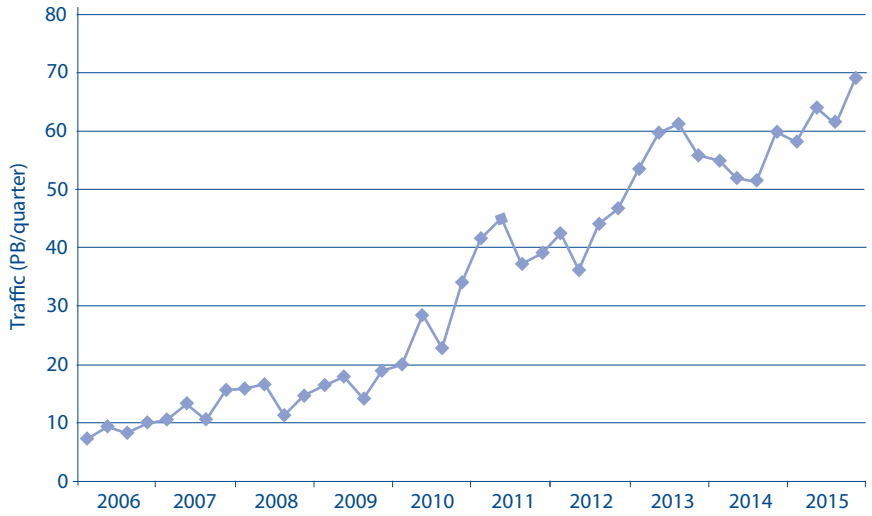
[3] Data for this section and the next were provide by Emma Apted, GÉANT

Clearly, over this ten-year period (2005-2014) NREN traffic has continued to grow steadily, even though growth in 2012/2013 was lower than in earlier years. The compounded annual growth rate was almost 30%. Not all NRENs' traffic is directed to GÉANT: some traffic is directed to providers; to other NRENs via cross-border fibre; or for specific connectivity outside the GÉANT infrastructure.

Using data from GÉANT monthly service reports, GÉANT IP traffic growth has been plotted in Graph 4.2.2 (below). It shows a similar pattern to the NREN traffic pattern. The decrease in traffic in 2014 may partially be explained by the technical halt of the Large Hadron Collider (LHC) at CERN for upgrading between 2013 and 2015.

GÉANT also transports traffic for LHC and other experiments, which is not accounted for in the graph (below) and has to be summed for a view of full use of the infrastructure.

Graph 4.2.2 – GÉANT basic IP traffic 2006-2015 (quarterly data)



The type of traffic shown in this graph has a strong component related to interactive use of the network. In addition, the GÉANT and NREN backbones are constantly being upgraded; therefore, traffic oscillation is to be expected.

The total traffic of GÉANT is the sum of the basic IP component, the Virtual Private Networks for experiments, peerings and the optical circuits (see below) amounting in late 2014 and early 2015 to about 240 PB per quarter.

4.3 Basic IP traffic and other types of traffic

GÉANT as well as the NRENs provide connectivity via the traditional means of a routed IP network but also - especially to larger customers - via Virtual Private Network (VPN) services and separate, dedicated circuits. The ability to measure traffic on these circuits depends on the hardware that is used. It has become easier only recently. Traffic statistics based on IP tend to understate the total traffic, to various degrees, depending on the scale of the VPN and related services being offered (see also section 4.7).

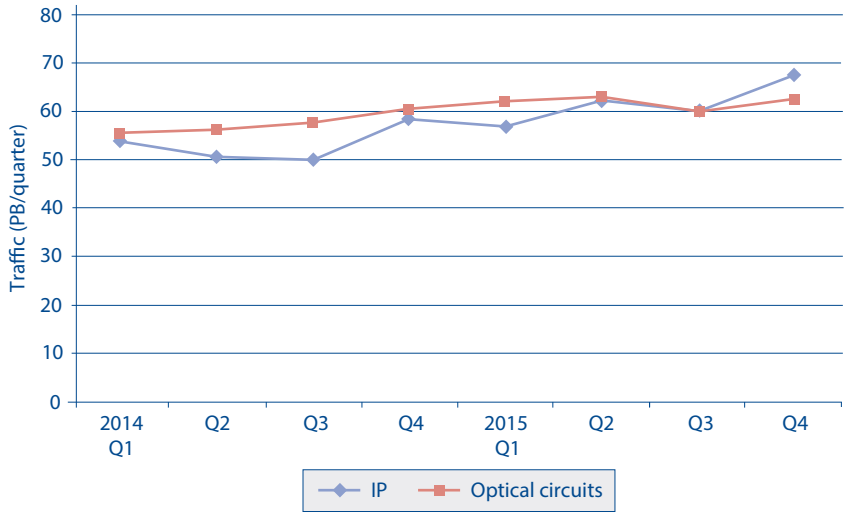
For GÉANT, it is possible to provide measurement of the average traffic on the GÉANT Lambda service[4]. In 2014 and 2015, GÉANT offered a number of circuits on this service, starting at 20 in 2014 and going up to 30 by the end of 2015. Four of these were at 100 Gb/s capacity, the remainder at 10 Gb/s capacity using optical equipment. Based on the data now available, a conservative estimate is that these links are used on average for at least 10% of their capacity[5]. This leads to the conclusion that currently, traffic on these circuits is at least as high as the traffic on the routed basic IP network, as shown in graph 4.3.1. It is also comparable to the total traffic carried on VPNs.

It is likely that several NRENs are also transporting more traffic than reported by the IP traffic alone. We have asked NRENs to provide information about these traffic streams, but at the moment most NRENs do not measure this. Because of

[4] http://www.geant.org/Services/Connectivity_and_network/Pages/GEANT_Point-to-Point.aspx
[5] Note that because of the nature of the traffic on these links, the traffic pattern tends to be erratic, with periods of low traffic and periods of intense traffic alternating frequently.

the potential traffic volumes (and associated costs) an NRENs shall try to record all traffic streams through circuits in addition to IP traffic, to the extent feasible.

Graph 4.3.1 – GÉANT basic IP traffic and optical circuits traffic, 2014 and 2015[6]



In addition to basic IP and optical circuit traffic shown above, GÉANT carries a significant amount of traffic in virtual private networks for projects and other services which is not shown. Recent measurements estimate that the total traffic is about 240 PB/quarter.

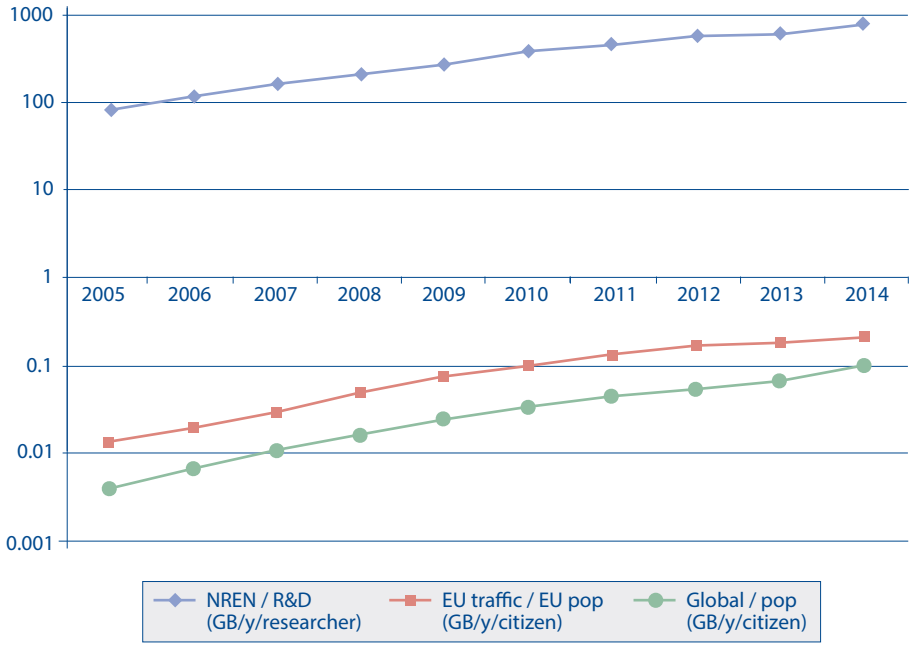
4.4 NREN traffic per researcher

In previous editions of the *Compendium*, we used traffic per inhabitant as a simple metric to compare NREN traffic in different countries. However, this metric, like any simplification, has its drawbacks.

For the 2015 edition of the *Compendium*, we have chosen a different approach, comparing traffic in the 24 countries of graph 4.2.1 per researcher with general Internet traffic per EU citizen and traffic per global inhabitant[7]. The result is shown in graph 4.4.1. As discussed below, the traffic per researcher is likely to be understated, as parts of traffic in dedicated circuits could not be added.

What the graph shows is that indeed the growth in traffic per researcher is similar to the growth in Internet traffic overall. However, traffic per researcher is at a much higher level than traffic per person – and remains so. Thus, traffic per researcher is around 10 000 times the traffic per EU citizen.

Graph 4.4.1 – World and research traffic growth, 2005 – 2014



[6] Statistics provided by Emma Apted and Sebastiano Buscaglione of GÉANT.

[7] Number of researchers and technicians per country, as published by the World Bank http://data.worldbank.org/indicator/SP.POP.SCIE.RD.P6
World Internet traffic as documented through the annual Cisco Visual Networking Index http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~completeforecast

4.5 Traffic Monitoring and Congestion

Most NRENs (~75%) provide tools for monitoring and troubleshooting the network towards their clients, such as: looking glass, ping/traceroute/AS path, throughput calculator, speed tests, multicast test, perfSONAR, etc. A weather map of the NREN's network is provided by some 50% of the NRENs.

The NRENs covered by this edition of the *Compendium* were asked to estimate the percentage of institutions connected to their networks that experience none-to-little, some-to-moderate, or serious congestion at the various network levels.

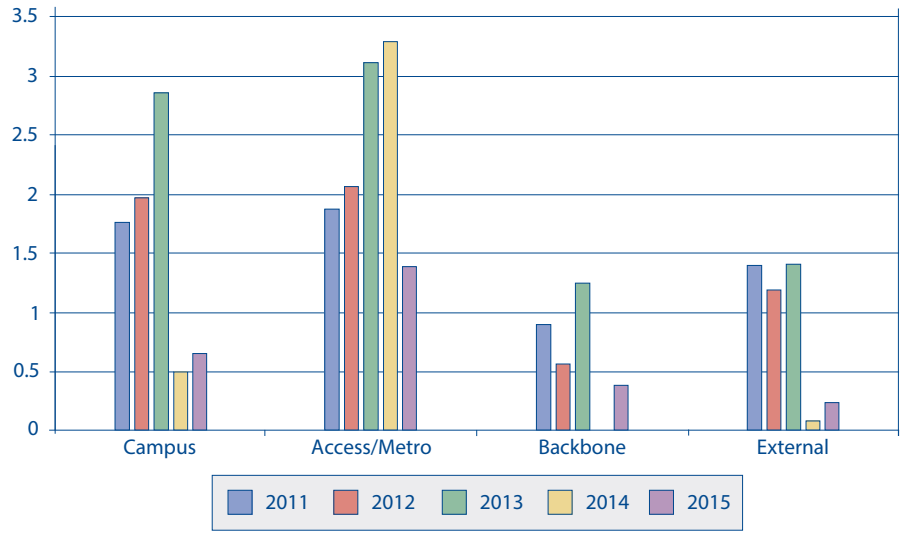
From the subjective levels reported by NRENs, a metric was derived for the level of congestion in each network element, using the following formula:[8]

congestion index = (0.05*little + 0.2*some + 0.5*serious) – 5

Note that the data for MANs and access networks were combined. Applied to all the submitted data on congestion, this formula provides a single uniform metric.

Re-examination of the data showed an anomaly in the 2014 data for congestion at the Campus level. This has been rectified in the table below. It shows that at the Campus level, congestion has decreased compared to two years ago. This could be due to investments in upgrading the Campus networks. Congestion for the Access/Metro-networks seems to have decreased a little. The Backbone and External network congestion indices continue to yield very low values.

Graph 4.5.1 – Congestion Index, GÉANT partner countries



4.6 IPv6 deployment

Respondents were asked to identify what proportion of their institutions are provided with IPv4 only, dual IPv4 + IPv6 or IPv6 only. No NREN reports providing IPv6 only. They were also asked what percentage of their IPv6 address allocation have been assigned to their client institutions so far. The responses are summarized in table 3.

IPv6 is still taking time to permeate across all of the institutions served by the NRENs. Nearly all NRENs offer some IPv6 service, however around half of NRENs still provide IPv4-only to 90% of their institutions. This low usage of IPv6 services is attributed to the rate of take-up from institutions. Many smaller institutions such as schools are still choosing not to make use of IPv6. So NRENs that service

[8] This index was developed for the *Compendium* by Mike Norris, formerly of HEAnet. The index was modified in 2009 to set the minimum value at 0 rather than 5.

schools as well as larger research institutions are likely to have a lower rate of IPv6 take up.

IP address allocation shows that IPv6 addresses are freely available. One NREN has allocated as much as 50% of its IPv6 addresses, 13 have allocated no or virtually no IPv6 addresses – and half of NRENs have allocated less than 0.5% of their IPv6 addresses.

Table 4.6.1 – Percentage of client institutions provided with IPv6, address space allocated

Country	IPv4 only	IPv4 & 6	% IPv6 address space used
Albania	100	0	0
Algeria	99	1	1
Armenia	80	20	2
Australia	75	25	
Austria	60	40	35
Azerbaijan	100	0	0
Belarus	100		
Belgium	0	100	1
Bosnia/Herzegovina	100		0
Brazil	77	23	11.2
Bulgaria	80	20	50
Canada	80	20	5
Croatia	99	1	
Cyprus	100	0	0
Czech Republic	80.4	19.6	0.15
Denmark	90	10	13
Ecuador	80		0.01
Estonia	92	8	0.1
Finland	62	38	1
France	85	15	0.45
Georgia	100		0
Germany	74	26	0.3

Table 4.6.1 – Continued

Country	IPv4 only	IPv4 & 6	% IPv6 address space used
Greece	75	25	9
Hungary	20	80	20
Iceland	12	88	0.1
Ireland	91	9	1
Israel	43	57	
Italy	90	10	0.07
Lithuania	91	9	25
Luxemburg	85	15	0.028
Macedonia, FYRo	80	20	
Moldova	100	0	100
Montenegro	99	1	
Morocco	95	5	5
Netherlands	0	100	3
New Zealand	95	5	5
Norway	81	19	0.2
Portugal		100	0.015
Romania	75	25	1
Russia	80	20	0
Serbia	80	20	5
Slovenia	95	5	1
South Africa	82	18	0.07
Spain	70	30	15
Sweden		100	0
Switzerland	0	47	0.1
Taiwan, PoC	94	18	0
Turkey	43	57	0.3
UK	0	100	0.3
Ukraine	90	10	5
USA		100	

4.7 VPN and Point-to Point Services

Many NRENs provide their customers with non-traditional connectivity services, giving them greater freedom and guaranteed quality of service. This is done either through Virtual Private Networks (VPNs) or through point-to-point (P2P) services, or both.

This year, we have asked NRENs to specify if they are offering such services at the Layer 3 or Layer 2 level. Of the 49 responding NRENs, 17 currently offer Layer 3 VPNs, 13 more plan to do this. Fifty NRENs answered the question about Layer 2 connectivity services: 35 of them offer such a service, with four more planning to introduce it[9].

The number of circuits on these services vary widely from NREN to NREN, from a handful to hundreds of circuits.

The questions in for this section were newly formulated for the 2015 *Compendium* and may not have been understood by all NRENs in the same way. Specifically, 'connectivity' may have been interpreted as only circuit type services and not all networking services. Nevertheless, we feel it may be of interest to show the responses that were gathered. They are summarized in table 4.7.1.

In addition, 57% of the 40 NRENs surveyed state that they are offering 'pure optical' services to their customers. 17 NRENs have current pure optical services in their networks. Here, again, it is possible that not all NRENs have interpreted the question in the same way.

Table 4.7.1 – VPN and Point-to-Point services

Country	Offering Layer 3 VPN services?	# of Layer 3 VPNs live at the end of January 2015	Offering Layer 2 connectivity services?	# of static Layer 2 P2Ps live at the end of January 2015	To external domain:	Static layer2 VPNs?	To external domain:	Charge for dynamic services?
Albania	Planned		Planned					
Algeria	Yes	3	Yes	123	123			
Armenia	Planned		Yes					
Australia	Yes	4	Yes	20	0	19	2	Yes
Austria	No		Yes	11	0	0	0	No
Azerbaijan	No		Yes					
Belarus	No		Yes	3	1	1	0	No
Belgium	Yes	9	Yes	206		12		We don't offer dynamic services
Bosnia/Herzegovina	No		Yes	3	0	5	0	No
Brazil	Planned		Yes	61	About 6 circuits	2	1	No
Bulgaria	No							
Canada	Yes	1	Yes	56	6	0	0	0
Croatia	Yes		No					

[9] Static Layer 2 point to point services are pseudowire circuits (as defined in RFC 4447); layer 2 VPN circuits are VPLS circuits (as defined in RFC 4761).

Table 4.7.1 – Continued

Country	Offering Layer 3 VPN services?	# of Layer 3 VPNs live at the end of January 2015	Offering Layer 2 connectivity services?	# of static Layer 2 P2Ps live at the end of January 2015	To external domain:	Static layer2 VPNs?	To external domain:	Charge for dynamic services?
Cyprus	No		No					
Czech Republic	Yes	8	Yes	25	5	2 (LHC,SAP)	1 (LHC)	not implemented, plan for dedicated services
Estonia	No		No					
Finland	Yes	70	Yes	93	2	2		Yes, in some cases.
France	Yes		Yes					Yes
Georgia	No		No					
Germany	Yes		Yes					Yes
Greece	Planned		Yes	~200	~15	0	0	no
Hungary	Yes	19	Yes	20	2	20	2	Depends on the subscribed bandwidth
Iceland	No		No					
Ireland	Planned		Yes	531	2	0	0	Yes
Israel	No		No					
Italy	Yes	9	Yes	0	0	13	7	Yes, if the institutions are not GARR members
Latvia	No		Planned					
Lithuania	Yes		Yes	2	0	6	0	No
Luxemburg	No		Yes	28	0	0	0	No
Macedonia, FYRo	Planned		Planned					
Malta	No							
Moldova	Planned		Planned					
Montenegro	Yes		No					
Morocco	No		No					
Netherlands	Planned	0	Yes		0	0	0	Yes
New Zealand	No		Yes	0	0	355	0	No

Table 4.7.1 – Continued

Country	Offering Layer 3 VPN services?	# of Layer 3 VPNs live at the end of January 2015	Offering Layer 2 connectivity services?	# of static Layer 2 P2Ps live at the end of January 2015	To external domain:	Static layer2 VPNs?	To external domain:	Charge for dynamic services?
Norway	No		Yes	3	0	0	0	Yes
Poland	Yes	Several	Yes	Few tens	Several	Several	Few	No
Portugal	No		Yes	9	0	9	0	No
Romania	Planned		No					We do not charge for our services
Russia	Yes	26	Yes	12				No
Serbia	Planned		Yes	0	0	1	1	No
Slovenia	Planned		Yes	5	1	0		No
South Africa	Yes		Yes					No
Spain	Planned		Yes	53	44	To my understanding L2 P2P is a subtype of L2 VPN.		
Sweden			Yes					
Switzerland	No		Yes	16	0	2	0	Yes
Taiwan, PoC			Yes					
Turkey	No		No					
UK	Yes	0	Yes	31	13	31	13	Yes - above 1Gb/s
Ukraine	Planned		Yes	50	0	0	0	No

5 MIDDLEWARE SERVICES

This Middleware section covers three areas of NREN activity: security services; digital certificates; and identity federations and eduroam. All are increasingly important to the daily work of research and education organisations. In each case, the distinctive requirements of NRENs and their customers challenge traditional ways of providing services. The relationship between networks, customers and suppliers, however, also creates opportunities to deliver services in new ways. The results may well lead how others approach the Internet in future.

In security services, NRENs created many of the earliest incident response teams. NREN Computer Security Incident Response Teams (CSIRTs) met in 1993: twenty years before industry declared "the year of incident response". GEANT's CSIRT Task Force, which for many years has welcomed teams from industry and government, provides a forum for developing the cross-sector incident response that is vital on today's Internet. *Compendium* data highlight the benefit of organised response to today's large-scale attacks: networks with mature CSIRTs suffer less disruption. However, damaging attacks on Internet naming and routing infrastructures remain a constant threat. Solutions already exist but are challenging at a technical and organisational level to deploy. NRENs could again lead improvements in Internet security.

In 2009 the Trusted Certificate Service (TCS) enabled encrypted communication with Internet servers. Digital certificates now have many more uses in standard software, such as ensuring the identity of organisations or the origin of e-mails, software and documents. In general, obtaining such certificates can be a lengthy and costly process. Because of NRENs' knowledge of their customers and secure federated authentication services, the TCS makes obtaining certificates a much simpler and quicker process for our customers and community as a whole.

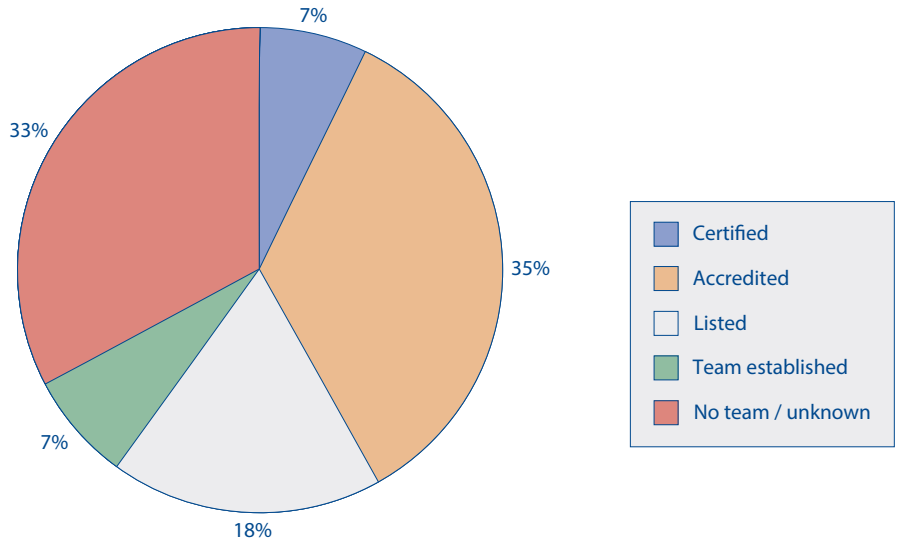
Identity federations and eduroam use NRENs as trusted intermediaries to link service operators to the educational organisations that can vouch for their users. The approach is now being extended to research services that require a wider range of protocols and, sometimes, more information about users. Eduroam may be the most used NREN service of all, and yet the least visible. One hundred million times a month, someone opens their laptop at another university, college, museum, railway station, airport, and is silently connected to the Internet. Federations and eduroam, like research and education, are now global in scope. Their success is inspiring other sectors to follow NRENs' expertise.

European e-Identity proposals could offer another leadership opportunity. Providers of public certificate and authentication services will need to implement risk management and incident response measures. As organisations that already operate all three services, NRENs could influence and inform these plans in the years to come and beyond.

5.1 Security Services

For many years security services – and management of security incidents – have been a growing concern within the NREN community. The GÉANT Task Force of Computer Security Incident Response Teams (TF-CSIRT) has not only become the task force with the longest duration ever, it is also including teams from industry and government sectors emphasizing the need for a broad response to security incidents. The task force origins can be traced back to 1993 when the few European NREN Computer Emergency Response Teams (CERTs) in existence then were assembled for the first time in Amsterdam. Later, in 2000, the task force was created and has continued since then.

Graph 5.1.1 – CSIRTs



All 55 responding NRENs commented on the impact of certain incidents and their CERT activities. From these responses we can deduce, that approximately 65% of those NRENs have established their own CERT. From these 36 teams all but four are registered with the Trusted Introducer service (**https://www.trusted-introducer.org**), the CERT listing service operated by the TF-CSIRT. The majority have already become accredited and three NREN teams plus the GÉANT team have chosen to become certified, proving their team's maturity according to the established frameworks approved by TF-CSIRT.

Two-thirds of the respondents reported negative impacts of DDoS including reflection and/or amplification attacks - possible using DNS, NTP and some other protocols - as well as route/IP hijackings. Based on the 2014 answers for the same question, it is also clear that the perceived impact has increased somewhat. From 56 responses for both years, 30 reported DDoS attacks for 2014 and 37 for 2015. Negative impact of route or IP hijacking was reported in 2014 by four, and in 2015 by seven NRENs.

Interestingly, analysis of the existence of a CERT shows that NRENs which have not commented on this question have, for the most part, not reported negative impacts: only three of these 16 reported an impact. But it is clear from all other answers that regardless of whether there is a CERT team, listed or accredited, or not, NRENs have suffered from negative impacts.

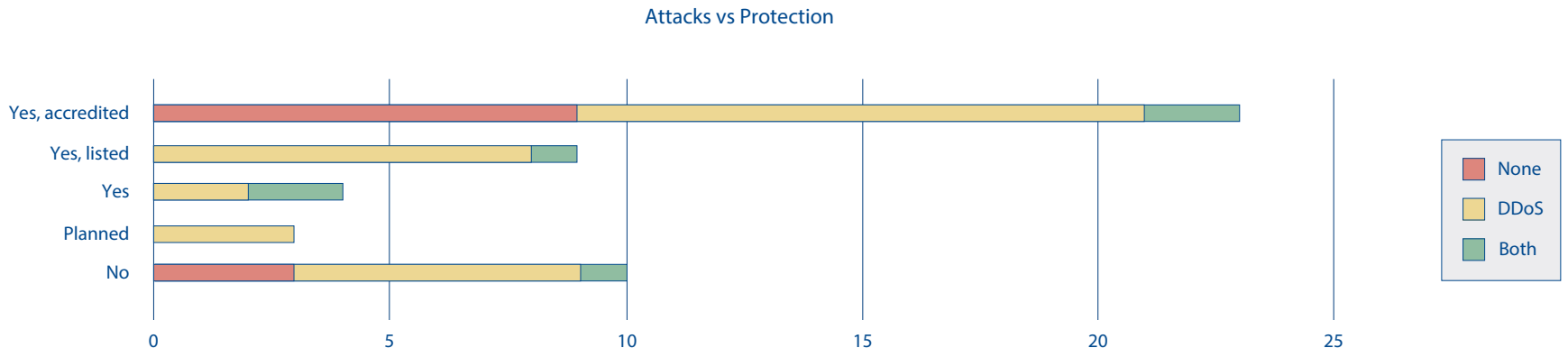
This comes as no surprise, especially due to the fact that DDoS attacks will never be fully mitigated or avoided as long as we build our networks based on vulnerable protocols. It is also not a grand revelation for security experts that, in many cases, without any consolidated security team or CERT, organisations are unable to answer related questions about incidents consistently, hence the missing answers.

Graph 5.1.2 demonstrates that a larger percentage of NRENs with accredited CERTs reported to have not been negatively impacted by DDoS or route/IP hijackings. This is encouraging and is probably related to the maturity of such NRENs. As the accreditation also means an investment of the organisation in staff and organisational structures, it is reasonable to assume that those NRENs are more mature in other areas too. It can therefore be further assumed that they have better detection and mitigation plans in place than other NRENs, resulting in fewer negative impacts over time.

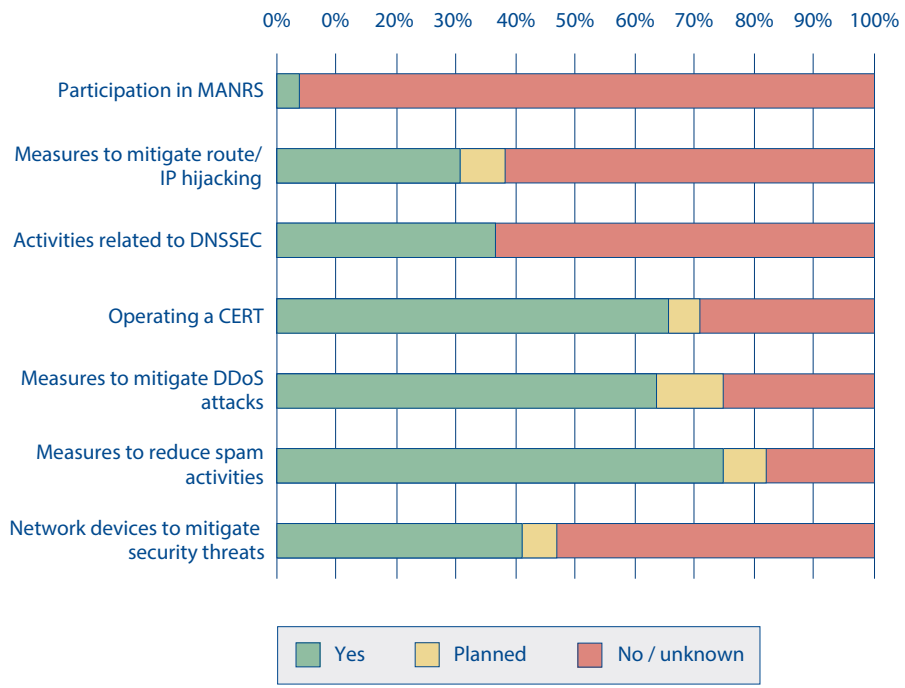
We will come back to DDoS and route/IP hijacking attacks again later, but first will take a closer look at all security activities of NRENs. A large number (75%) already have network devices implemented to mitigate security threats and others (11%) are planning to introduce such devices in the future. While it is not explicit from this answer what kind of devices are used, it is safe to assume that such devices are instrumental in mitigating spam, DDoS or route/IP hijacking, or providing traditional network security for critical services, just as traditional firewall or intrusion detection systems do. The additional remarks offered by the respondents certainly suggest that much.

Two particular questions addressed topics that need more support from NRENs. Only 36% of the responding NRENs reported activities related to DNSSEC. For the GÉANT partner NRENs, this figure is 43%. While without DNSSEC specific attacks against users cannot be mitigated or detected, using it needs careful consideration and preparation. What is clear is that only if all sites participate in this effort will global protection become possible. Of course, this is not easily achieved, but NRENs have a long history of supporting their user communities and NREN networks have a large user base that needs protection and robust security services. Also NRENs have a tradition and responsibility to be at the forefront of technological developments.

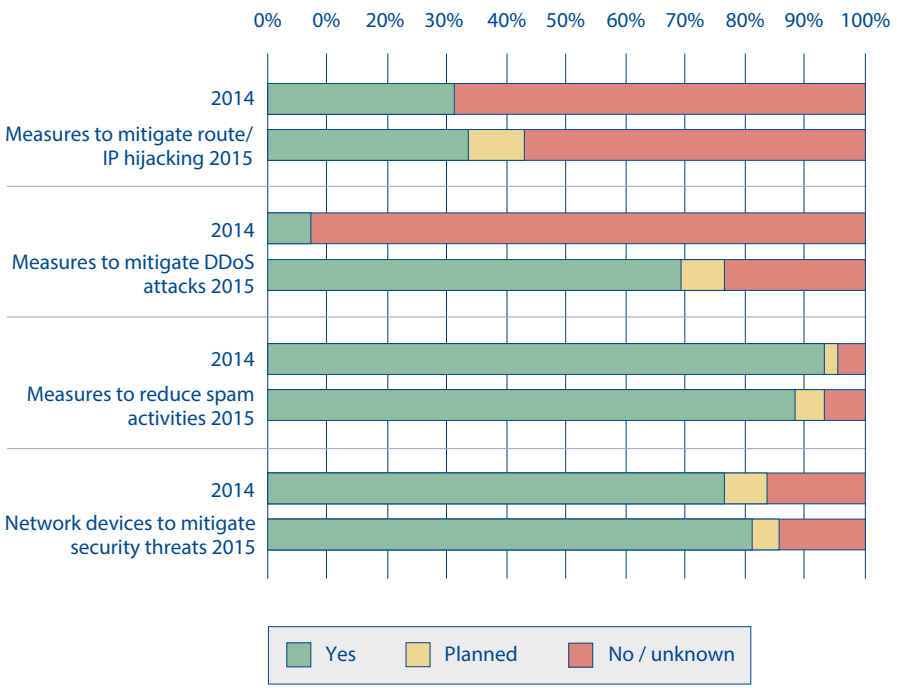
Graph 5.1.2 – CSIRTs and protection against attacks



Graph 5.1.3 – Security measures



Graph 5.1.4 – Security measures GÉANT area, 2014 and 2015

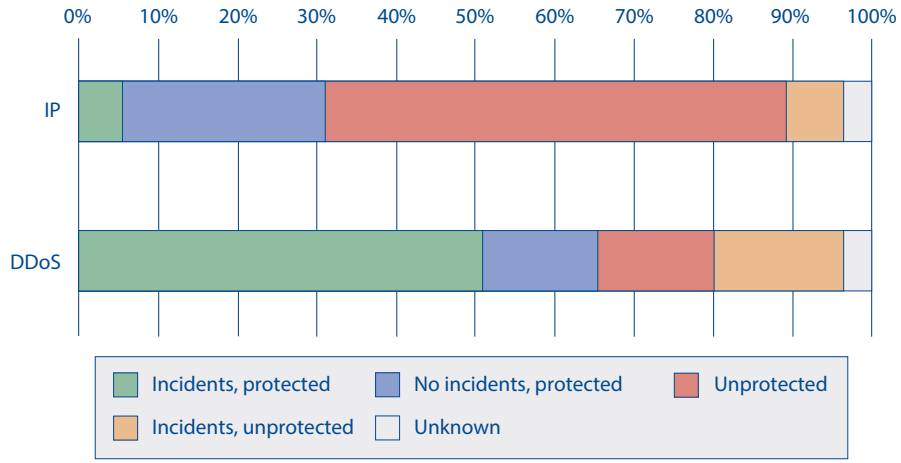


For the GÉANT partner NRENs, four of these questions could directly be compared to the feedback received in 2014. Clearly, the most significant change is the sharp increase for DDoS mitigation measures.

The most prominent need for NRENs seems to be DDoS protection as we can safely consider spam protection to address the needs of the user communities. DDoS attacks can render the NREN itself, its services or even access paths, useless. Nowadays, reflecting and amplifying attacks make it even more difficult to mitigate such attacks because dropping regular responses from valid servers is not a popular solution, except during the peak of the attack. Route/IP hijacking has the same potential to cripple the NREN networks. It is therefore of interest to correlate the answers given in regard to these two topics.

Graph 5.1.5 illustrates that approximately 50% of the NRENs are protected against DDoS attacks. Compared to the numbers in 2014, this is the most significant change in regard to counter measures, as already shown. In 2014 only 10% had implemented measures, with most of those actually having experienced DDoS attacks. While a relatively large number (20%) of NRENs did not answer the questions related to both attacks, it is clear that some of the unprotected NRENs also experienced DDoS attacks.
Comparing route/IP hijacking with DDoS, it is clear that incidents have been experienced, but in much smaller numbers: six NRENs reported such incidents compared to 34 for DDoS, for example. Only four NRENs actually reported both. It is no wonder that the number of NRENs investing in protection against route/IP hijacking is much lower at approximately 30% instead of over 50% for DDoS. But by comparing the rather small numbers of incidents, it is evident that the underlying threat is indeed recognised, and that NRENs are trying to address those proactively.

Graph 5.1.5 – Attacks and mitigation measures



5.2 Digital certificates

Digital certificates are in use when cryptographic keys need to be published for secure applications, together with a validation signature made by a Certificate Authority (CA).

Common application areas that use certificates are:

1. secure servers (mail, www etc.) that users connect to or which communicate with other secure servers
2. individuals using personal certificates to sign e-mail or sign PDF documents
3. software that is securely signed, so users can be confident that the assumed producer of the software is legitimate, without malicious additions by malware authors
4. authentication for end-users and server credentials for eScience use cases to prove to general purpose and research infrastructures that they are legitimate participants in what may be globally distributed computing and data processing.

GÉANT operates the Trusted Certificate Service (TCS). At the start of 2014, TCS supported 28 NRENs for server certificates, 18 for personal certificates and eight for code-signing certificates. Of the 54 NRENs who responded, 39 confirmed that certificates are provided by or via the NREN, with 2 planning to introduce provision. Only 13 of the responding NRENs are not involved in certificate services at all. Out of the 42 GÉANT partner NRENs, only six NRENS are not involved in certificate services.

2014 was quite interesting in the certificate world. On 7 April the 'Heartbleed' bug in OpenSSL was published. Many organisations decided to urgently replace certificates for sensitive services running on vulnerable machines. In October 2014, three years after the authoritative CA/Browser Forum deprecated the use of the SHA-1 algorithm, the leading web browsers of Google, Microsoft and Mozilla started 'sunsetting' it. In practise this meant that certificates valid past 31 December 2016 were only to be issued using SHA2. This implied that the GÉANT

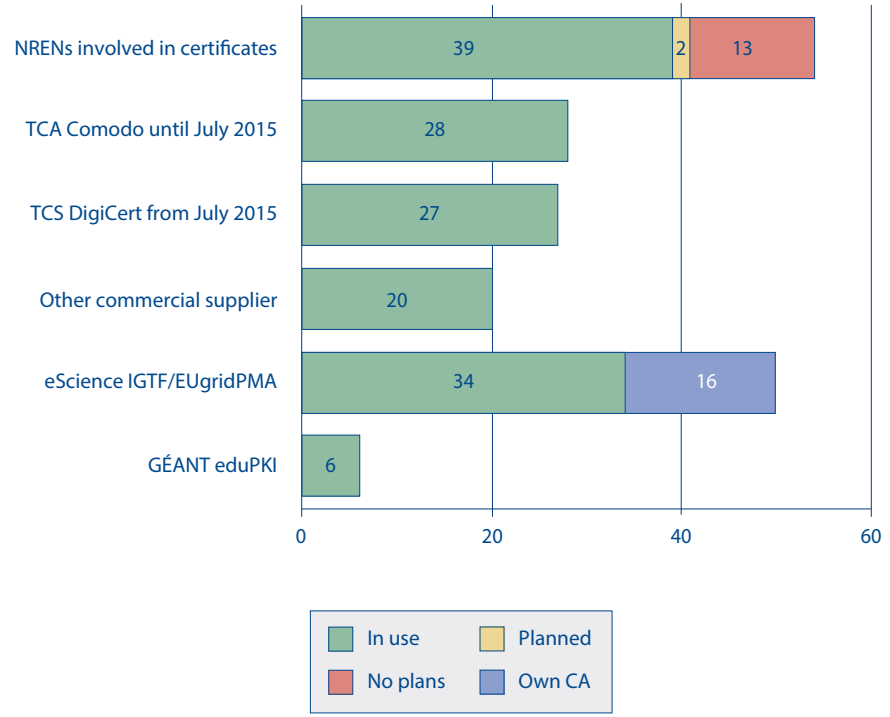
community, like the rest of the world, started ordering 3-year validity certificates using new CA certificates and chains. Comodo, for example, made five new certificate types available for TCS.

For over a decade, GÉANT has been offering a successful Trusted Certificate Service (TCS) to its members. Initially, the service was bought from GlobalSign, but since 1 July 2009 Comodo has been the supplier. The most popular type of certificate globally is used for SSL/TLS communication with secure servers. Requests for these certificates, when ordered from a public CA are subject to a validation process. Three varieties are in common use: Domain Validation (DV), Organisation Validation (OV) and Extended Validation (EV). If an organisation name is to be included in a certificate, that name must be validated by the CA. In the contracted Comodo certificate profiles, GÉANT began using OV validation, but in 2011, after a Comodo security breach and the DigiNotar drama, the service largely migrated to DV certificates. This was perceived by many as a reduced quality service, but nevertheless the Comodo contract was extended until 1 July 2015.

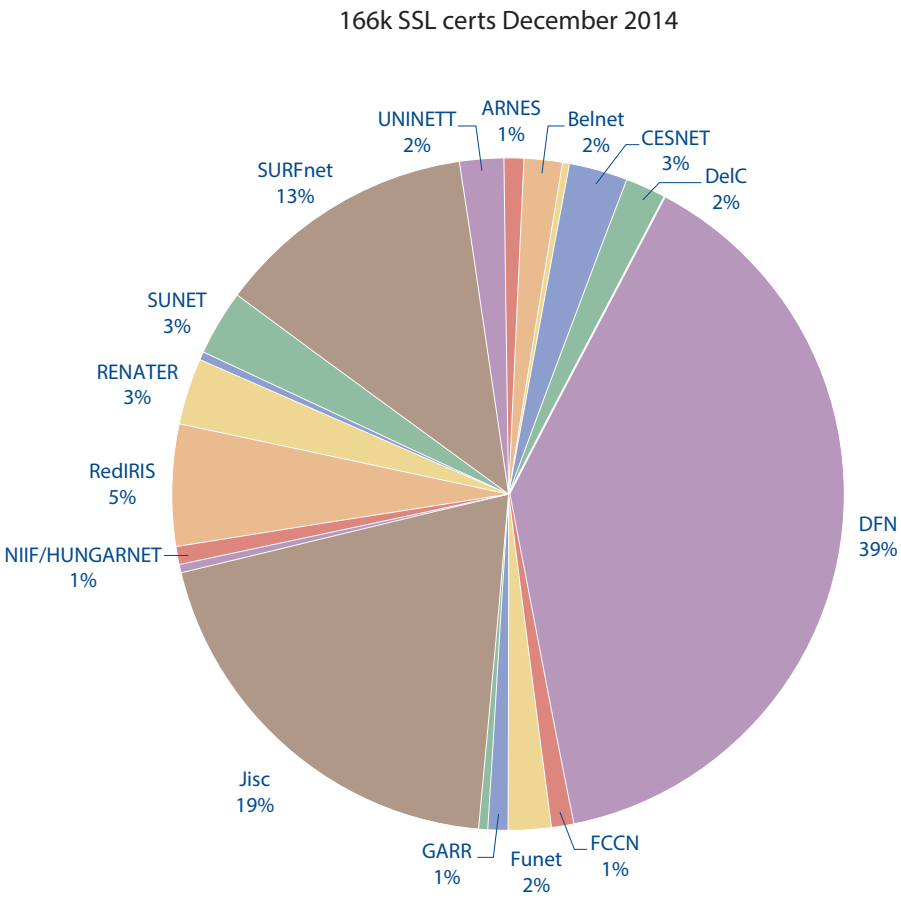
In early 2014 a tendering process was initiated for the TCS service after June 2015. It was clear that DV certificates were no longer fit-for-purpose, leading to the service description targeting OV and 'green' EV only. This approach has proved wise as the free 'Let's Encrypt' initiative, aiming to making DV certificates a ubiquitous commodity without actually offering additional assurance, was due to commence in late 2015. In order to ensure that users are communicating with the 'right' organisation, the TCS needs to be of a higher quality than the free service. Not only SSL/TLS server certificates were requested in the TCS tender process: also personal certificates, eScience variants, code-signing and institutional document signing were included. The 2014 GÉANT TCS tender was awarded to DigiCert. In December 2014 a small group of volunteers started testing and tuning the DigiCert service for GÉANT use. This led to an on-time operational service. A lot of effort was invested but once again, the newest service is better than any other before. At the beginning of 2014, who could have dreamed of an affordable EV certificate within an hour? EV certificates are increasingly important as end-users are conditioned (by banks and others in e-commerce) to look for the 'green bar' before entering personal data and passwords.

Also now personal certificates can be requested directly by end-users after a federated login, and as the service is offered directly by DigiCert, it no longer requires an intermediate service operated and maintained by GÉANT or its members.

Graph 5.2.1 – NREN involvement in certificates



Graph 5.2.2 – SSL certificates outstanding



5.3 Middleware services: Identity federations and eduroam

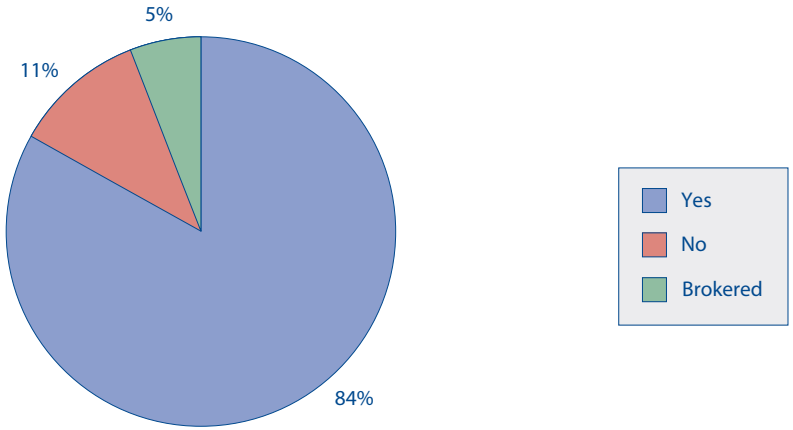
While networks connect machines to machines, middleware services are needed to connect people with a layer of trust. This is delivered by specific authentication and authorisation infrastructures, such as identity federations and eduroam. Identity federations currently focus primarily on providing trusted web Single Sign-on using SAML, with eduroam enabling trusted network access. These are increasingly seen as part of the core service portfolio of NRENs globally and an important distinguishing factor from commercial services in their approach to privacy which has become particularly relevant in the post-Snowden world.

Identity federations

- An identity federation enables a user registered in the identity management system of a university or home institution to access services provided either by a university or by other institutions participating in the identity federation.
- Identity providers enable authentication to take place while a minimum of information necessary about the user is shared.
- Service providers offer services to users authenticated by the identity providers, minimising the amount of user management they have to do.

There are 56 known research and education federations as of October 2015 (see REFEDs, **https://refeds.org/federations**). From the *Compendium* survey, we know that NRENs operate at least 46 of these, and a further 3 are brokered to another non commercial entity. Two NRENs have plans to establish a federation. Of those operated by NRENs, the majority are delivered using a combination of self-built or self-integrated systems, indicating a strong connection with specific requirements of research and education rather than a solution easily obtainable on the market.

5.3.1 – NREN operation of Identity Federations



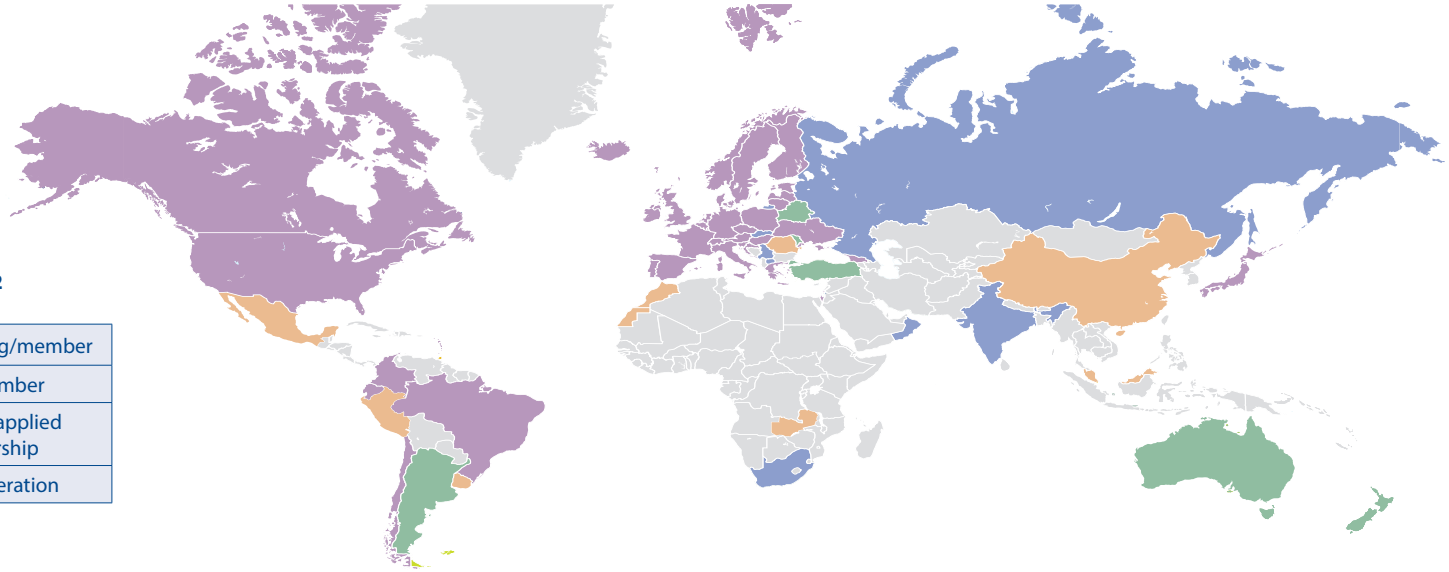
Within identity federations, over 3 000 identity providers operate. In some cases these represent single campuses, in others, entire countries. Over 7 000 services are also present (Source **https://met.refeds.org**).

Research and education is, of course, increasingly borderless. The purpose of the eduGAIN interfederation service 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. As the service has matured, the number of identity providers and service providers added by federations has increased dramatically from 301 entities at the end of March 2014 up to almost 2 500.

The main services supported by identity federations have typically been e-journal access, access to e-Learning platforms and collaboration tools, such as wikis. Fine-grained access management of research data has become a topical issue in science. e-Research projects and infrastructures, driven by the interest in using Federated Identity Management technologies in 2012, produced a paper called 'Federated Identity Management (FIM) for Research Collaborations' (**https://cdsweb.cern.ch/record/1442597**). This paper provided requirements for the usage of federated access from various e-Research communities and identified issues that pose challenges for the wider adoptions of FIM technologies offered by national federations and by eduGAIN. Projects such as GÉANT[1] and AARC[2] have been engaging in development work and pilots with research communities to demonstrate more complex use cases involving data protection concerns, attribute authorities, bridging between different sectors, for example, and with such activities, expanding the scope of identity federations. Research communities, such as Elixir[3], DARIAH and others, now continue work to make their services available via eduGAIN and federated identity.

[1] http://www.geant.net/Resources/Deliverables/Documents/D9-4_DS5-5-1_Towards-Horizon-2020_The-Enabling-Users-Experience%20(3).pdf
[2] https://aarc-project.eu
[3] https://www.elixir-europe.org/events/introduction-elixir-excelerate

5.3.2 – Global Identity federation and eduGAIN status



Legend for map 5.3.2

	Participating/member
	Joining/member
	Candidate/applied for membership
	Known Federation

eduroam

The eduroam service allows students, researchers and staff from participating institutions to obtain Internet connectivity across campus and when visiting other participating institutions. The architecture that enables this is based on a number of technologies and agreements, which together provide the essential eduroam user experience: "open your laptop and be online". Having started in Europe, eduroam has gained momentum throughout the research and education community and is now available in 78 countries worldwide. Up-to-date information on eduroam is available at **www.eduroam.org**.

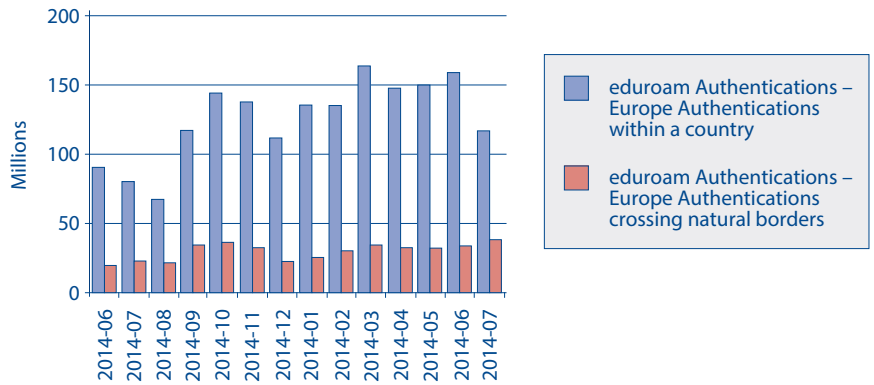
The basic principle underpinning the security of eduroam is that the authentication of a user is carried out at his/her home institution using the institution's specific authentication method. The authorisation required to allow access to local network resources is carried out by the visited network.

The service is delivered globally by different regional confederations. GÉANT operates the regional level service for members of the European eduroam Confederation. This alliance is comprised of 48 autonomous roaming services who agree to a set of defined organisational and technical requirements that ultimately constitute eduroam.

Although the rate of increase of participating countries is slowing with a mere 9 additional countries or territories having joined since the 2014 *Compendium*, the number of authentications supported by eduroam shows remarkable growth. In Europe alone, the national roaming figures for June 2015 are almost twice those of the equivalent period in 2014, with international roaming only slightly behind.

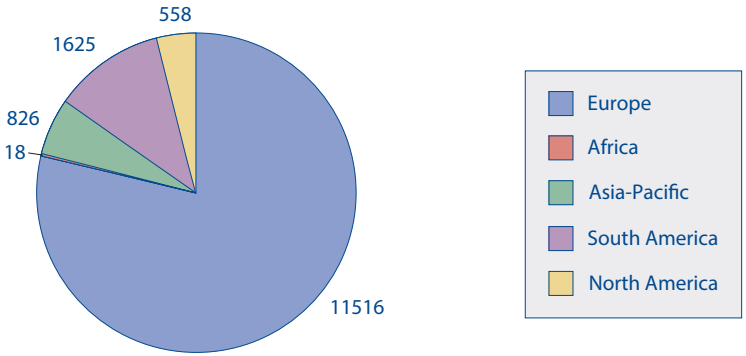
The number of authentications supported by eduroam also shows a remarkable increase. In Europe alone, the monthly national roaming figures broke the 100 million barrier.

5.3.3 – eduroam authentications, GÉANT area[4]



In addition, the range and number of places users can access eduroam is growing year on year, with Europe still dominating.

5.3.4 – Reported eduroam service locations (Source https://monitor.eduroam.org)



Source: eduroam operations team, collated by Miroslav Milinović, SRCE.

On campus, growth of eduroam is supported by means of eduroam CAT (Configuration Assistant Tool), which provides administrators with an easy way to automate high quality deployment profiles for a range of operating systems. Launched by GÉANT in 2013, the service saw 1.2 million user downloads this year compared to just under 500 000 downloads in its first year of use. (Source, GÉANT Annual Management reports, GN3plus Y1 and Y2, restricted).

We are seeing service locations become increasingly broad to include airports (including Geneva in Switzerland and multiple airports in Norway and Sweden), train stations (Sweden) and municipalities (Zagreb and Rijeka in Croatia, supporting the 2015 European University Games, and Vienna and Innsbruck in Austria).[4] Reaching further than only campuses and research institutions reflects the expectations of users to be connected anywhere, at any time.

This coverage of eduroam beyond the borders of research and education is also reflected in the growing interest of deploying the technology in different policy environments, e.g. government, the schools sector or public wifi alliances. Fourteen out of forty-five respondents were aware of such initiatives, with a number having already become engaged in planning.

[4] Source: eduroam operations team, collated by Miroslav Milinović, SRCE.

[5] http://www.geant.net/MediaCentreEvents/news/Pages/eduroam_beyond_the_campus.aspx

6 COLLABORATION SUPPORT SERVICES

It is becoming easier to introduce collaboration support services, because middleware services (see Section 5) are increasingly widespread. Section 6.1 documents NREN involvement in cloud services. Section 6.2 examines videoconferencing services and Section 6.3 looks at Open Science and e-Infrastructures.

56% of the GÉANT partner NRENs are currently active in delivering cloud services and a further 22% are planning to be involved. The number of NRENs offering own cloud services is higher than the number of NRENs that are brokering cloud services. This may be related to the fact that establishing cloud service agreements requires specialised expertise and a substantial scale. This might be an area where collaborative ventures, for example within the GÉANT framework, can bring results.

There is a clear top three in service types: Infrastructure as a Service (IaaS); file storage and backup; and Software as a Service, collaboration services and video conferencing.

Centrally-managed videoconferencing services remain strategically important for many NRENs. 41% of the 54 NRENs that answered this question reported offering or planning to offer a traditional centrally-managed videoconferencing service. Usage is increasing across all forms of videoconferencing or webconferencing, and from most NRENs. NRENs with the most activity amass tens of thousands of traditional MCU sessions over a year.

For the future, there is a noticeable interest in browser-based access and/or WebRTC access to services. Out of the 20 NRENs who described plans for development, 14 plan to expand desktop options and 11 specifically mention WebRTC as the technology they plan to investigate.

NRENs have a defining role in providing high performance communications networks within the digital infrastructure. Nearly 60% currently offer dedicated high-capacity point-to-point circuits. Almost half of NRENs have connected research organisations that provide and manage research resources and facilities to the network, such as synchrotrons and accelerators, telescopes and radio telescopes, sensor networks, seismic stations, meteorology and weather stations, and lab equipment.

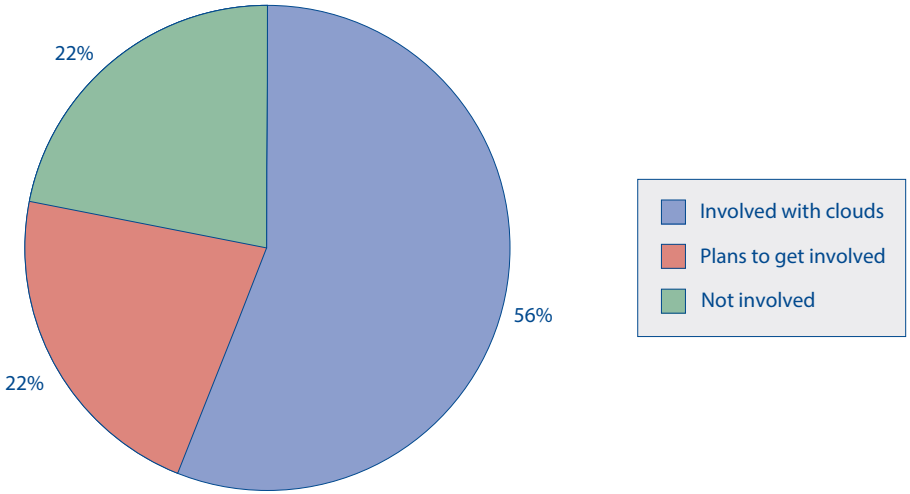
NRENs typically provide digital infrastructure services such as grid middleware, compute resources or storage resources, sometimes being the only provider, but often in conjunction with others. Other services NRENs offer typically include monitoring services, large data transfer services and research portals as well as e-learning resources.

In sum, we are seeing a significant move to e-Infrastructure in our community with NRENs providing more than just the underpinning network services.

6.1 Cloud services

Many NRENs are involved with cloud and online application services, aiming to bring these to their communities with the right conditions of use. 56% of the GÉANT partner NRENs are active in delivering suitable cloud services and a further 22% are planning to be involved. The NRENs from other regions that responded to the survey are also working in this area or are planning to become involved.

Graph 6.1.1 – GÉANT NREN Cloud Involvement



Building clouds

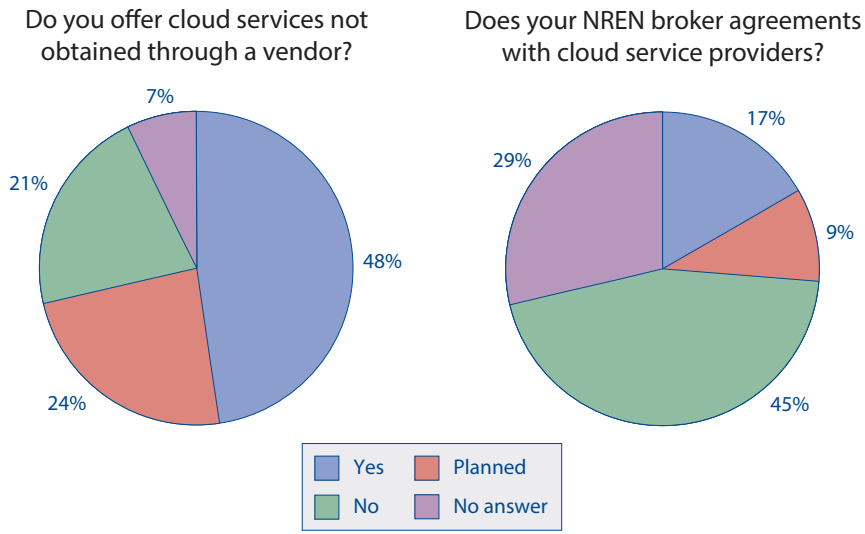
20 GÉANT partner NRENs offer cloud services not obtained through a vendor and ten more are planning to do this. This is a modest growth from previous years with the 2014 *Compendium* reporting that 17 NRENs offered such services and a further 12 has plans. For these NREN cloud offerings, both open-source and commercial infrastructure are being used.

Brokering clouds

Seven GÉANT partner NRENs broker agreements with cloud service providers (up from five last year); four more are planning to do so.

The number of NRENs offering own cloud services is higher than the number of NRENs that are brokering cloud services. This may be related to the fact that establishing cloud service agreements requires specialised expertise and a substantial scale. This might be an area where collaborative ventures, for example within the GÉANT framework, can bring results.

Graph 6.1.2 and 6.1.3 – GÉANT NREN involvement in building and brokering clouds



Hybrid approach

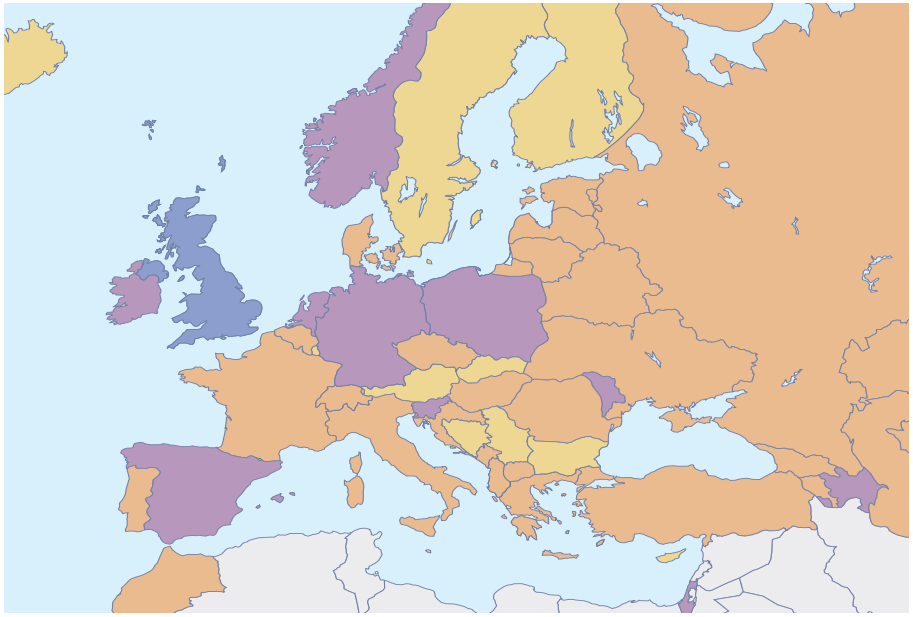
Also important to remember is that 13 of the responding NRENs have adopted a hybrid cloud strategy and are both building and brokering clouds.

Map 6.1.4 visually demonstrates NREN feedback received on Cloud for this *Compendium* from Europe and the Mediterranean.

Legend for Map 6.1.4

build	NRENs which (have plans to) offer cloud services not obtained through a vendor, are marked orange
broker	NRENs which (have plans to) broker agreements with cloud service providers, are labeled blue
build and broker	NRENs which (plan to) do both, a hybrid approach, are presented in purple
	NRENs with no plans, no interest, or which have provided no input, are marked yellow
	Remaining countries are displayed in grey

Map 6.1.4 – involvement in Clouds



Experience in Cloud

There are differences between the NRENs in levels of Cloud experience.

Based on the responses received, the following NRENs are labeled as experienced in an area, as they are currently offering services:

Table 6.1.5 – Experience in cloud services

NRENs experienced in building clouds	NRENs experienced in brokering clouds	NRENs experienced in building and brokering clouds
Armenia, ASNET-AM	Ireland, HEAnet	Australia, AARNet
Belarus, BASNET	Israel, IUCC	Azerbajian, AzScienceNet
Belgium, Belnet	Norway, UNINETT	Germany, DFN
Canada, CANARIE	Sweden, SUNET	Netherlands, SURFnet
Croatia, CARNet	United Kingdom, Jisc	Slovenia, ARNES
Czech Republic, CESNET		
Denmark, DEIC		
Ecuador, CEDIA		
Estonia, EENet		
Greece, GRNET		
Hungary, NIIF/HUNGARNET		
Latvia, SigmaNet		
Macedonia, MARnet		
Poland, PIONIER		
Russian Federation, e-ARENA		
Switzerland, SWITCH		
Taiwan, NCHC		
Turkey, ULAKBIM		
Ukraine, URAN		

Launching cloud activities

NRENs which plan to launch activities in an area are as follows:
11 NRENs are planning to set-up cloud services not obtained through a vendor, and three plan cloud brokerage efforts.

A number of the NRENs mentioned in one of these areas are already experienced in the other area, clearly demonstrating a move to diversify.

There are four NRENs planning to start building and brokering efforts without experience in either of those areas:

Table 6.1.6 – cloud plans

NRENs planning to start building clouds	NRENs planning to start brokering clouds	NRENs planning to start building and brokering clouds
Albania, ANA	Czech Republic, CESNET	Brazil, RNP
Algeria, ARN	New Zealand, REANNZ	Moldova, RENAM
Bosnia/Herzegovina, SARNET	Poland, PIONIER	Portugal, FCCN
France, RENATER		Spain, RedIRIS
Georgia, GRENA		
Ireland, HEAnet		
Israel, IUCC		
Italy, GARR		
Lithuania, LITNET		
Morocco, MARWAN		
Norway, UNINETT		
Romania, RoEduNet		

Such vast experience and interest in cloud, brings opportunities for collaboration and knowledge- sharing for the future benefit of the NREN community.

Service types

There is a clear top three in service types:

Infrastructure as a Service (IaaS)

Virtualized computing resources, such as data processing and the ability to run virtual machines over the Internet

File storage and backup

Dedicated solutions for storing, managing, archiving, sharing and/or synchronising files.

Software as a Service, collaboration services and video conferencing

A broad category encompassing (web-based) tools, such as e-mail, calendars, document management and sharing, messaging and real-time communication (live messaging, co-editing shared documents, screen-sharing, audio and video conferencing).

Suppliers

Several suppliers are explicitly mentioned by NRENs who either already have an agreement in place or are interested in establishing one. For the vast majority it is the latter, with NRENs seeking a framework contract which establishes the right conditions of use.

Suppliers named by multiple NRENs:

- Amazon Web Services
- Blackboard
- BOX
- Google Apps
- Microsoft Azure and Office 365
- OwnCloud

Cloud breakdown by NREN

Table 6.1.7 presents the detailed answers from each NREN on Cloud services:

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Albania	ANA	Planned	Yes		No					
Algeria	ARN	Planned	Yes		No					
Armenia	ASNET-AM	Yes	Yes		No					
Australia	AARNet	Yes	Planned	Storage, Videoconferencing, VPN, SaaS, IaaS	Yes	Cloud backup / storage, video-conferencing / unified comms	Box, Zoom, Code42, Ezuce, Labarchives	Microsoft Azure	Cloud collaboration; XaaS; VPNs; researcher workflow automation	AARNet needs to work in harmony with government programmes NeCTAR and RDS to avoid duplication of cloud and related services
Austria	ACOnet	No			No					
Azerbaijan	AzScienceNet	Yes	Yes		Yes					
Belarus	BASNET	Yes	Yes		No					
Belgium	Belnet	Yes	Planned	Storage and compute	No					
Bosnia / Herzegovina	SARNET	Planned	No		No					
Brazil	RNP	Planned	Yes	Storage, email, agenda	Planned				Storage, email, agenda.	
Bulgaria	BREN	No			No					
Canada	CANARIE	Yes	Yes	identity and access management, research software, funding	No					DAIR cloud (canarie.ca/cloud)
Croatia	CARNet	Yes	Yes		No					
Cyprus	CYNET	No		Secondary DNS	No					

Table 6.1.7 - Continued

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Czech Republic	CESNET	Yes	Yes	IaaS HPC cloud, PaaS for scientific users planned, SaaS and storage	Planned				Multimedia (WebRTC, SW MCU), PaaS	Distributed hierarchical storage infrastructure with 22 PB raw capacity
Denmark	DeIC	Yes	Planned	Storage+Computing	No					
Ecuador	CEDIA	Yes	Yes							
Estonia	EENet	Yes	Yes	SaaS	No					
Finland	Funet	No			No					
France	CNRS	Not planned			No					
France	RENATER	Planned	Yes		No					
Georgia	GRENA	Planned	Yes							
Germany	DFN	Yes	Yes		Yes	Storage, VM	DFN-members, non-commercial			
Greece	GRNET S.A.	Yes	Yes	End-user self-service on-demand Computing and Storage services: okeanos.grnet.gr is an IaaS Service hosted in GRNET datacenters. Cyclades is the Virtual Compute and Network service of ~okeanos, and Pithos+ is the Virtual Storage service. Scientific SaaS/ PaaS services under development.	No					We offer two IaaS services addressed to different end-users (namely ViMa is offered to NOCs while ~okeanos to end-users). The characteristics of the VMs vary. Maximum allowed values are 4vCPUs, 4GigRAM, 100Gig Disk. More resources may be provided upon request and justification.

Table 6.1.7 - Continued

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Hungary	NIIF/ HUNGARNET	Yes	Yes	IaaS virtual machines, virtual interconnects	No					
Iceland	RHnet	No			No					
Ireland	HEAnet	Planned	Planned	Planning VMs as a service, planning cloud compute (virtual servers)	Yes	Storage, Compute, LMS	Microsoft, Blackboard, Moodlerooms, Desire2Learn, Instructure	AWS, Google, VMWare	Storage, Compute, SaaS	Continued funding for pan-european collaborative brokerage initiatives is essential
Israel	IUCC	Planned	Yes	HPC with Infiniband	Yes		AWS, GCP, Azure	Softlayer	Compute, storage, etc.	
Italy	GARR	Planned	Yes	IaaS, Storage-aaS (personal, initially), PaaS (like Identity Provider as a Service)	No			ownCloud, Google, Box	ownCloud storage, Google apps, Box storage	
Latvia	SigmaNet	Yes	Yes	Web harvesting service as part of Big Data platform	No					
Lithuania	LITNET	Planned	Planned	Backup, storage, webspace, email	No					
Luxembourg	RESTENA	No								
Macedonia	MARnet	Yes		Part of health information system (Ministry of health)						
Moldova	RENAM	Planned	Yes	GRID in CLOUD	Planned			Amazon, Microsoft Windows Azure	VMs, Computing Resources, Storage	

Table 6.1.7 - Continued

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Montenegro	MREN	No			No					
Morocco	MARWAN	Planned	Planned							
Netherlands	SURFnet	Yes	Planned		Yes		http://www.surf.nl/diensten-en-producten/surfconext/op-surfconext-aangesloten-diensten/index.html	Today's focus is on Microsoft, IaaS-providers, PaaS-providers, Identity as a Service providers, global services (and others)		Commercial (cloud) service agreements are provided via SURFmarket, HPC services via SURFsara. HPC services of SURFsara amongst others, for an overview see https://surfsara.nl/SURFsara-services. Overview of all the cloud services from commercial service providers and member institutes is available via http://www.surf.nl/diensten-en-producten/surfconext/op-surfconext-aangesloten-diensten/index.html
New Zealand	REANNZ	No		Net+ - http://www.internet2.edu/netplus/	Planned			Box, Dropbox, Amazon, Azure		
Norway	UNINETT	Planned	Planned	IaaS, PaaS, SaaS	Yes	Personal storage and collaboration		Box.com	All kinds of services, SaaS	
Poland	PIONIER	Yes	Yes	Cloud computing (IaaS, PaaS, SaaS), cloud storage: backup archive and sync& share services	Planned	Office365	Microsoft			We offer IaaS platform based on the OpenStack, as well as home grown SaaS solutions that enables on-demand access to applications installed on VMs

Table 6.1.7 - Continued

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Portugal	FCCN	Planned	Yes		Planned			National	IaaS, storage	
Romania	RoEduNet	Planned	No		No					
Russian Federation	e-ARENA	Yes	Yes		No					
Serbia	AMRES	No								
Slovakia	SANET	Not planned			No					
Slovenia	ARNES	Yes	Yes	IaaS, PaaS	Yes	Office365	Microsoft			
South Africa	SANReN	No			No					
Spain	RedIRIS	Planned	Planned	We offer cloud spam filtering. We are planning to offer more services - main candidates are mail, VoIP, electronic signature, IaaS or webconferencing	Planned	Spam filtering	Spamina		IaaS, mail, VoIP, webconference, digital signature, etc	
Sweden	SUNET	No			Yes		Not official yet		*AAS (including backup)	Will hopefully be launched end of this year
Switzerland	SWITCH	Yes	Yes	SWITCHdrive - ("sync & share") service based on ownCloud	No			Not clear yet	Depends on customer demand, added value through joint provisioning, and opportunities emerging from work with other NRENs, for example in the GN3+ SA7 framework	VMs based on OpenStack, offered to all universities who elect to opt in
Taiwan PoC	NCHC	Yes	Yes		No					http://ezilla.info/

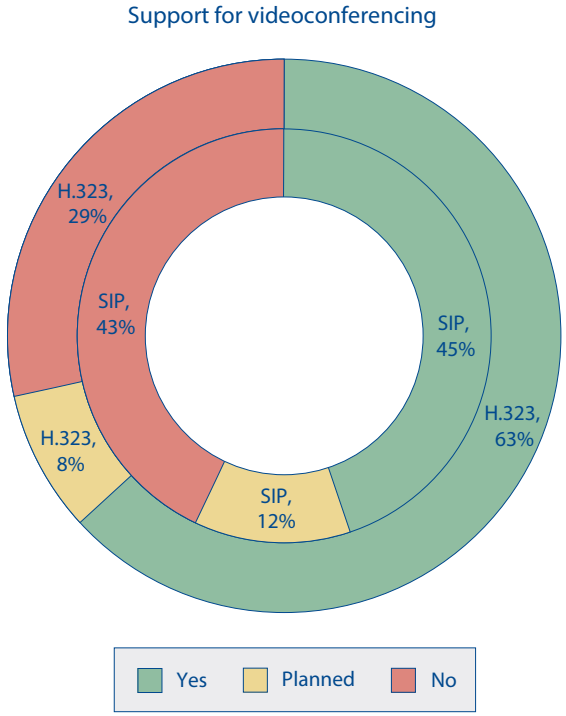
Table 6.1.7 - Continued

Country	Organisation	Do you offer cloud services not obtained through a vendor?	Does this include virtual machines?	Which other services do you offer or are you planning to offer?	Do you broker agreements with cloud service providers	What services are offered through such agreements?	Which vendors do you have agreements with?	Which vendors would you like to reach agreement with?	What services would you like to offer through such agreements?	Please provide any further remarks or information
Turkey	ULAKBIM	Yes	Yes	Production level IaaS and Hadoop services are offered	No					
Ukraine	URAN	Yes	Yes	PaaS						
United Kingdom	Jisc	No			Yes	1 Microsoft Office 365 amendments to the standard agreement 2 Google Apps for Education amendments to the standard agreement 3 Financial X-ray 4 Cloud and data centre	1. Microsoft 2. Google 3. Arkivum 4. Box 5. Capito 6. Q Associates 7. Infinity 8. Arcus Global Cloud & Data Centre framework suppliers: 9. Capita 10. Dell 11. eduserv 12. Fujitsu 13. HP 14. Liberata 15. Logicalis 16. Verizon Telephony Purchasing Service suppliers: 17. Voicenet Solutions Ltd 18. Vodafone Limited 19. Telecoms World Plc 20. Simplecall Business 21. Redcentric Solutions Ltd 22. Pivotal Networks 23. Pennine Telecom 24. MPS Networks plc 25. Maintel 26. Voice and Data Ltd 27. Gamma 28. Network Solutions 29. Freedom Communications 30. (UK) Ltd 31. Focus 4 U Ltd 32. Evolve 33. ETS Communications Ltd 34. Damovo UK Limited 35. APR Telecoms 36. ADA Network		Depends on customer requirements	We have framework agreements or DPS's for the above services

6.2 Videoconferencing

Centrally-managed videoconferencing services remain strategically important for many NRENs. 41% of the 54 NRENs that answered this question reported offering or planning to offer a traditional centrally-managed videoconferencing service. The prevalence of the support for the older H.323 standard and SIP shows that H.323 is still a very important technology with 71% of NRENs supporting this standard. Marginally less, sitting at 57%, reported supporting (or planning to support) SIP-based videoconferencing.

Graph 6.2.1 – Support for videoconferencing



Growth in use of video collaboration services

Usage is increasing across all forms of videoconferencing or webconferencing, and from most NRENs. NRENs with the most activity amass tens of thousands of traditional MCU sessions over a year; most notably, 108 000(France), 60 000(UK), 30 000(Ireland), and 24 000 (both New Zealand and Germany). Mature web conference services in Scandinavia are showing similar levels of usage with the most coming from the Danish NREN, DeIC, reporting 150 000 sessions in 12 months.

While usage seems to be increasing across all forms of videoconferencing or web conferencing, we have seen a significant increase compared with data collected in 2013.

Current videoconferencing services and feature sets

The feature set offered by NRENs associated with traditional videoconferencing services is illustrated in Table 6.2.2.

While all NRENs, except one, claim to offer a traditional videoconferencing service supporting H.323 conferencing and MCU (multipoint conferencing), a slightly smaller number report supporting SIP.

NRENs offering a videoconferencing service also offer featured services (in order of number of occurrences), browser plug-in, recording and streaming. From the data collected, it is less clear how commonly the feature of PSTN/VoIP interoperates with traditional videoconferencing environments, but many NRENs do claim a connection between a video service, be it traditional videoconferencing or webconferencing.

When describing the manufacturers used to provide the traditional service, there has not yet been a significant move away from the "legacy" videoconferencing hardware providers. Certainly, some of the more flexible cloud- and VM-based MCU manufacturers were mentioned, but it was clear that, with the possible exception of Vidyo, they have not yet deeply penetrated NREN video services.

Table 6.2.2 – Videoconferencing services

	Question	Do you provide a centrally managed traditional (H.323/SIP) video conferencing service?	Is ITU-T H.323 based videoconferencing supported?	Is Session Initiation Protocol (SIP) based videoconferencing supported?	Is any web client (browser plug in) to the videoconferencing service supported?	Do you provide multi-point MCU/ Video Server services?	Do you offer centrally provided recording of video/ web conferences?	Do you offer centrally provided streaming of videoconferences?
	Question Shortform	Traditional H.323 Service?	ITU H.323 ?	SIP?	Browser plugin/ web client?	MCU?	Rec?	Stream?
Country	NREN	No 41%, Plan 22%, Yes 37%	No 29%, Plan 8%, Yes 63%	No 43%, Plan 12%, Yes 45%	No 43%, Plan 21%, Yes 36%,	No 4%, Plan 6%, Yes 54%	No 47%, Plan 13%, Yes 40%	No 44%, Plan 16%, Yes 40%
Albania	ANA	No	Planned	Planned	Planned	No	No	No
Australia	AARNet	No	Yes	Yes	Yes	Yes	Yes	Yes
Austria	ACOnet	No	No	No	No	No	No	No
Belarus	BASNET	No						
Belgium	Belnet	No	Yes	Yes	Yes	No	No	No
Bulgaria	BREN	No	No	No	No	No	No	No
Canada	CANARIE	No	No	No	No	No	No	
Cyprus	CYNET	No	No	No	No	No	No	No
Estonia	EENet	No	Yes	No	No	No	No	No
Finland	Funet	No	Yes	No	Planned	Yes	No	No
Georgia	GRENA	No	No	No	No	No	No	Planned
Greece	GRNET	No	Yes	Yes	Yes	No	No	Yes
Iceland	RHnet	No	No	No		No	No	No
Israel	IUCC	No	No	No	No	Yes	Yes	No
Latvia	SigmaNet	No	No	No	No	No	No	No
Lithuania	LITNET	No	No	No	No	No	No	No

Table 6.2.2 – Continued

	Question Shortform	Traditional H.323 Service?	ITU H.323 ?	SIP?	Browser plugin/ web client?	MCU?	Rec?	Stream?
Country	**NREN**	**No 41%, Plan 22%, Yes 37%**	**No 29%, Plan 8%, Yes 63%**	**No 43%, Plan 12%, Yes 45%**	**No 43%, Plan 21%, Yes 36%,**	**No 4%, Plan 6%, Yes 54%**	**No 47%, Plan 13%, Yes 40%**	**No 44%, Plan 16%, Yes 40%**
Montenegro	MREN	No	No	No	No	No	Yes	Yes
Morocco	MARWAN	No	Yes	No	Yes	Yes	No	No
Netherlands	SURFnet	No	No	No	No	No	No	No
Slovakia	SANET	No	No	Yes	Yes	No		
Spain	RedIRIS	No	Planned	No	Yes			
Sweden	SUNET	No	Yes	Yes	Yes	Yes	Yes	Yes
Taiwan, PoC	NCHC	No	Yes	No	No	No	No	No
Turkey	ULAKBIM	No	No	No	No	No		
Ukraine	URAN	No	Yes	No	Yes	Yes	Yes	Planned
Armenia	ASNET-AM	Planned	Yes	Yes	Yes	Planned	Planned	Planned
Bosnia / Herzegovina	SARNET	Planned	Planned	Planned	Planned	Planned	Planned	Planned
Ireland	HEAnet	Planned	Yes	No	Planned	Yes	Yes	Yes
Macedonia	MARnet	Planned	Planned	Planned	Planned	No	Planned	Planned
Moldova	RENAM	Planned	Planned	Planned	Planned	No	Planned	No
Algeria	ARN	Yes	Yes	Yes	No	Yes	Yes	Yes
Azerbaijan	AzScienceNet	Yes	Yes	Yes	No	Yes	No	No
Brazil	RNP	Yes	Yes	Planned	No	Yes	Yes	Yes
Croatia	CARNet	Yes	Yes	Planned	No	Yes	Yes	Yes
Czech Republic	CESNET	Yes	Yes	Yes	No	Yes	Yes	Yes
Denmark	DeIC	Yes	Yes	Yes	Yes	Yes	Yes	No
France	RENATER	Yes	Yes	Yes	Yes	Yes	Planned	Planned
Germany	DFN	Yes	Yes	Yes	Planned	Yes	Yes	Yes
Hungary	NIIFI/HUNGARNET	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Italy	GARR	Yes	Yes	Yes	Planned	Yes	No	Yes
Malta	UoM/RicerkaNet		Yes	Yes		Yes		
New Zealand	REANNZ	Yes	Yes	No	Yes	Yes	No	

Table 6.2.2 – Continued

	Question Shortform	Traditional H.323 Service?	ITU H.323 ?	SIP?	Browser plugin/ web client?	MCU?	Rec?	Stream?
Country	**NREN**	**No 41%, Plan 22%, Yes 37%**	**No 29%, Plan 8%, Yes 63%**	**No 43%, Plan 12%, Yes 45%**	**No 43%, Plan 21%, Yes 36%,**	**No 4%, Plan 6%, Yes 54%**	**No 47%, Plan 13%, Yes 40%**	**No 44%, Plan 16%, Yes 40%**
Norway	UNINETT	Yes						
Poland	PIONIER	Yes	Yes	Yes	Planned	Yes	Yes	Yes
Portugal	FCCN	Yes	Yes	No	No	Yes	Yes	No
Romania	RoEduNet	Yes	Yes	Yes	Yes	Yes	Planned	Planned
Russia	e-ARENA	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Serbia	AMRES	Yes	Yes	Yes	Yes	Yes	No	Yes
Slovenia	ARNES	Yes	Yes	Yes	Yes	Yes	Yes	Yes
South Africa	SANReN	Yes	Yes	Yes	Yes	No	Yes	No
Switzerland	SWITCH	Yes	No	No	Planned	Yes	No	No
UK	Jisc	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Direction of Development

Many NRENs expressed their intentions for development either by describing their plans or by choosing a "planning" response for certain features. A particularly noticeable interest was in development towards browser-based access and/or WebRTC access to services. Out of the 20 NRENs who described plans for development, 14 plan to expand desktop options and 11 specifically mention WebRTC as the technology they plan to investigate.

This was also reflected in questions on the existence of a web-based videoconferencing service (proprietary or WebRTC). 37% of the responding NRENs offer this service and a further 22% are planning to offer it. We saw this trend again in response to a question asking if a web client or browser plug-in was supported in a traditional videoconferencing service.

Within the videoconferencing area, this is the area where most NRENs are planning to do work. This response, along with the high number of mentions of WebRTC, clearly indicates a shared direction of development for NREN video services.

Importantly, these two questions in particular show that browser access from WebRTC is equally important as a direction of development to traditional (H.323/SIP) videoconference services and web conference services.

Dialling schemes

The Global Dialling Scheme (GDS) is used to address and reach endpoints. Numbering within the GDS is prefixed with a country code in the same way as the E.164 standard. Within a country, the GDS can be delegated to avoid overlap with the E.164 numbering scheme, as used by the PSTN network.

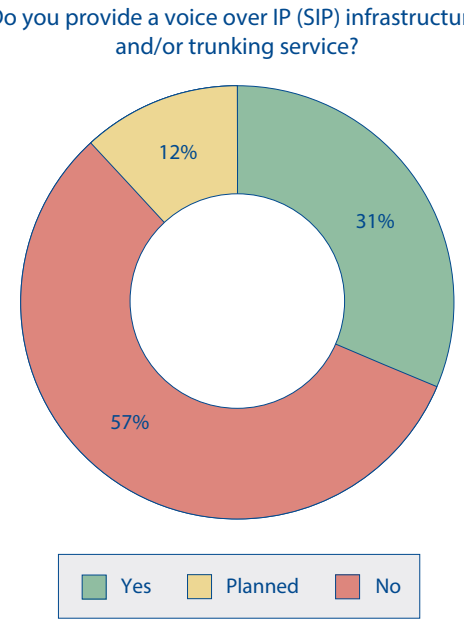
Around the same number of NRENs (38% of respondents) support the GDS as support SIP access to video services. The GDS is used to address and reach endpoints and is based on the E.164 numbering scheme, as used by the PSTN network.

Due to complexities in negotiating with national telephony service regulators, the majority of NRENs do not offer valid E.164 numbers (no risk of overlap with PSTN) for their video- or webconferencing service. This has the effect of preventing NRENs from listing these numbers on the NRENum.net registry service infrastructure, as shown in the low response to that question.

VoIP and SIP trunking

Somewhat surprisingly, given the overlap of communications networks and IP networks in the modern world and the savings available, 58% of NRENS are not offering or planning to offer a VoIP or SIP trunking service.

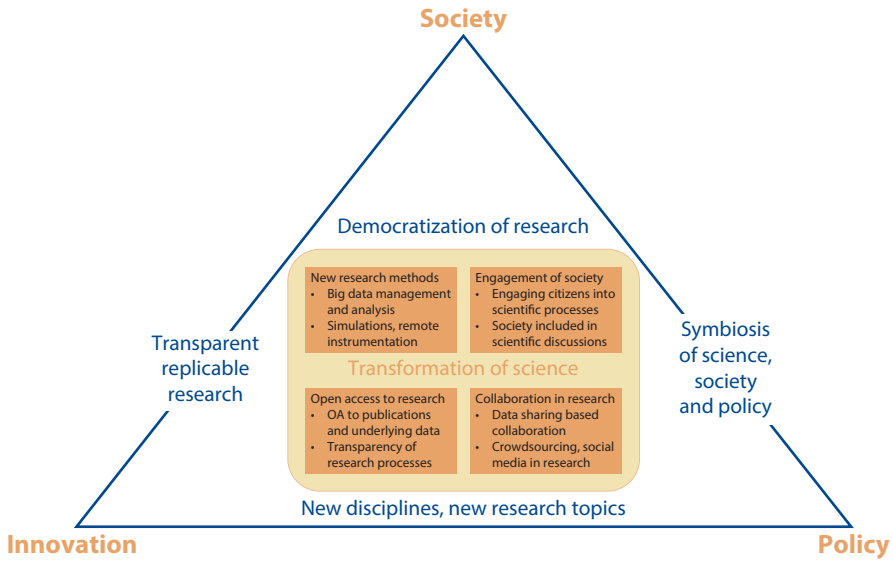
Graph 6.2.3 – VoIP service



Deploying VoIP / SIP Trunking services is considered technically simple, but can often face a number of challenges in terms of regulation. A number of NRENs are routing public telephony traffic on an IP infrastructure, which by its nature is not circuit-based and is, in some cases, not allowed as some European telecommunications organisations face stronger regulation than others.

Another barrier to adoption is the inability to provide Quality of Service (QoS) within a multi-management domain environment. It is incredibly difficult to agree an end-to-end QoS mechanism that (a) meets the customers need, (b) meets the NREN's need and (c) meets the supplier(s) need. Some telecommunications organisations are incapable of delivering their VoIP services without end-to-end QoS because some customers are unwilling to move their voice traffic onto a non-QoS enabled IP infrastructure. As protocols and technologies evolve, we may see an increase in adoption. The uptake of VoIP is, however, predominantly driven by cost, in that SIP Trunks are, in most cases, significantly cheaper than ISDN circuits. As budgets are stretched more and more, some customers and NRENs may find themselves in a position where they do not appear to have a choice. Similarly, telecommunications organisations and suppliers may find that if they do not untether the QoS requirement for their requirement, the uptake of their services will ultimately be too slow, likely leading to a stagnant and then declining curve in business need.

Figure 6.3.1 - Open Science



6.3 Open Science and e-Infrastructures

A key pillar of the European Union's current European Digital agenda is the promotion of Open Science. Open Science aims at transforming science through ICT tools, networks and media, to make research more open, global, collaborative, creative and closer to society (see figure 6.3.1[1]). Underpinning this is the need for digital infrastructures or e-infrastructures to enable online access to distributed and high performance computing infrastructures, storage and data infrastructures, scientific instruments and resources, as well as connectivity and communication between research communities.

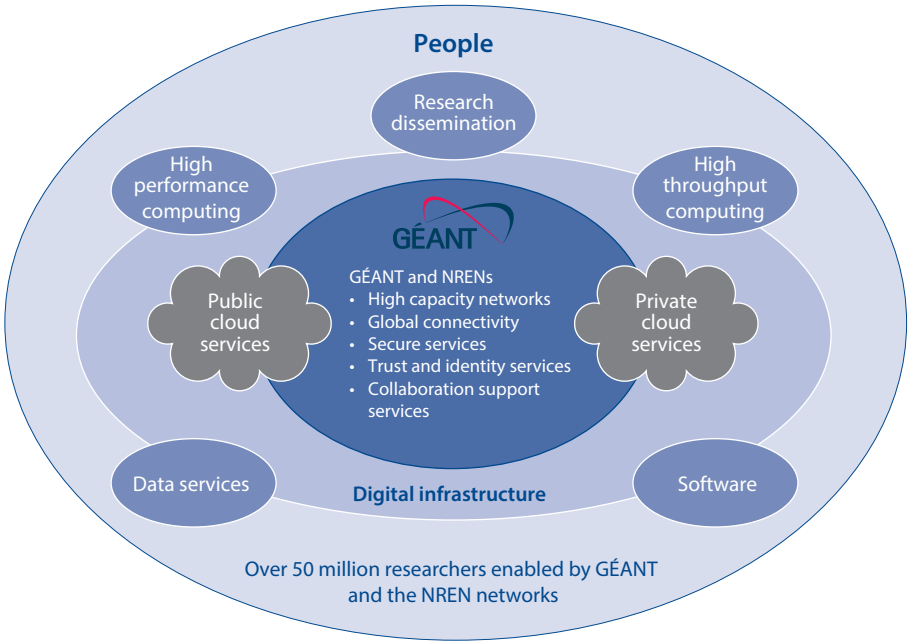
e-Infrastructure

e-Infrastructure is a term that has emerged over the last few years to cover the ensemble of resources from communications networks, computation and storage facilities and the middleware and software systems that bind them together to provide services. It encompasses traditional hardware aspects, such as computers and data storage, but also software, skills and training, access routes, and management and governance.

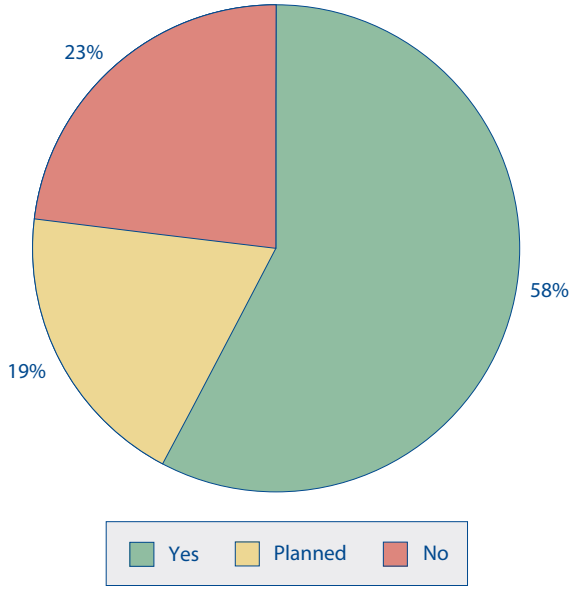
As perspectives evolve to a more coherent and integrated view of services in an e-Infrastructure environment, NRENs are expanding their service portfolios in various ways beyond traditional data communications and are increasingly involved in discussions with the communities they support about the nature, scope and scale of these emerging service requirements.

[1] https://ec.europa.eu/digital-agenda/en/open-science

Figure 6.3.2 - e-Infrastructure



Graph 6.3.3 - Dedicated Point-to-Point IP circuits



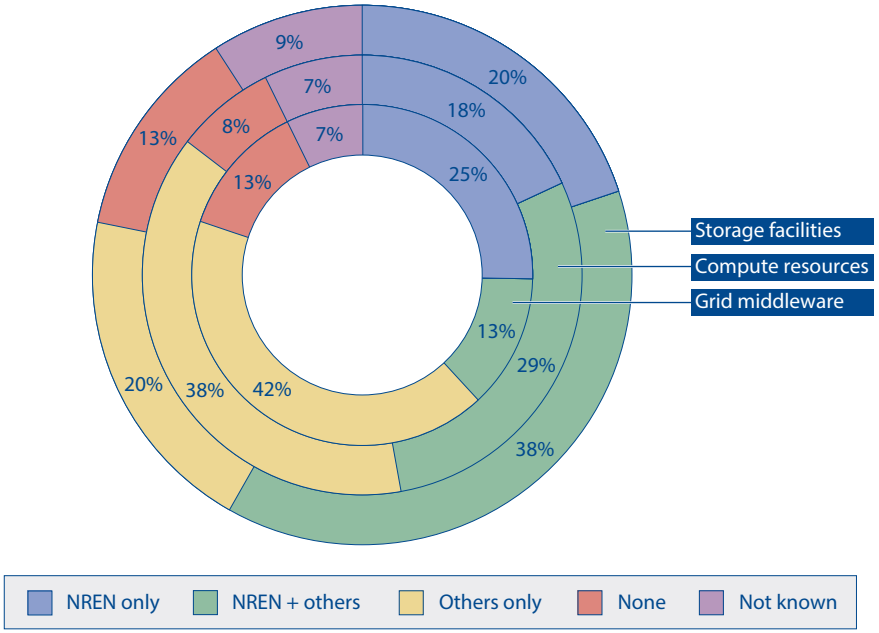
A number of NRENs participate in the e-Infrastructures Reflection Group (e-IRG) as national representatives (**www.e-irg.eu**) to facilitate coordination and collaboration in the e-Infrastructure arena; the e-IRG roadmap is a key output of this group. There is also a number involved in projects under European programmes, such as the EC's Horizon 2020.

NREN contribution

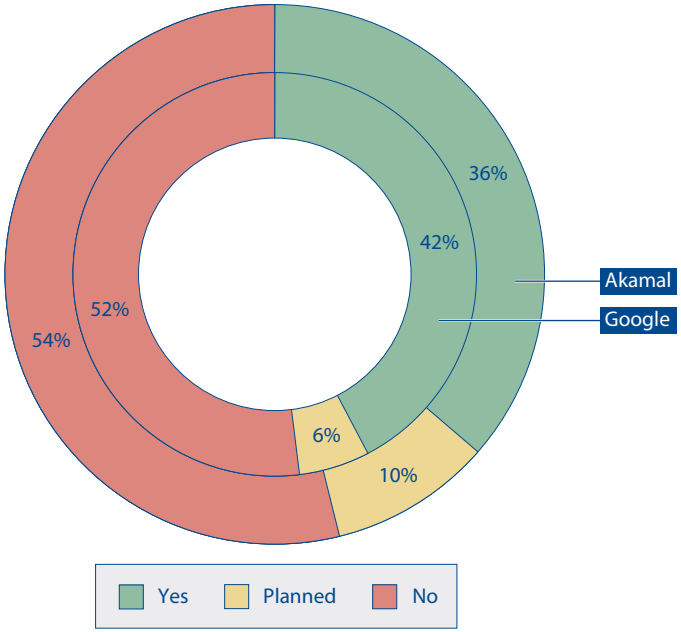
NRENs have a defining role in providing high performance communications networks within the digital infrastructure. Nearly 60% currently offer dedicated high-capacity point-to-point circuits (see graph 6.3.3). Almost half of NRENs have connected research organisations that provide and manage research resources and facilities to the network, such as synchrotrons and accelerators, telescopes and radio telescopes, sensor networks, seismic stations, meteorology and weather stations, and lab equipment.

NRENs typically provide digital infrastructure services such as grid middleware, compute resources or storage resources, sometimes being the only provider, but often in conjunction with others. Graph 6.3.4 shows the distribution of provision of these services between NRENs and other providers. Other services NRENs offer typically include monitoring services, large data transfer services and research portals as well as e-learning resources. Of the NRENs offering data archival services, only Jisc in the UK offers services via a brokered non-commercial deployment, with others preferring an internally-built solution.

Graph 6.3.4 – e-Infrastructure services



Graph 6.3.5 – Caching services



- Just over 1/3 NRENs offer hosting of commercial content servers or commercial content on the NREN network, and of the others, only one has plans to do so.
- The number of NRENs using or planning to use Akamai or Google caching services is still below half (see graph 6.3.5), with a significant proportion having no plans to offer these. Those who do, offer these services to all NREN users.

Mirroring of external content from outside the NREN network remains unchanged from the last few years with only 17 currently offering this, and two more plan to do so.

We are seeing a significant move to e-Infrastructure in our community with NRENs providing more than just the underpinning network services. There are structural changes happening within our NRENs in order to provide richer portfolios driven by organisational needs, such as access to data centre and external resources. The drive towards hybrid models of provision, from solely internal to mixed internal and external services, demands a shift in profile of network services for NRENs in order to respond to community and customer demands.

7 FUNDING AND STAFFING

Some NRENs provide services only to their country's research and/or education community. Others also provide services beyond this community; for example, they administer the country-code top-level domain, or they connect companies and/or institutions outside the research or education community. To enable comparison, we asked the NRENs covered by this 2015 edition of the *Compendium* to provide information only about their activities for national research and/or education communities. We refer to such activities simply as 'NREN activities'.

It is no easy task to compare NRENs by staff or budget size, because their budgets are variously structured depending on their tasks, while their funding also differs greatly. Compared to 2010, overall budgets in the GÉANT area have risen by 2%, while staff size has increased by 27%. Transmission capacity and equipment costs have decreased, but new services have necessitated staff size increases.

Comparing 2015 budget data with those from previous editions of the *Compendium* reveals that generally, NREN budgets increased compared to 2014, though this is not necessarily the case for individual NRENs. Comparison of the three-year average of 2013-2015 with 2010-2012 shows a 10% decrease. For some NRENs the budget situation is unclear because final budget decisions are made in the course of the year. Obviously, this is not to be recommended, as it makes forward planning very difficult for the NRENs in question. The general trend is that each year, NRENs are able to deliver more bandwidth and more services for roughly the same amount of money as in the previous year. Belarus, Cyprus and Georgia all suffered budget cuts of more than 20%.

Over the past few years, infrastructural investments have led to savings in transmission costs. In addition, the resulting infrastructural improvements, coupled with innovations in the area of authentication and authorisation, have enabled a new generation of networked services, which have required some increases in staff size.

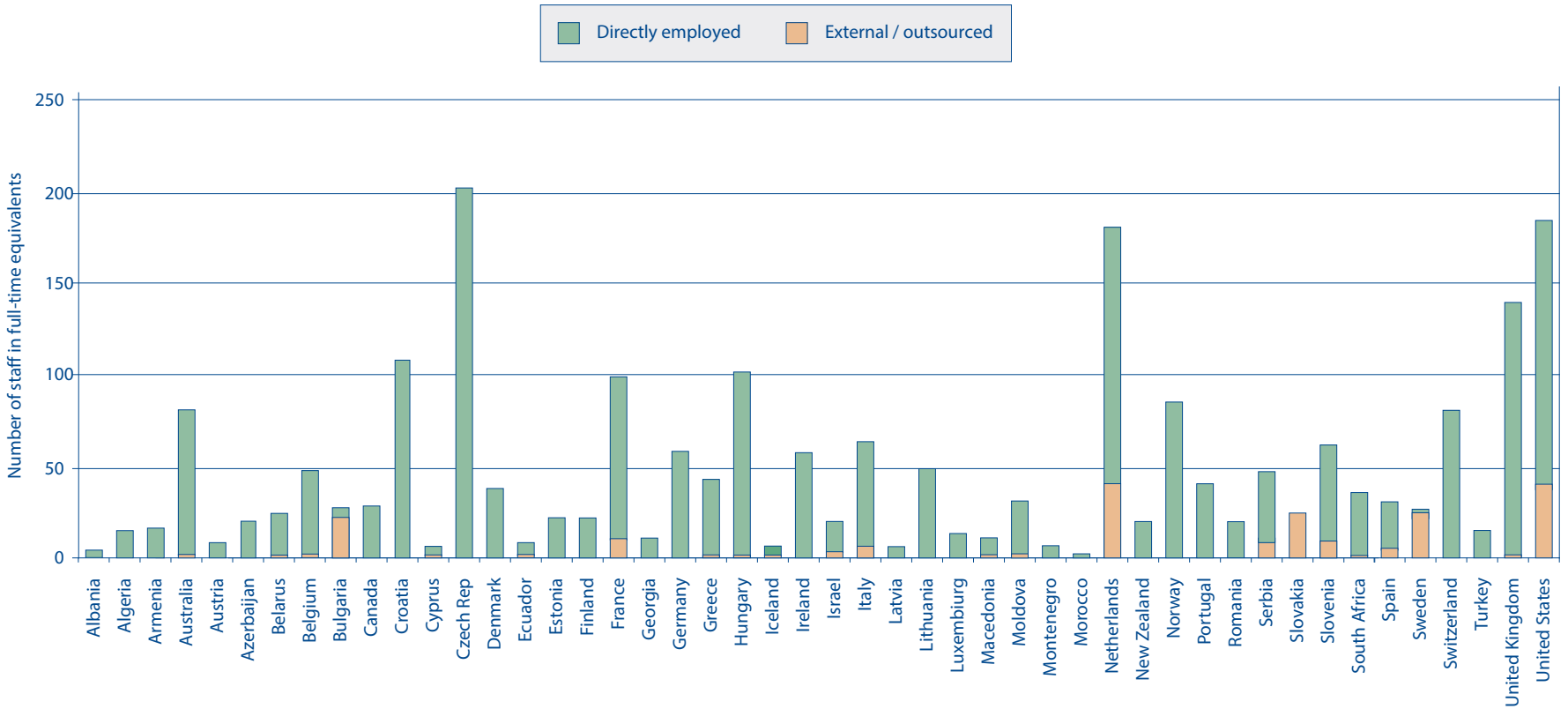
Although it is impossible to make general recommendations on NREN funding mechanisms, a model that in some way involves all the various stakeholders in an NREN would seem to provide the best guarantees for its continued success. In their respective fields, many NRENs are engaged in innovations, which are often steered by dedicated funding mechanisms. It is important for NRENs to use such funds to their advantage wherever they exist.

7.1 Staffing

Graph 7.1.1 gives an overview of all the staff who are directly employed in NREN activities, as well as subcontracted staff, in full-time equivalents (FTE). Graph 7.1.2 provides similar information specifically for technical staff. The data is presented in this way because many NRENs use subcontractors; as a result, staff size alone is not a reliable indicator of the total person-power available to an NREN.

As in previous years, considerable differences from NREN to NREN are evident, not only in the number of staff employed but also in their set of skills. One explanation for these differences is that in some NRENs, the research network is a service provided by a parent organisation or by an outsourced company; therefore, it is not possible for all such NRENs to specifically estimate the non-technical staff time (e.g. in accounting and human resources, etc.) related to NREN activities. This partially explains why some NRENs have a higher ratio of technical to total staff than others.

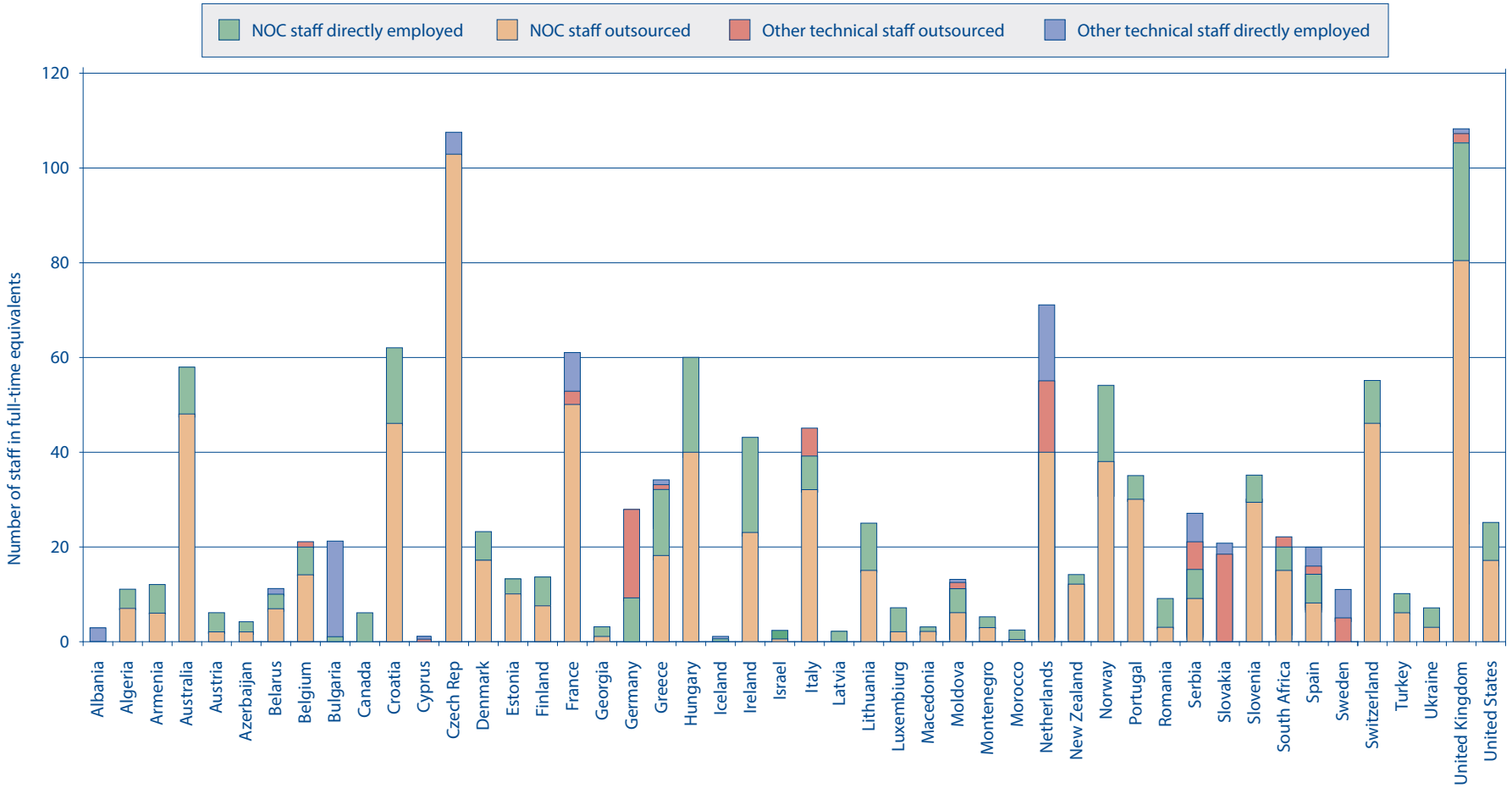
Graph 7.1.1 – Total NREN staff in FTE



NRENs differ considerably in the tasks they perform: for example, some provide connections to metropolitan area networks (MANs) or to access networks, which in turn connect institutions. Other NRENs connect institutions directly, and some manage MANs themselves. The connection policies of NRENs also differ with respect to secondary and primary schools, for example. This affects the remit of the NRENs and explains some of the differences in staff numbers that are apparent in Graphs 7.1.1 and 7.1.2.

Finally, some NRENs provide extensive support to individual end-users at institutions, some provide limited customer support, and many have service levels that are somewhere in between. This factor can have a significant effect on staff levels.

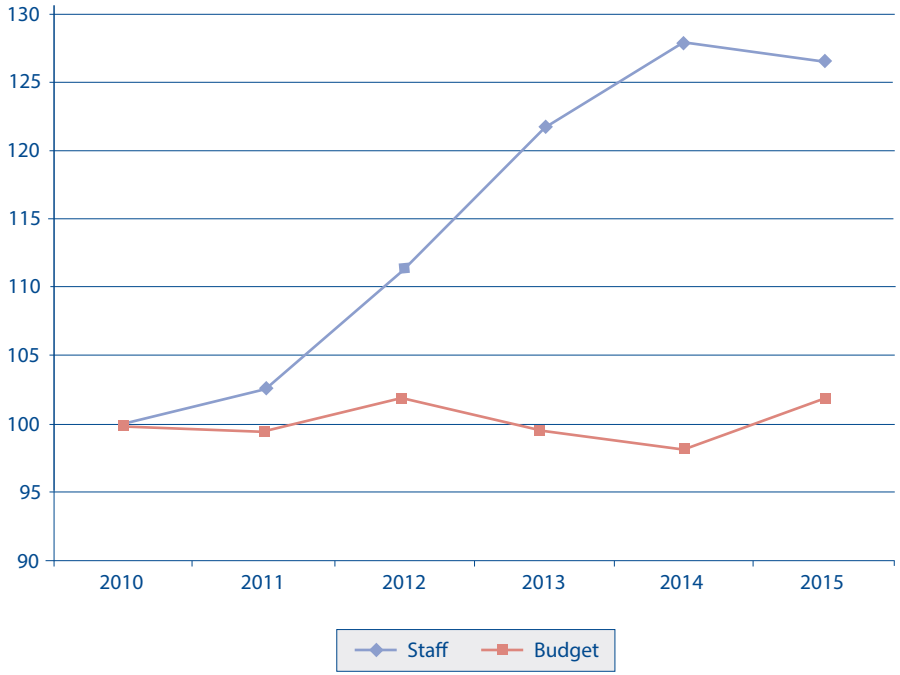
Graph 7.1.2 – NREN technical staff in FTE



RNP of Brazil has more staff than any European NREN: in June 2015 it had 176 employees and 421 outsourced staff. For scaling purposes, Brazil is omitted from both graphs above.

Graph 7.1.3 (below), which compares budget with staff size for the entire GÉANT region, indexed on 2010 (=100), illustrates the key points made above in this section. Clearly, budgets have been relatively stable. Nevertheless, staff size has grown considerably over the entire period. As documented in Section 7.5, the costs of transmission capacity and hardware have decreased. Over the same period, improvements in infrastructure, coupled with innovations in authentication and authorisation, have enabled a new generation of networked services, and where these services are administered by NRENs, they require more staff. (The decrease in 2015 is due mainly to relatively large decreases in Greece and the UK, partially offset by staff increases in the Czech Republic.)

Graph 7.1.3 – Total NREN budget and NREN staff size in the GÉANT partner countries, 2010–2015, indexed on 2010 (=100)



7.2 Total budgets, 2010-2012 and 2013-2015

NREN budgets may fluctuate as investment levels vary from year to year. In order to filter out as much of this effect as possible, in Graphs 7.2.1 and 7.2.2 (below, for the GÉANT partner countries) we have compared the total NREN budgets averaged over two three-year periods: 2010 2012 and 2013 2015. Note that for Jisc (UK), the financial year is from August to July; therefore, its 2015 budget is actually its 2014/2015 figure.

How total annual budgets have varied over the period 2010 to 2015 is shown in Graph 7.2.3, together with the growth in GÉANT traffic[1].

For some NRENs the budget situation is unclear because funders make their final budget decisions in the course of the year rather than at the beginning. Obviously, for the NRENs in this category this makes forward planning more difficult, if not virtually impossible.

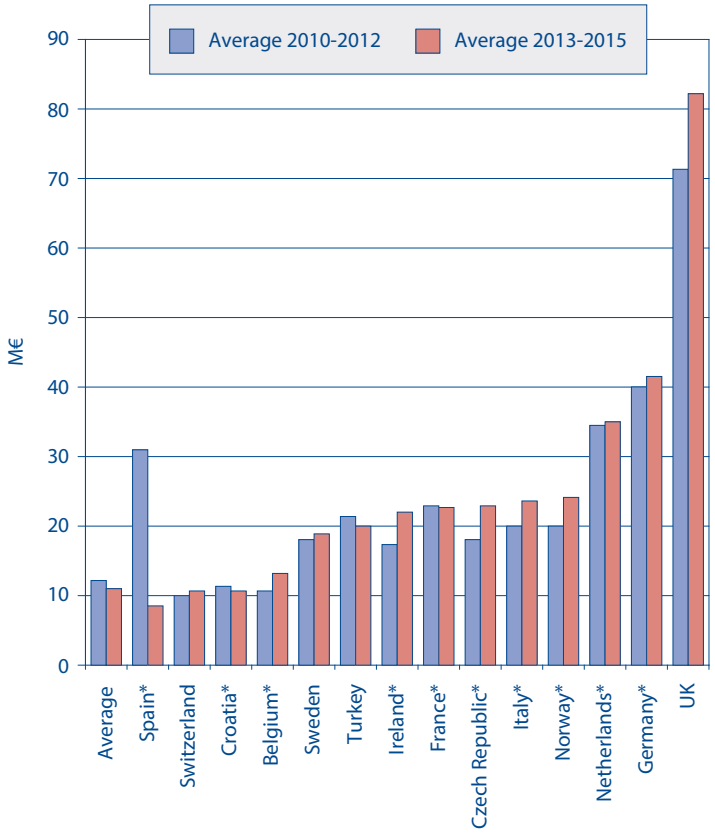
[1] Traffic through the GÉANT network is only one of many components of a NREN's traffic. Nevertheless, it is used here as a comparator because it reflects the overall activity of an NREN and is centrally measured.

For several reasons (see bulleted list below) it remains difficult to directly compare budgets. We asked the NRENs whether their submitted budget figures include the EU grant for GÉANT activity. For some NRENs, this is the case; for others, this grant is not shown as part of the income but as a reduced cost. In Graphs 7.2.1 and 7.2.2, the NRENs that include the GÉANT subsidy in their budget figure are marked with an asterisk.* As shown in Section 7.3 (below), the proportion of funds received from the EU (though not always exclusively for GÉANT) differs considerably. There are other reasons why comparison of NREN budgets is difficult:

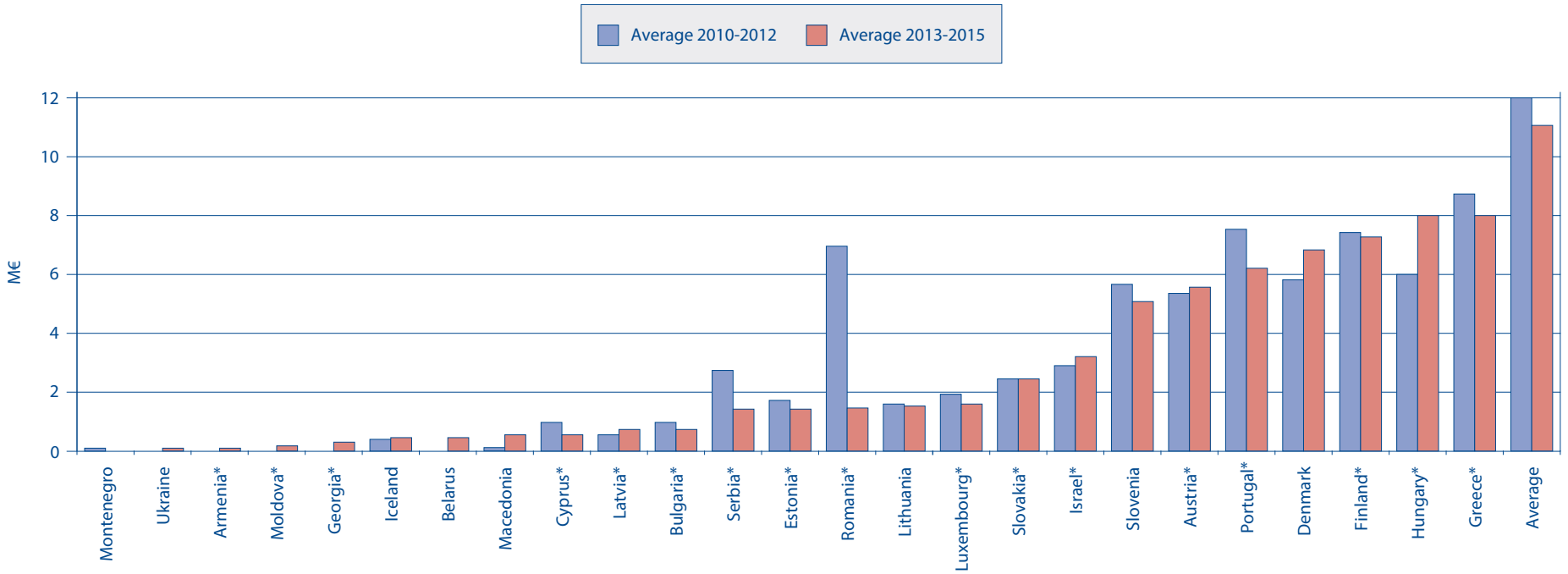
- Regional and/or metropolitan area networks (RANs/MANs) are funded differently in different countries;
- In some countries clients pay for their link to the nearest NREN point of presence; in others, the NREN pays for this;
- Some NRENs spend a large part of their budget on connecting primary and secondary schools; others do not or may take this separately into account;
- There are large differences in how staff are paid. In the GÉANT area, one NREN spends only 2% of its budget on staff, whereas another spends 59% of its budget on this aspect. In this context it should be noted that some NRENs have staff who are not paid from the NREN budget. Similar differences also exist in other expenditure categories;
- Some NRENs provide network connectivity only, others also provide services such as community clouds; shared services, etc.
- In cases where the NREN is part of a larger institution it is not always possible to isolate work specifically done for NRENs from other work.

A few NRENs, including GRENA of Georgia do not have budget certainty until quite late in the year. This may be because there is uncertainty about projects, payments from client institutions or government funding. In some cases, salary payments to NREN staff are relatively stable, whereas additional budgeting for investments is only known later in the year. Obviously, a NREN that is to be at the forefront of Internet developments in its country requires reliable budgeting.

Graph 7.2.1 – Total budgets, 2010-2015 averages, GÉANT partner countries with annual budgets > 10 M€



Graph 7.2.2 – Total budgets, 2010-2015 averages, GÉANT partner countries with annual budgets < 10 M€



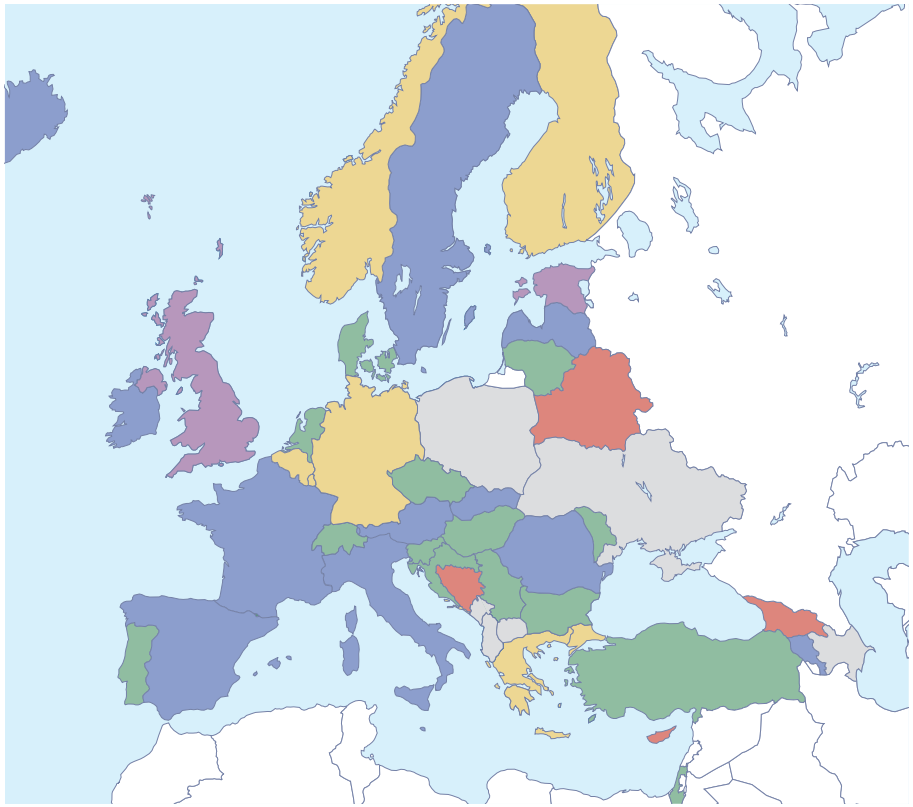
Graphs 7.2.1 and 7.2.2 show a mixed situation: some NREN budgets have increased, others have decreased; the overall average has decreased by 10%. Comparing the three-year averages reveals quite large budget decreases in Bulgaria, Cyprus, Montenegro, Romania, Serbia and Spain. In part, these can be explained by investments in network upgrades in the earlier period that led to savings in the later period. Budgets increased in the Czech Republic, Hungary, Ireland, and Macedonia.

Map 7.2.3, which compares budget changes from 2014 to 2015, reveals the relatively large budget decreases in Belarus, Cyprus and Georgia. There were relatively large budget increases in Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Hungary, Lithuania (after several years of budget cuts), Israel, Moldova, Portugal, Serbia, Slovakia, Switzerland and Turkey. The reasons for these changes are different for every NREN.

Legend for map 7.2.3

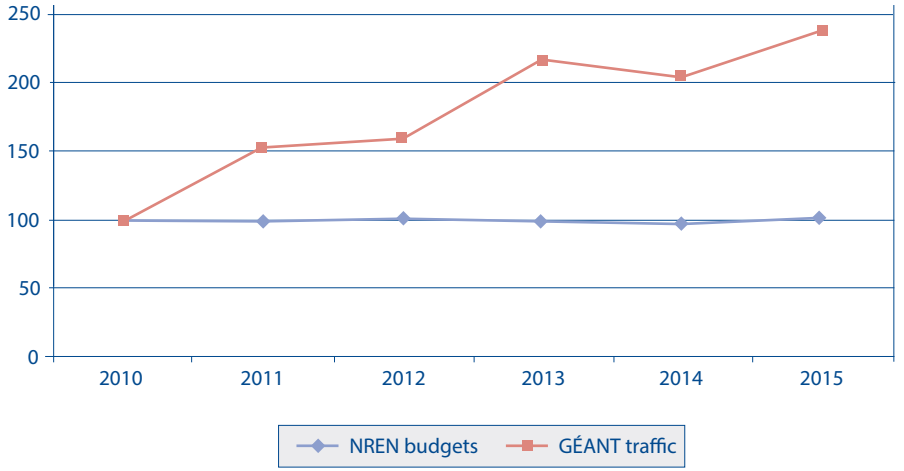
	Budget decrease < 5%
	Budget increase > 5%
	Budget equal or increase < 5%
	Budget decrease > 5%, < 15%
	Budget decrease > 15%
	No data received or decrease <5%

Map 7.2.3 – Budget increases and decreases in the GÉANT area, from 2014 to 2015



Traffic has more than doubled since 2010, as illustrated by the figures for traffic on the GÉANT backbone, which are plotted in Graph 7.2.4:

Graph 7.2.4 – Total NREN budgets and traffic, 2010-2015, GÉANT partner countries (indexed on 2010 = 100)



As Graph 7.2.4 shows, the investments in infrastructure upgrades that many countries have made in recent years have enabled steady traffic growth for roughly the same amounts of money each year. This has also enabled growth in both diversity and number of services offered on the network.

The data obtained from the non-GÉANT countries are not sufficiently time-consistent to allow them to be presented in the same form as those from the GÉANT partner countries.

The current funding levels of several of the non-GÉANT countries are unlikely to be sufficient for them to reach the standards now common in the GÉANT area, despite the falling prices of connectivity in recent years.

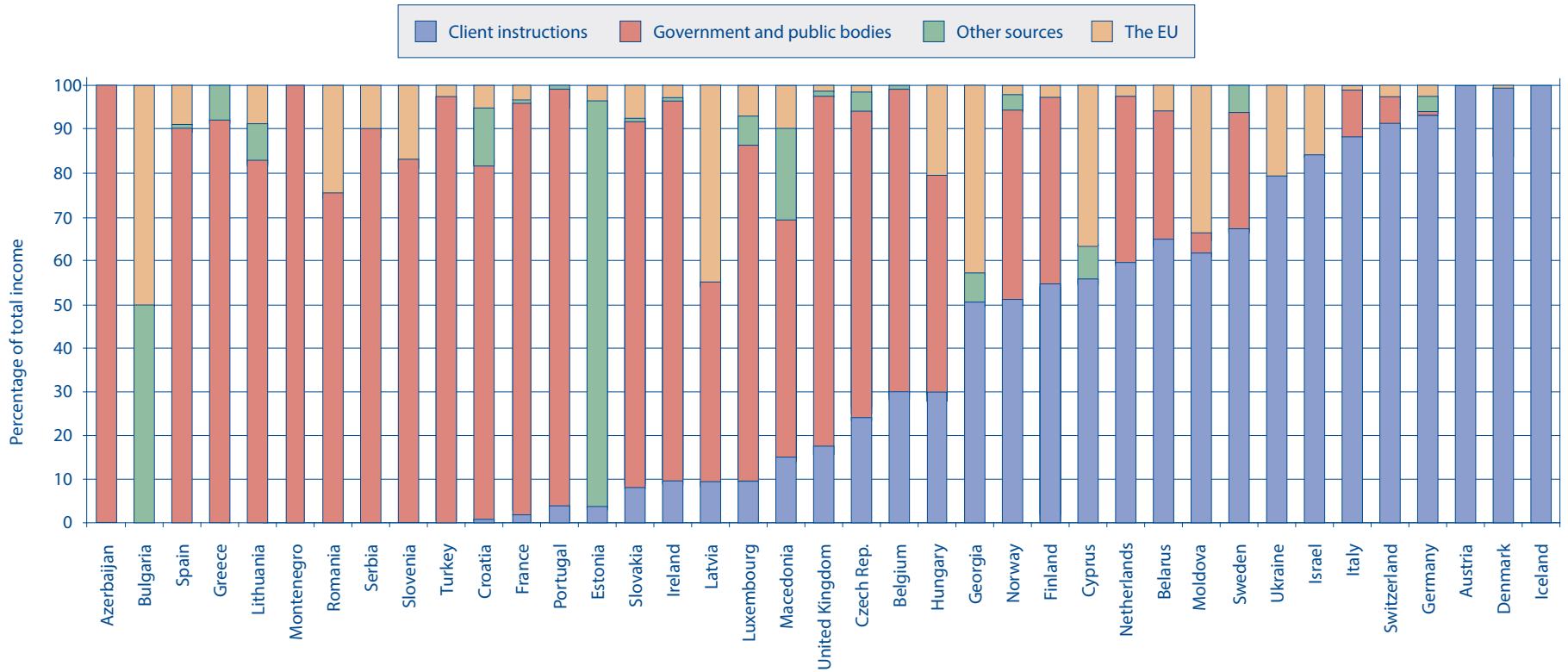
7.3 Income sources

NRENs are funded in various ways: some receive all their funding directly from national government; others are funded entirely by their users (who may in turn, be government-funded to some extent). Between those extremes there are many variants. Graphs 7.3.1 and 7.3.2 indicate what percentage of NREN funding comes from which source.

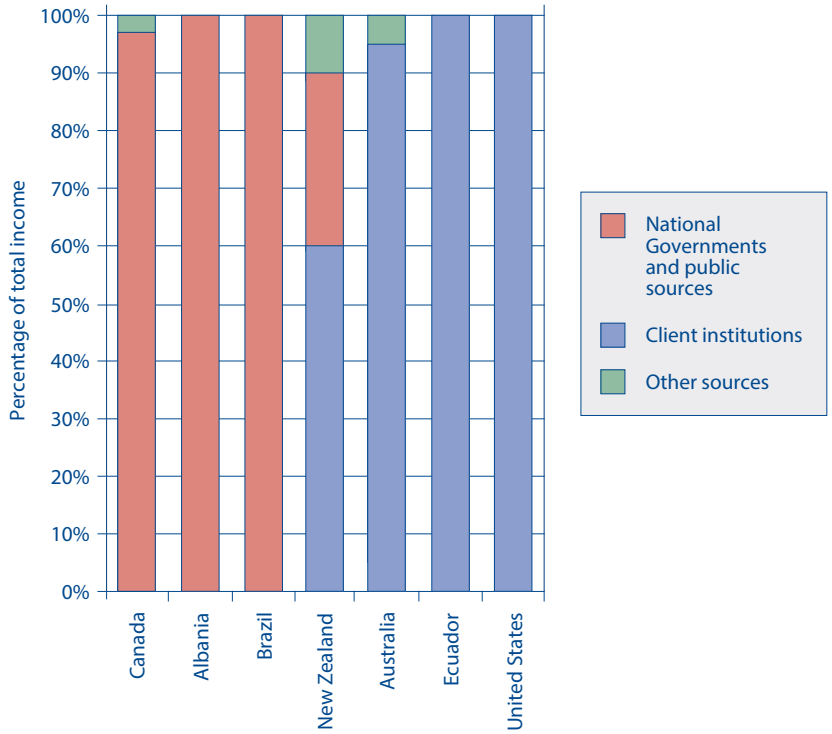
Although it is impossible to make general recommendations on NREN funding mechanisms, a model that in some way involves several stakeholders in an NREN would seem to provide the best guarantees for its continued success. It should be noted that, in their respective fields, many NRENs are engaged in innovations, which are often steered by dedicated funding mechanisms. NRENs should apply for such funds wherever they are available.

As in previous years, NRENs were asked whether they have multi-annual budgets. Of the responding NRENs, about half confirmed that they can use such budgeting.

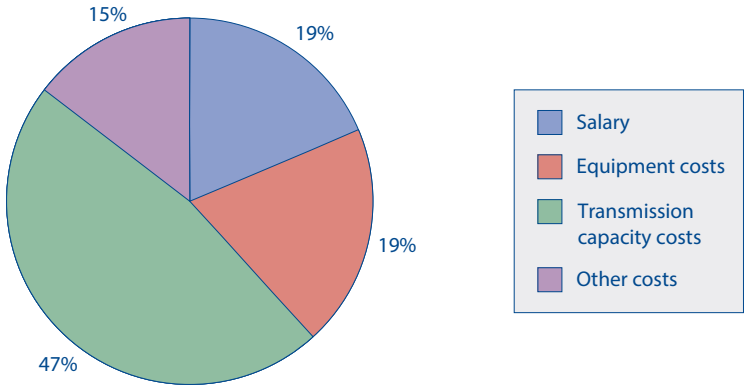
Graph 7.3.1 – Income sources, GÉANT partner countries



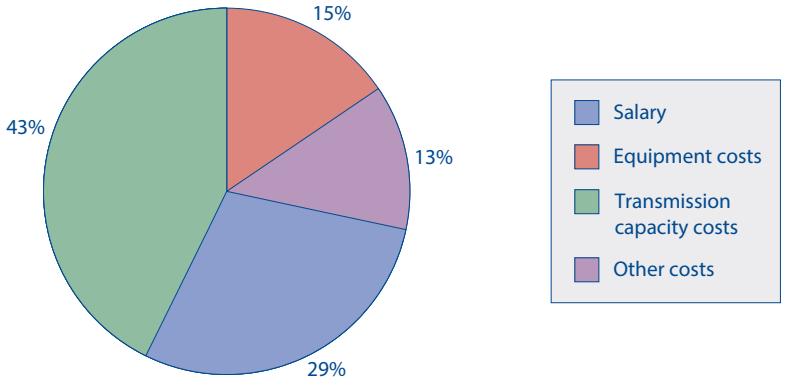
Graph 7.3.2 – Income sources, other countries



Graph 7.4.1 – Expenditure by category, EU/EFTA countries, 2009



Graph 7.4.2 – Expenditure by category, EU/EFTA countries, 2015



7.4 Expenditure by category

Graphs 7.4.1 and 7.4.2 (below) show the average percentage of NREN income spent on various cost categories. To enable comparison, the graphs show the situation in the same set of (current) EU/EFTA countries for 2009 and 2015[2].

Since 2009, the proportion of transmission capacity costs in the EU/EFTA countries has decreased from 47% of total expenditure to 43% (as in 2014). The proportion of salary costs has increased (in line with the rise in the number of staff as documented in Section 7.1) from 19 to 29%. The proportions of remaining costs have declined slightly.

[2] This includes those of the current 28 EU countries that submitted data, plus Iceland, Norway and Switzerland.

7.5 Expenditure by network level

GÉANT partner NRENs differ widely in terms of which network levels they specifically fund from their budget and how they account for those levels. This makes it difficult to effectively compare NREN budgets.

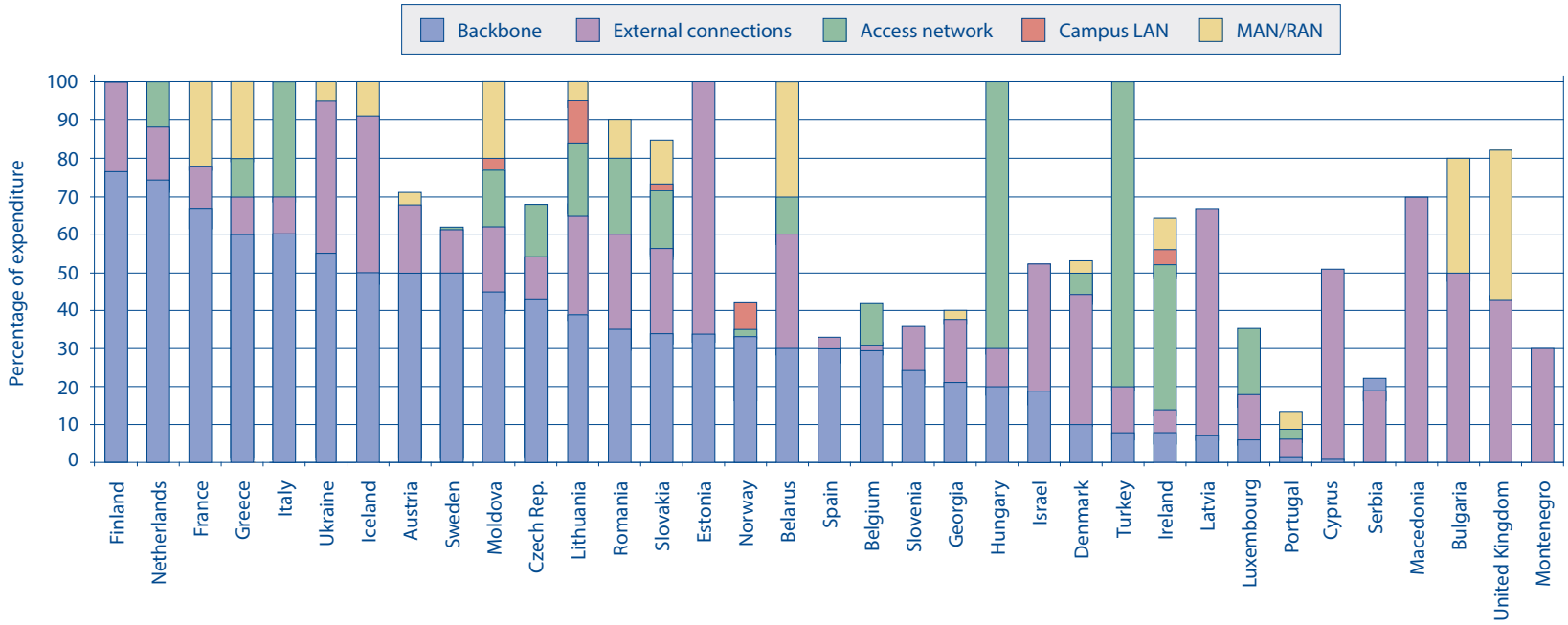
Although most NRENs pay for their external connections, the budget proportion actually spent on this network level differs widely from country to country.

NRENs also differ in how they account for their expenditure. HEAnet (Ireland) reports that it spends 6% of its budget on external connections. The reason why this figure seems unusually low is explained by the fact that HEAnet's most expensive external connection – i.e. to GÉANT – is regarded as part of the core infrastructure, not as part of the external connections. In the case of UNINETT (Norway), the external connections are not funded through the NREN budget.

Expenditure on other network levels also differs widely. In some GÉANT partner countries, metropolitan area networks (MANs) and regional area networks (RANs) are financed under the NREN budget. In other countries, this is not the case.

These disparities in expenditure and accounting methods highlight the complexity of comparing NREN budgets, as illustrated by Graph 7.5.1. Note that the combined expenditures on the five network levels do not necessarily constitute 100% of the NREN's budget. This can be due to differences in the NRENs' accounting methods or because the NRENs also spend money on items that are not (directly) network-related.

Graph 7.5.1 – Expenditure by network level, GÉANT countries



Appendix 1 Alphabetical list of NRENs

N.B.: For additional information on these NRENs, see the country entries at **compendium.geant.org**

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
AARNet	Australia's Academic and Research Network	Australia
ACOnet	Österreichisches akademisches Computernetz	Austria
AMRES	Akademska Mreza Srbije	Serbia
ANA	Rrjeti Akademik Shqiptar	Albania
Ankabut	UAE Advanced Network for Research and Education, Ankabut	United Arab Emirates
ARNES	Akademska in raziskovalna mreža Slovenije	Slovenia
ASNET-AM	Hayastani Akademiakan Gitahetazotakan Kompyuterayin Ts'ants'	Armenia
AzRena	Azərbaycan Elmi-Tədqiqat ve Təhsil Şəbəkələri Assosiasiyası	Azerbaijan
AzScienceNet	Azərbaycan Milli Elmlər Akademiyası Şəbəkəsi	Azerbaijan
BASNET	Setka Natsianalnai Akademii Nauk Belarusi	Belarus
BdREN	Bangladesh Education and Research Network	Bangladesh
Belnet	(NL): Het Belgische telematicaonderzoeksnetwerk, Belnet. (FR): Belnet, Réseau télématique belge de la recherche	Belgium
BREN	Sdruzhenie Bulgarska Izsledovatelska i Obrazovatelna Mrezha	Bulgaria
CANARIE	CANARIE Inc.	Canada
CARNet	Hrvatska akademska i istraživačka mreža - CARNet	Croatia

NREN acronym	NREN name	Country
CEDIA	Consorcio Ecuatoriano para el Desarrollo de Internet Avanzado	Ecuador
CERIST	Centre de Recherche sur l'Information Scientifique et Technique	Algeria
CERNET	China Education and Research Network - Zhōngguó jiàoyù hé kēyán jìsuànjī wang	China
CESNET	CESNET, zájmové sdružení právnických osob	Czech Republic
CSC / Funet	CSC - Tieteen tietotekniikan keskus Oy/ Funet	Finland
CSTNet	China Science and Technology Network - Zhōngguó kējī wǎng	China
CUDI	Corporación Universitaria para el desarrollo de Internet	Mexico
CYNET	Kypriako Erevnitiko Kai Akadimaiko Diktio	Cyprus
DeiC	Danish e-infrastructure Cooperation	Denmark
DFN	Deutsches Forschungsnetz	Germany
e-ARENA	Nacionalnaia Associacia issledovatelskih i nauchno-obrazovatelnih electronnih infrastructur "e-ARENA"	Russian Federation
EENet / HITSA	Eesti Hariduse ja Teaduse Andmesidevork / Hariduse Infotehnoloogia Sihtasutus – Information Technology Foundation for Education	Estonia
ErdemNET		Mongolia
ERNET	Education and Research Network	India

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
EUN	Shabaket El Gamaat ElMasria	Egypt
FCCN / FCT	Fundação para a Computação Científica Nacional / Fundação para a Ciência e a Tecnologia	Portugal
GARNET	Ghanaian Academic Research Network	Ghana
GARR	Consortium GARR (Gestione Ampliamento Rete Ricerca)	Italy
GRENA	Saqartvelos samecniero-saganmanatleblo kompiuteruli qselebis asociacia	Georgia
GRNET S.A.	Ethniko Diktio Ereynas & Technologias	Greece
HARNET	Hong Kong Academic and Research NETwork	Hong Kong
HEAnet	HEAnet Ltd.	Ireland
INHERENT-DIKTI	Indonesian Higher Education Network - Direktorat Jenderal Pendidikan Tinggi	Indonesia
INNOVA|RED		Argentina
Internet2		United States
IRANET/IPM	Markaze Tahghiqaate Fizike Nazari va Riaaziaat, IRANET	Iran (Islamic Republic of)
iRENALA	Research and Education Network for Academic and Learning Activities	Malagasy Republic
IUCC	Merkaz Hachishuvim haBain Universitai	Israel
Jisc / Janet		United Kingdom
JUNet	Shabakat Aljamiat Al Urduniyeh	Jordan

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
KazRENA	Qazaqstannyn' bilim beru zhane gylymi kompyuter zhelisin koldanushylar kauymdastygy / Asociaciya polzovateley nauchno obrazovatrlnoi kompyuternoi seti Kazakhstana	Kazakhstan
KENET	Kenya Education Network Trust	Kenya
KOREN	Korea Advanced Research Network	Korea, Republic of
KRENA-AKNET	Kyrgyzskaya Nauchnaya i Obrazovatel'naya Kompyuternaya Set-AKNET	Kyrgyzstan
KREONET	Korea Research Environment Open NETwork	Korea, Republic of
LEARN	Lanka Education and Research Network	Sri Lanka
LERN	Lebanon Education and Research Network	Lebanon
LITNET	Lietuvos mokslo ir studiju instituciju kompiuteriu tinklas	Lithuania
MAREN	Malawi Research and Education Network	Malawi
MARNet	Makedonska akademska nauchno-istrazhuvachka mrezha	Macedonia, Former Yugoslav Republic of
MARWAN	MARWAN- Réseau informatique national pour l' éducation, la formation et la recherche	Morocco
Ministry of Education and Science	Izglītības un zinātnes ministrija	Latvia
MoRENet	Mozambique Research and Education Network - Rede de Educação e Pesquisa de Moçambique	Mozambique

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
MREN	Crnogorska mreza za razvoj i nauku	Montenegro
MYREN	Rangkaian Pendidikan & Penyelidikan Malaysia	Malaysia
NASATI	National Agency for Science and Technology Information - Cục Thông tin Khoa học và Công nghệ Quốc gia	Vietnam
NCHC	National Center for High-performance Computing	Taiwan, PoC
ngNREN	Nigerian Research and Education NetworK	Nigeria
NiCT	Dokuritu Gyousei Houjin Jyouhou Tuusin Kenkyuu Kikou	Japan
NII	National Institute of Informatics	Japan
NIIF/HUNGARNET	Nemzeti Informacios Infrastruktura Fejlesztesi Intezet / Magyar Kutatasi es Oktatasi Halozati Egyesulet	Hungary
NREN	Nepal Research and Education Network	Nepal
OMREN		Oman
PERN	Pakistan Education & Research Network	Pakistan
PIONIER	Polski Internet Optyczny - Konsorcjum Akademickich Sieci Komputerowych i Centrów Komputerów Dużej Mocy	Poland
PREGINET	Philippine Research, Education, and Government Information Network	Philippines
Qatar Foundation		Qatar
RAAP	Red Académica Peruana	Peru

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
RAGIE	Red Avanzada Guatemalteca para la Investigación y Educación	Guatemala
RAICES	Red Avanzada de Investigación, Ciencia y Educación Salvadoreña	El Salvador
RAU	Red Académica Uruguaya	Uruguay
REACCIUN	Red Académica de Centros de Investigación y Universidades Nacionales	Venezuela
REANNZ	Research and Education Advanced Network New Zealand Limited	New Zealand
RedCONARE	Red Consejo Nacional de Rectores	Costa Rica
RedCyT	Red Científica y Tecnológica - Panamá	Panama
RedIRIS	RedIRIS	Spain
RedUNIV		Cuba
RENAM	Asociatia Obsteasca RENAM	Moldova, Republic Of
RENATA	Corporación Red Nacional Académica de Tecnología Avanzada - RENATA	Colombia
RENATER	Réseau national de télécommunications pour la technologie, l'enseignement et la recherche	France
RENU	Research and Education Network of Uganda	Uganda
RESTENA	Fondation RESTENA, Réseau Téléinformatique de l'Education Nationale et de la Recherche	Luxembourg
REUNA	Red Universitaria Nacional	Chile

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
RHnet	Rannsókna- og háskólanet Íslands hf (RHnet)	Iceland
RITER	Réseau Ivoirien de Télécommunications pour l'Enseignement et la Recherche	Ivory Coast
RNP	Rede Nactional de Ensino e Pesquisa	Brazil
RNU	Réseau National Universitaire Tunisien	Tunisia
RoEduNet	Agentia de Administrare a Retelei Nationale de Informatica pentru Educatie si Cercetare — 'RoEduNet'	Romania
RUNNET	Russian University Network - Federal'naya universitetskaya komp'yuternaya set' Rossii	Russia
SANET	Združenie používateľov slovenskej akademickej dátovej siete — SANET	Slovakia (Slovak Republic)
SANReN	South African National Research Network	South Africa
SARInet	Saudi Academic Research and Innovation Network	Saudi Arabia
SARNET	Akademska i istraživačka mreža Republike Srpske	Bosnia/ Herzegovina
SigmaNet	SigmaNet, Latvijas Universitātes Matemātikas un Informātikas institūta Akadēmiskā tīkla laboratorija	Latvia
SINET	Science Information Network	Japan
SingAREN	Singapore Advanced Research and Education Network (SingAREN)	Singapore
SnRER	Réseau National pour l'Enseignement Supérieur et la Recherche au Sénégal	Senegal

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
SomaliREN		Somalia
SudREN	Shabakt Albahth Alilmi wa AlTaaaleem AlSudania	Sudan
SUNET	Det svenska universitetsdatornätet SUNET	Sweden
SURFnet		Netherlands
SWITCH		Switzerland
TARENA	Tajik Academic, Research and Educational Network Association	Tajikistan
TENET	Tertiary Education and Research Network of South Africa	South Africa
TERNET	Tanzania Education and Research Network	Tanzania, United Republic Of
ThaiREN	Šmākhm kherụ̄x k̄hāy thịy pheụ̄x kār ṣ̄ụkṣ̄'ā wicạy	Thailand
TTRENT	Trinidad and Tobago Research and Education Network	Trinidad and Tobago
TuRENA	Türkmenistanyň milli ylym-bilim tory	Turkmenistan
TWAREN	TaiWan Advanced Research & Education Network	Taiwan, PoC
UARNet	Derzavne pidpryemstvo naukovo-telekomunikacijnyj centr "Ukrainska akademichna i doslidnytska mereza" IFKS NAN Ukrainy	Ukraine
ULAKBIM	Ulusal Akademik Ag ve Bilgi Merkezi	Turkey
UniNet		Thailand
UNINETT	UNINETT AS	Norway
UoM/RicerkaNet	Is-Servizzi tal-IT, L-Università ta' Malta/RiċerkaNet	Malta

Alphabetical list of NRENs – Continued

NREN acronym	NREN name	Country
URAN	Asociacija Korystuvachiv Ukrainskoji Naukovo-Osvitnioji Telekomunikacijnoji Merezhi	Ukraine
UzSciNet	O'zbek ilmiy va o'quv tamog'i	Uzbekistan
ZAMREN		Zambia

APPENDIX 2 Glossary of terms

Terms not listed in this glossary are either explained in the main text or presumed to be commonly understood.

AAI	Authentication and Authorisation Infrastructure: a term used for systems that support the process of determining both (1) whether users are who they declare themselves to be (authentication) and (2) that they have the appropriate rights or privileges necessary to access a resource (authorisation).
AARC	AARC is an EC funded project that aims to develop and pilot an integrated cross-discipline authentication and authorisation framework, built on existing AAIs and on production federated infrastructures
APAN	Asia-Pacific Advanced Network: APAN provides an advanced networking environment for the research and education community in the Asia-Pacific region and promotes global collaboration. For further information, see **http://www.apan.net/**.
APN	Access Point Name: a computer protocol that typically allows a user's computer to access the Internet using the mobile phone network.
ASREN	Arab States Research and Education Network.
AUP	Acceptable Use Policy
Bandwidth on Demand (BoD)	A data communication technique for providing additional capacity on a link, as necessary, to accommodate bursts in data traffic, a videoconference, or other special requirements.
bit or b	Binary digit: the smallest unit of data in a computer. In this *Compendium*: kilobit (kb), Megabit (Mb), Gigabit (Gb), Terabit (Tb), Pb (Petabit).
Byte or B	8 bits. In this *Compendium*: kB (kilobyte) MB (Megabyte), GB (Gigabyte), TB (Terabyte), PB (Petabyte).
CA	Certification/Certificate Authority
CA/Browsert	
Forum	A voluntary group of certification authorities (CAs), vendors of Internet browser software, and suppliers of other applications that use digital certificates for SSL/TLS and code signing.
ccTLD	Country-code Top-Level Domains: Internet Top-Level Domains (TLDs) are geographically specific and can be assigned to a dependent territory in addition to a country.

CLARA	Cooperación Latino Americana de Redes Avanzadas (= Latin American Cooperation of Advanced Networks): an international organisation whose aim is to interconnect Latin America's academic computer networks. For more information, see http://www.redclara.net/.
confederation	A federation formed by multiple independent federations with a common purpose. An example in the NREN community is the European eduroam Confederation, which unites country-level eduroam federations.
congestion index	A measure of congestion at different levels of network access. Developed by Mike Norris, formerly of HEAnet.
CRM	Customer Relations Management
CSIRT	Computer Security Incident Response Team.
Dark Fibre	Optic fibre cable that is not connected to transmission equipment by the vendor or owner of the cable and therefore has to be connected (i.e. 'lit') by the NREN or the client institution.
DDos	Distributed Denial of Service (DDoS) is a type of DOS attack where multiple compromised systems are used to target a single system causing a Denial of Service (DoS) attack.
DNSSEC	The Domain Name System Security Extensions (DNSSEC) is a set of extensions to DNS which provide to DNS clients (resolvers) origin authentication of DNS data, authenticated denial of existence, and data integrity, but not availability or confidentiality.
DWDM	Dense Wavelength-Division Multiplexing: in fibre-optic communications, a technology that uses multiple wavelengths of light to multiplex signals in a single optical fibre.
E.164	The ITU recommendation that defines the international public telecommunication numbering plan used in the PSTN and some other data networks.
EaPConnect	Eastern Partnership project that aims to establish and operate a high-capacity broadband internet network for research and education (R&E) across six countries: Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine
EC	European Commission
eduGAIN	The eduGAIN service enables the trustworthy exchange of information related to identity, authentication and authorisation between federations (in the GÉANT area and beyond).
eduroam®	education roaming service: provides a secure international roaming service to users in the international research and education community. It allows a user visiting another institution that is connected to eduroam to log on to the WLAN using the same credentials he/she would use if he/she were at his/her home institution.

ENUM	E.164 NUmber Mapping, a suite of protocols to unify the telephone system with the Internet
EU	European Union
EUGridPMA	The international organisation that coordinates the trust fabric for e-Science grid authentication in Europe
EUMEDCONNECT	high-capacity dedicated internet network for the research and education communities across the eastern Mediterranean region
FIM technologies	Technologies used for Federated Identity Management
FTE	Full-Time Equivalent
GDS	Global Dialling Scheme: a hierarchy of video-conference gatekeepers that support the mapping of a telephone number format to access MCUs and VC end-points worldwide.
GN4-1	The first phase of the Multi-Gigabit European Research and Education Network and Associated Services (GN4) project of the European Community's Horizon 2020 research and innovation programme. It succeeds the GN3plus project. It operates and develops the GÉANT network.
Grid computing	Applying the resources of many computers in a network to a single problem.
Identity Management System	IdM: a system that combines technologies and policies to allow institutions to store users' personal information and keep it up to date. An IdM is the first step to providing AAI (see above) for a local or federated environment.
interfederate	Exchanging of metadata by two or more federations to allow members within different federations to connect via a federated access management exchange.
IP	Internet Protocol: the method whereby data, in the form of packets, is transmitted over a network.
IPR	Intellectual property rights
IPv4	Internet Protocol version 4: the fourth iteration and first widely deployed implementation of the Internet Protocol. IPv4 supports 32-bit addressing and is the dominant Internet-layer protocol.
IPv6	The latest generation of the Internet Protocol (designated as the successor to IPv4) with 128-bit addressing as its most significant feature.
IRU	Indefeasible Right to Use: the granting of temporary ownership of a fibre-optic cable, allowing the unencumbered use of DWDM (see above) technology to maximize the capacity of the link.
ISCD Classification	International Standard Classification of Education developed by UNESCO

Lambda	An individual optical wavelength.
Lightpath	A dedicated point-to-point optical connection created through the use of wavelengths in an optical network, to provide guaranteed service levels for demanding applications bypassing the shared IP network.
MAN	Metropolitan Area Network: covers a geographical region such as a city. This term is often used interchangeably with Regional Area Network (RAN), which generally covers a wider geographic area.
MCU	Multi-point Conferencing Unit: used to interconnect multiple video-conferencing (VC) end-points. An MCU is also able to translate between different video formats, including SD (standard definition) and HD (high definition), in order to provide an optimized viewing experience for each VC unit connected.
MPLS	Multiprotocol Label Switching (MPLS) is a protocol for speeding up and shaping network traffic flows.
NaaS	Network as a Service: creates dynamic bandwidth reservation capabilities for cloud users.
NAT	Network Address Translation.
Network Function virtualisation	The process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network
NOC	Network Operations Centre: a place from which a network is supervised, monitored, and maintained.
NORDUnet	An international collaboration between the Nordic NRENs. It interconnects those networks with the worldwide network for research and education, as well as with the general purpose Internet. NORDUnet is a member of GÉANT
NREN	National Research and Education Network (May also refer to the operator of such a network.)
NRENUM.NET	NRENum.net - end-user ENUM service run by GÉANT and participating NRENs (National Research and Education Networking organisations.
OpenSSL	OpenSSL is an open source tool for using the Secure Socket Layer (SSL) and Transport Layer Security (TLS) protocols for Web authentication.
OTN GMPLS	Version of MPLS suitable for Optical Transport Networks
PKI	Public Key Infrastructure: enables the use of encryption and digital signature services across a wide variety of applications.
PoP	Point of Presence: the location of an Internet access point.
PSTN	Public Switched Telephone Network: the traditional circuit-switched telephony service using dedicated circuits for the duration of a call.

PSTN	The public switched telephone network (PSTN) is the aggregate of the world's circuit-switched telephone networks that are operated by national, regional, or local telephony operators, providing infrastructure and services for public telecommunication.
RAN	Regional Area Network: covers a wider geographic area than a Metropolitan Area Network (MAN, see above).
SAML	Security Assertion Markup Language: a fundamental component of federated identity and access management systems.
SDN	Software-Defined Networking: a method that allows the creation of virtual networks.
SHA-1	SHA1 (Secure Hash Algorithm 1) - a message digest algorithm which takes as input a message of arbitrary length and produces as output a 160-bit 'fingerprint'.
SIP	Session Initiation Protocol: an IETF-defined signalling protocol widely used for controlling communication sessions such as voice and video calls over Internet Protocol (IP).
SIP	The Session Initiation Protocol (SIP) is a communications protocol for signaling and controlling multimedia communication sessions.
SSL/TLS	Transport Layer Security (TLS) and its predecessor, Secure Sockets Layer (SSL), both of which are frequently referred to as 'SSL', are cryptographic protocols that provide communications security over a computer network.
TCP	Transmission Control Protocol: one of the core protocols of the Internet Protocol suite.
TCS	Trusted Certificate Service: offers a variety of digital certificates for server, personal and e-Science use at research and educational institutions served by participating National Research and Education Networks (NRENs, see above).
UbuntuNet Alliance	A not-for-profit association of NRENs that aims to provide a research and education backbone network for Africa.
University	Institution providing courses of education equivalent to ISCED levels 5 and 6. 'Higher/further education' is equivalent to ISCED level 4; 'secondary education' corresponds to ISCED levels 2 and 3, and 'primary education' to ISCED level 1. For more information on ISCED levels, see **http://www.uis.unesco.org**
VoIP	Voice-over-Internet Protocol: a protocol for transmitting voice via the Internet or other packet-switched networks. VoIP is often used to refer to the actual transmission of voice (rather than the protocol implementing it). This concept is also referred to as IP telephony, Internet telephony, voice over broadband, broadband telephony, or broadband phone.

VPN	Virtual Private Network: a network that uses a public infrastructure such as the Internet to provide remote offices or individual users with secure access to their organisation's network. A virtual private network can be contrasted with an expensive system of owned or leased lines that can only be used by one organization. The goal of a VPN is to provide the organization with the same capabilities, but at a much lower cost.
WACREN	West- and Central African Research and Education Networks.
WebRTC	Web Real-Time Communication supports browser-to-browser applications for voice calling, video chat, and P2P file sharing without the need of either internal or external plugins.

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