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Deliverable DN5.0.3: Final EARNEST Report

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Abstract

This deliverable is the final report on the EARNEST foresight study. The EARNEST foresight study is activity NA5 of the GN2 project.

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0 Executive Summary

Since the beginning of the Internet, research and education networks, which provide connectivity and services to researchers and to teachers and students in universities and other institutions of higher education, have been at the forefront of technological developments. Much of the network and service innovation happens there. Research and education networking organisations are a source of innovation and provide fast and widespread technology transfer to society and industry. Consequently, they are an important asset for economic growth and prosperity.

0.1 EARNEST

The EARNEST foresight study has looked at the expected development of research and education networking in Europe over the next 5-10 years. The study was carried out between March 2006 and November 2007. EARNEST was funded by the GN2 project, which also provides funding for the GÉANT2 network that interconnects Europe's national research and education networks.

The aim of EARNEST was to provide input for initiatives that will help to keep the evolution of European research and education networking at the forefront of worldwide developments and enhance the competitiveness of the European Research Area. EARNEST has prepared the ground for the planning of the development of research and education networking infrastructure and services after the completion of the GN2 project, at the local, national, European and intercontinental level.

The EARNEST work has focused on seven study areas: researchers' requirements, technical issues, campus issues, economic issues, geographic issues, organisation and governance issues, and requirements of users in schools, the healthcare sector, and the arts, humanities and social sciences. Reports have been published on each of these sub-studies, as well as an additional report on regulatory issues related to telecommunications and data networks. The EARNEST study is rounded off with the current Summary Report.

The main text of the report has been kept short, in order to enable the reader to get an overview of the most interesting results of the EARNEST study in a relatively short time. For more details about the findings and for the background and motivations of the recommendations, the reader is referred to the appendices and to the EARNEST sub-study reports.

0.2 SERENATE and beyond

EARNEST can be seen as the successor of the successful study that was carried out in the SERENATE project (2002-2003). The SERENATE Summary Report has been very influential in the planning and development of research and education networking in Europe in subsequent years. When that report was published in December 2003, research and education networking was on the brink of a major paradigm shift, related to the introduction of 'self-owned' network infrastructures and hybrid IP-optical network architectures.

SERENATE realised that it was an important challenge for research and education networking organisations to continue serving at the same time researchers, teachers and students with modest network and service requirements as well as the most demanding users, whose requirements need special arrangements by research and education networkers at European, national and local level. It recommended using the opportunities offered by 'dark fibre' to create hybrid network architectures. Such networks offer classic routed IP traffic to cater for the needs and the 'many-to-many' traffic patters of users with low bandwidth requirements; at the same time they offer switched optical paths to meet the needs of the high-end users and their 'few-to-few' traffic patterns. This recommendation has been acted upon by the European research and education networking community, to a much greater extent and much faster than the authors of the SERENATE report had expected.

SERENATE predicted that there would be a growing demand for researchers to be able to access networks and their own usual set of network and information services wherever they happened to be. It recommended setting up a major project to implement and validate a coherent pan-European Authentication and Authorisation Infrastructure. These two areas are currently addressed by the eduroam and eduGAIN initiatives.

SERENATE found evidence that by 2003 campus networks were often the weakest link in the chain of end-to-end service provision. EARNEST has revisited this area, and found little evidence that the 'campus bottleneck' in terms of network capacity still exists.

Some of the SERENATE recommendations have not been acted upon by the relevant stakeholders. Unfortunately, many of them relate to the problem of the digital divide, i.e., the disparity in the infrastructures and services available to researchers and teachers in different parts of Europe. Therefore, EARNEST has paid a significant amount of attention to this problem area, and has formulated a number of recommendations.

SERENATE's final recommendation was directed at the European Council and the European Parliament. They were asked to ensure that the European Commission would continue to play a significant role in enabling Europe's research and education network facilities to remain competitive at the global level. EARNEST is content to note that research and education networking – and research infrastructures in general – have come higher on the political agenda since 2003.

0.3 Impact on research

EARNEST has made an assessment of the impact that research and education networking has had in recent years on the efficiency and working methods of research and higher education in Europe.

In a large-scale EARNEST survey of researchers and academic teachers, almost all respondents testified to the very positive effect of networks and network-related services on their work. The largest impact appears to be related to the benefits of easier access to publications and other information via digital libraries and repositories. There is also a positive effect on the growth of interdisciplinary research.

Looking at the future, researchers and academic teachers expect that networks and network-related services will facilitate a further substantial growth in collaboration between researchers.

0.4 Challenges for the next 5-10 years

Historically, leaders of research and education networking in Europe had to give priority to dealing with two major challenges: economic issues and the fast developments in technologies. These challenges remain, and have taken on a new guise as a consequence of the revolutionary changes in the past years. In addition, there are a number of new challenges, such as the shift in emphasis from providing connectivity to providing network-related services, the wider deployment and use of existing services, the integration of international, national and local research networking, and more intensive collaboration between national research and education networking organisations. Matters related to the digital and geographic divides also remain an important challenge.

0.5 Technical challenges

The fundamental changes in recent years in the way that research and education networks and services are provided mean that new technologies are being used that bring new technical challenges. EARNEST has conducted a detailed and broad study of relevant technical issues, focusing on four main areas of investigation: transmission technologies, control-plane technologies, operation and performance issues, and middleware.

In each of these areas there are a number of technical issues that require further investigation, development and tests by the European research and education networking community.

0.6 Wider deployment of services

In recent years, perhaps too little attention has been paid to the challenge to ensure that services that are available to researchers, teachers and students in principle, are actually also available in practice, and are being used efficiently and effectively. Indeed, EARNEST has found that many beneficial services are being deployed and used to a much smaller extent than one would expect.

The underlying problems are related to technical issues and to matters of culture, resources and skills. The teams providing network connectivity and network-related services at the campus level in institutions play a crucial and increasingly important role. However, often the institutional IT support teams are understaffed, lack resources and training, and receive insufficient support from the highest management in the organisation. EARNEST makes a number of recommendations to address these problems.

0.7 Serving users

A cultural change in networking is taking place with the emphasis moving from providing connectivity to providing network-related services. This is a major challenge, not only for campus networkers but also for

research and education networking organisations at the national and European level. Research and education networks are forerunners in technological development and continuously introduce innovative technologies and services. Generally, research and education networking organisations are primarily technology driven, and are still in the process of becoming more demand-driven and service-oriented.

EARNEST makes a number of recommendations about ways to provide an adequate range of services in a better structured and managed manner.

Research and education networking organisations should pay special attention to user communities that have different working methods, constraints and needs than the research and higher-education communities that have been the dominant users of research and education networks for many years. EARNEST has studied three communities of this kind – schools, the healthcare sector, and the arts, humanities and social sciences – and makes a number of recommendations based on its investigations.

0.8 Integration

The organisational structure of research and education networking in Europe has been key to its success. Infrastructure and services are provided by technicians at the local (campus), national and international level. This modular structure was particularly suited when IP-based connectivity was the main service offered and there were not many network-related services provided to end-users. Various technical developments and the growth of the number of network-related services mean that the international, national and local research networking communities cannot remain rather separate worlds any longer.

Closer collaboration between networkers at national and at local level is needed in the area of policies, service provision, performance optimisation and knowledge transfer. The same holds for the collaboration between the national research and education networking organisations from different European countries. EARNEST has formulated a number of recommendations to promote collaboration between network engineers and organisations, as well as integration of service provision.

0.9 Economic challenges

Increased competition in the telecommunications markets and access to ‘dark fibre’ mean that also in economic terms research and education networking organisations have entered a new era. This also brings a number of new economic challenges, while not all earlier problems have gone away.

At the European level, the changing economic environment makes it necessary to adapt the model for sharing the costs of GÉANT2 (and its successor network) among the national research and education networking organisations from time to time, taking into account both solidarity and a fair balance of sharing costs. Nationally, the funding models of national research and education networking organisations and infrastructures appear to be quite stable, although very different in different European countries. If connected institutions are charged for the connectivity and services provided by the national research and education networking organisations, this should be done in such a way that it is not a disincentive for innovation. Finally, it is important that national research and education networking organisations plan and budget over a period of several years, in line with best practice in the planning of major infrastructure projects.

0.10 Digital and geographic divides

EARNEST has found that the digital divide that was described by SERENATE has not disappeared. Actually, there are signs that the divide in research and education networking between different parts of Europe may be widening. In addition, EARNEST has studied a new phenomenon, caused by the direct relation between distance and costs in optical networks, which can be referred to as the 'geographic divide'. Both challenges need to be addressed at the political level, and EARNEST makes a number of recommendations addressed to the European Union and national governments.

1 Introduction

The research and higher-education community played a key role in the creation of the Internet. Today, the networks that provide connectivity and services to researchers and to teachers and students in universities and other institutions of higher education still form a distinctive part of the entire Internet. These ***research and education networks*** are at the forefront of technological developments, and much of the network and service innovation happens there. They offer new technologies, advanced services and very high network capacities that are not available in the commercial Internet.

Research and education networking organisations are a source of innovation and provide fast and widespread technology transfer to society and industry. Consequently, they are an important asset for economic growth and prosperity.

In many respects, Europe has become a world leader in research and education networking. One of the success factors has been the way in which Europe has organised itself. The organisational model of a single national research and education networking organisation per country with co-ordination and collaboration at the continental level has been key to success. That model, which is explained in a bit more detail below, is now being copied in other world regions.

Closest to the researchers, teachers and students is the Local Area Network (LAN) at the site (for example, the campus) where they work. This level is the responsibility of the institution: the research institute, university, school etc. The IT staff that provide network connectivity and related services at the campus level play a crucial role in the networking chain.

The next level is the national network that connects the local networks of the research institutes and institutions of higher education in a country. This level is the responsibility of the National Research and Education Networking organisation (the NREN) of that country.

In some countries, campus networks are not connected directly to the national research network, but via Metropolitan Area Networks (MANs) or regional networks.

The NRENs in Europe have created two pan-European organisations:

- *DANTE (Delivery of Advanced Network Technology to Europe Ltd.) is the not-for-profit company, owned by NRENs in Europe, whose mission is to organise, manage and provide international advanced data network services for the research community.*
- *TERENA (the Trans-European Research and Education Networking Association) fosters new initiatives, supports joint work in developing, evaluating, testing and integrating new technologies, organises conferences and workshops, promotes knowledge transfer to less advanced networking organisations, and represents the common interests and opinions of its membership.*

The third level is provided by the GÉANT2 network, which interconnects Europe's national research and education networks. GÉANT2 is managed by DANTE on behalf of the NRENs.

Connectivity to research and education networks in other continents is provided by DANTE, while some NRENs have their own links to key destinations. The same holds for connectivity to the commercial Internet: peering (i.e., exchange of traffic) with the commercial Internet takes place both at the NREN level and, to a limited extent, at the GÉANT2 level.

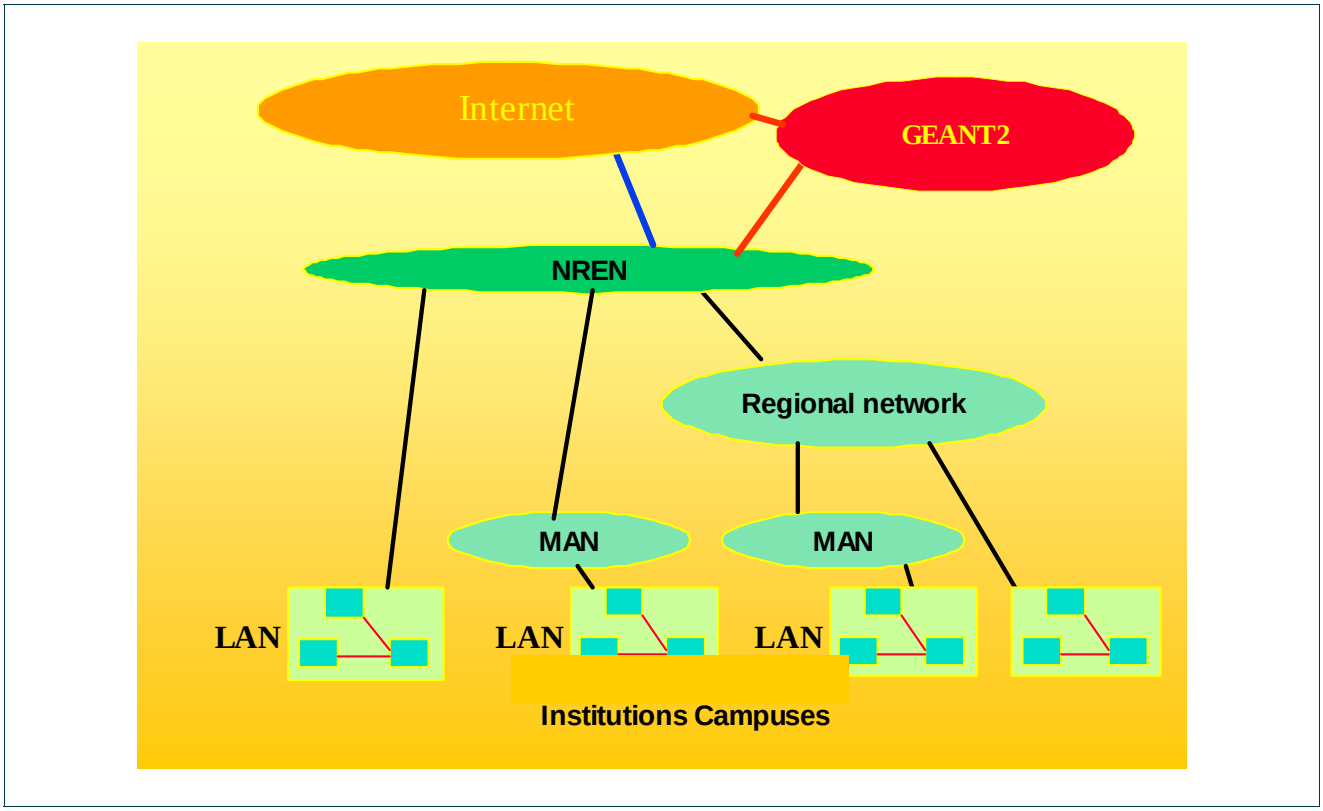

Figure 1.1: Structure of research and education networks in Europe

The EARNEST (Education And Research Networking Evolution Study) foresight study has looked at the expected development of research and education networking in Europe over the next 5-10 years. The study was carried out between March 2006 and November 2007. EARNEST was funded by the European Union through the GN2 project, which also provides funding for the GÉANT2 network. More information about the structure and management of the EARNEST study and the organisations and people involved can be found in Appendix A.

The aim of EARNEST was to provide input for initiatives that will help to keep the evolution of European research and education networking at the forefront of worldwide developments and enhance the competitiveness of the European Research Area. EARNEST has prepared the ground for the planning of the development of research and education networking infrastructure and services after the completion of the GN2 project, at the local, national, European and intercontinental level.

EARNEST can be seen as the successor of the very successful study that was carried out in the SERENATE (Study into European Research and Education Networking As Targeted by *e*Europe) project in the period from May 2002 until December 2003. The results of the SERENATE study, and in particular the recommendations in its Summary Report, have been very influential in the planning and development of research and education networking in Europe in subsequent years.

After an initial preparatory phase, the EARNEST work has focused on seven study areas:

- researchers' requirements;
- technical issues;
- campus issues;
- economic issues;
- geographic issues;
- organisation and governance issues;
- requirements of users in schools, the healthcare sector, and the arts, humanities and social sciences.

Reports have been published on each of these EARNEST sub-studies, as well as an additional report on regulatory issues related to telecommunications and data networks. The EARNEST study is rounded off with the current Summary Report.

Summaries of the major findings in the sub-studies can be found in the appendices to this report. The main text of the report has been kept short, and focuses on the most important trends and on recommendations to stakeholders. That will enable the reader to get an overview of the most interesting results of the EARNEST study in a relatively short time. For more details about the findings and for the background and motivations of the recommendations, the reader is referred to the appendices and to the EARNEST sub-study reports.

2 SERENATE and beyond

Before discussing the major findings and recommendations from the EARNEST study, it is useful to revisit the recommendations made by the predecessor study, SERENATE, and to consider to what extent those recommendations have been acted upon. As mentioned in the previous section, the SERENATE Summary Report has been very influential in the planning and development of research and education networking in Europe in subsequent years. In hindsight we can say that when that report was published in December 2003, research and education networking was on the brink of a major paradigm shift, related to the introduction of 'self-owned' networks and hybrid IP-optical network architectures. The two ingredients of that change were both major themes in the SERENATE report.

The first development was the result of the liberalisation of the telecommunications markets, which was implemented in most European countries towards the end of the last century. SERENATE described how in the years 1996-2001 the liberalisation had dramatically reduced the prices that Europe's research and education networking organisations had to pay for national and international connectivity. However, at the same time the price reductions opened a 'digital divide' between the parts of Europe with well-functioning markets and the parts where liberalisation had not been implemented to the extent that would produce the full benefits of a truly competitive telecommunications market.

In addition, market liberalisation created a new opportunity for research and education networking organisations, namely the option that organisations 'own' the telecommunications infrastructure that they use. The key word here is 'dark fibre', defined by SERENATE as optical fibre dedicated to use by a single organisation – in our case a research and education networking organisation – where the organisation itself is responsible for attaching the transmission equipment to 'light' the fibre. SERENATE predicted that 'dark fibre' could bring substantial benefits to research and education networking organisations, because of potential reductions of the cost of network capacity and because of the freedom to use different transmission technologies.

Those benefits of 'dark fibre' were closely related to the second major theme of the SERENATE report. The report described how the user community of research and education networks could be divided into three categories. There were very many researchers, teachers and students whose network use was limited to relatively simple applications and whose individual bandwidth needs could be met satisfactorily by the equivalent of an ADSL connection (typically 512 kb/s). A smaller number of users was involved in applications that require streaming media or the use of Virtual Private Networks; their bandwidth requirements exceeded ADSL and extended up to Gigabit connections. And finally there was a third category of users, who worked on

special scientific applications such as Grid computing and virtual presence; they needed network capacities of 1 Gb/s or more. Four years later, the networking needs of each of these groups may have shifted somewhat, but the categorisation is still a very valid way to consider the needs of network users.

SERENATE realised that it was an important challenge for research and education networking organisations to continue serving the needs of all three categories of users. It recommended using the opportunities offered by 'dark fibre' to create 'hybrid' network architectures. Such networks offer classic routed IP traffic to cater for the needs and the 'many-to-many' traffic patterns of users with low bandwidth requirements; at the same time they offer switched optical paths to meet the needs of the high-end users and their 'few-to-few' traffic patterns.

This recommendation has been acted upon by the European research and education networking community, to a much greater extent and also much faster than the authors of the SERENATE report had expected. In December 2003, SERENATE merely recommended to reflect on the rapid move to optical transmission technologies and to explore the use of hybrid network architectures. However, the GÉANT2 network, which was planned in the second half of 2004 and rolled out in 2005, was already based largely on 'dark fibre' and offered optical paths in addition to classic IP connectivity. In the same period, many national research and education networks made the same transition.

Another main topic in the SERENATE study was the finding that the expectations of network users in the research and education community had evolved beyond the provision of pure bandwidth towards the supply of more sophisticated services. There were concerns about security, privacy and confidentiality. SERENATE predicted a strong demand for authentication and authorisation services. It stated that there would be a growing demand for researchers to be able to access networks and their own usual set of network and information services wherever they happened to be.

That last demand has been addressed by eduroam (Education Roaming). eduroam® offers researchers, teachers and students from institutions participating in the eduroam service easy access to wireless networks at other institutions that participate in the service, because they can use the same credentials as at their home institution. eduroam started as a pilot project under the umbrella of TERENA in 2003, with initially six countries participating. Since then, many more national research and education networking organisations have joined the service, and the technology has been developed further with support from the GN2 project. Since September 2007, the European top-level of the service is funded by the GN2 project.

Based on the perceived need for authentication and authorisation services in the research and education community, SERENATE recommended setting up a major project to implement and validate a coherent pan-European Authentication and Authorisation Infrastructure. Although perhaps at a smaller scale than envisaged by SERENATE, this challenge is taken up by the eduGAIN (Education GÉANT Authorisation Infrastructure) authentication and authorisation framework, which is being developed by the joint research activity on roaming and authentication in the GN2 project.

Campus issues were not a major topic in the SERENATE study. Nevertheless, SERENATE found evidence that after the large investments that had taken place in research and education networks at national and international level, by 2003 campus networks in Europe were often the weakest link in the chain of end-to-end service provision. Therefore, SERENATE asked universities and research institutes to ensure that their campus networks were appropriately resourced.

EARNEST has revisited this area, and neither the EARNEST study of researchers' requirements nor the study of campus issues found much evidence that the 'campus bottleneck' in terms of network capacity still exists. Anecdotal evidence suggests that in the last five years, local networks in many institutions in Europe have been substantially upgraded. Nevertheless, EARNEST found a significant number of other problems at the campus level, which are discussed elsewhere in this report.

Some of the SERENATE recommendations have not been acted upon by the relevant stakeholders. Unfortunately, many of them relate to the problem of the digital divide. In some parts of Europe, the problems related to imperfections of the telecommunications market and very limited access to 'dark fibre' persist. National governments and the institutions of the European Union have not taken the actions that SERENATE hoped for. Moreover, while SERENATE recommended the use of EU Structural Funds to finance investments in research and education networking, in many cases this still turns out to be too cumbersome to have any effect.

SERENATE's final recommendation was directed at the European Council and the European Parliament. They were asked to ensure that the European Commission would continue to play a significant role in enabling Europe's research and education network facilities to remain competitive at the global level. EARNEST is content to note that research and education networking - and e-Infrastructures and research infrastructures in general - have come higher on the political agenda since 2003. Research infrastructures are perhaps the most prominent priority in the European policies for research and technological development. Those infrastructures are all critically dependent on the availability of advanced networks and network-related services at local, national and pan-European level. As SERENATE concluded, there will be no successful European Research Area without the long-term commitment of adequate resources to the evolution of Europe's research and education networking.

3 Past and current impact on research

Being a foresight study, EARNEST looked most of all to the future. However, EARNEST also made an assessment of the impact that research and education networking has had in recent years on the efficiency and working methods of research and higher education in Europe.

The EARNEST study of researchers' requirements conducted a large-scale survey of the current use of networks and related services by researchers and academic teachers in Europe, and of researchers' current and future needs. Responses were received from almost 4,400 scientists and scholars all over Europe, covering a broad range of disciplines. The response to the survey questionnaire was very high, which indicates that researchers understand and appreciate the importance of networks and related services as crucial instruments for their work. The large number of responses made it possible to derive some meaningful statistics about the use of those tools and the needs of researchers.

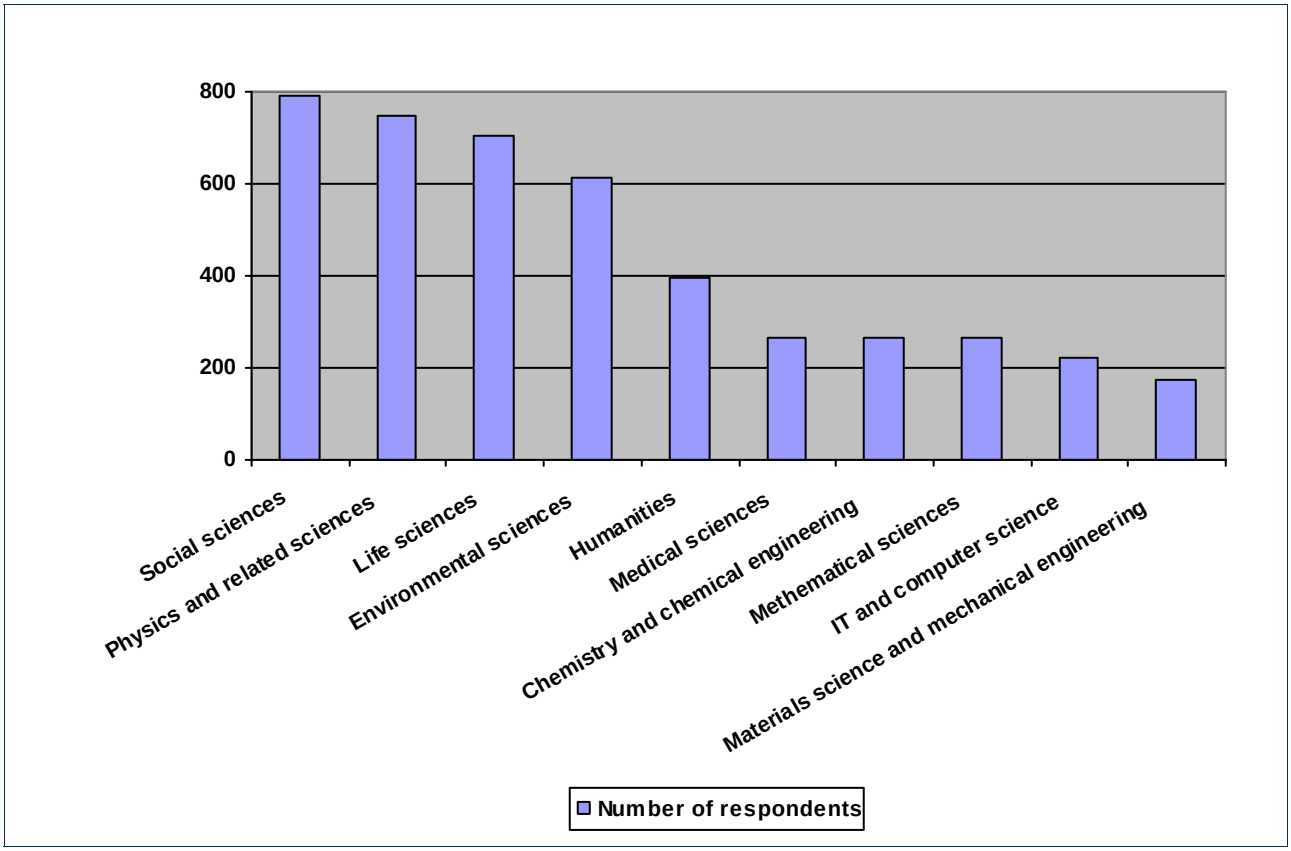

Figure 3.1: Respondents to EARNEST survey of researchers and academic teachers

Very many respondents testified to the positive effect that the use of networks and network-related services had had in recent years on the efficiency and methodology of their research work. The largest impact appears to be related to the benefits of easier access to publications and other information via digital libraries and repositories. Almost 98% of researchers stated that access to publications of others had become much easier; two thirds felt that the efficiency of access to publications had increased by a factor of 10 or more. Similar figures were given for the access to other information needed for research: 36% felt that the impact of network-related services had been positive, and 62% qualified that impact as very positive.

An interesting finding was that network-related services play an important role in the growth of multidisciplinary research. Almost 92% of respondents reported that in recent years network-related services had had a positive or very positive impact on access to new fields of research. Many comments from respondents related to the increase in their ability to keep up-to-date with the latest developments and research in their own field. However, a large number of responses also highlighted how easy it had become to start looking into other fields and enhancing the interdisciplinary nature of research.

It is well-known that there have been enormous developments in the area of digital libraries and repositories in recent years. However, most research and education networking organisations are not directly involved. They tend to concentrate on the provision of connectivity and network services, and the research and education networking community and the community of content providers are often two separate worlds. For a very large majority of researchers and academic teachers, the most important positive impact of networks and network-related services is in the more efficient access to scientific content, and hence it might be advisable to establish closer links between these two worlds.

The research and education networking community should establish closer links with the world of digital libraries and other content providers.

Researchers are not only users but also producers of scientific information. About 75% of survey respondents felt that network-related services had had a positive or very positive impact in recent years on the rate at which they publish. Many comments related to the improvements in the submission and editorial processes. Electronic submission of manuscripts to periodicals has been a key factor accelerating publication speeds over the last decade. In addition, the wider editorial process has also improved as a result of network developments, because, for example, authors in different countries can collaborate much more easily and much more efficiently on joint publications. Finally, the Internet has created a much greater variety of publication channels for conference papers, working papers etc.

Survey respondents also commented on the improvements that network-related services had brought to the access to work-related non-scientific information. Examples are information about meetings and conferences (where network-related services have had a positive or very positive impact according to 93% of respondents) and information on funding opportunities for research (where the impact was qualified as positive or very positive by 71% of respondents).

For teaching in higher education, educational material is very important. More than 85% of respondents reported that network-related services had had a positive or very positive impact on the availability of that

material in recent years. The EARNEST study of the requirements of users in schools found similar positive reports in surveys of teachers in primary and secondary schools.

Looking at the future, researchers and academic teachers expect that networks and network-related services will facilitate a further substantial growth in collaboration between researchers. More than 82% of respondents expect to collaborate more with researchers abroad in the next decade, 73% expect to participate more in large collaborative projects, and 67% predict an increase of their collaboration with researchers in their own country. More than 60% of respondents expect that digital communications will replace travel to a certain extent over the next decade, but an increase in tele-working or distance-teaching is only predicted by a minority (45% and 35%, respectively).

In addition to improving the efficiency of research, networks and network-related services have also enabled completely new forms of scientific investigation that were simply impossible earlier, when networks had small capacities and a lack of guaranteed quality of service. Many respondents quoted well-known examples from 'big sciences' like high-energy physics and radio-astronomy, including the use of computational and data-storage Grids. However, new forms of research have also been enabled in the social sciences and the humanities, for example, by digital access to data bases and new, electronic collaboration tools.

Looking back, it is easy to see a number of scientific methods that are available today thanks to research and education networks and services, but that were not available ten years ago. It is much more difficult to predict such new opportunities when looking five or ten years ahead. Very few researchers and academic teachers were able to give an answer to the question what they would like to do using data networks for their research or teaching five years from now that they are not doing today, even when they were asked to ignore problems of technical or financial feasibility.

Interestingly, many of the responses to this question mentioned forms of network use – for example, videoconferencing, interactive exchange of data and results with colleagues, running tele-experiments, submitting and running jobs on supercomputers independent of their location – that are already possible today from a technical point of view. This illustrates one of the major findings of the EARNEST study: the fact that services and tools that are beneficial to scientific research and that should be available, are not actually being used to the extent that one would expect. We will come back to that problem area in the next sections.

4 A new priority: wider deployment of services

Historically, leaders of research and education networking in Europe had to give priority to dealing with two major challenges: coping with the limitations imposed by the economic context (in particular, the extremely high prices that had to be paid for connectivity, which put Europe at a disadvantage compared to, for example, the United States) and keeping up with other continents in the fast developments in networking and service technologies. As was explained in Section 2, by 2004-2005 a combination of regulatory, economic and technical developments led to a significant reduction of international and national connectivity prices in many locations in Europe, the opportunity for research and education networking organisations to 'own' their own fibre infrastructures, and the option to deploy hybrid IP-optical networks. This made it possible to introduce a new paradigm for European research and education networking, putting Europe at the forefront of worldwide developments. At the same time, European developers and technicians received much recognition from their counterparts in other continents because of their leading role. In the area of middleware, for example, Europe is recognised as a world leader in service development.

At the present time, EARNEST does not foresee a similar revolutionary change as SERENATE announced. However, this does not mean that there are no challenges anymore in the two fields that have always been priorities for European research and education networking.

Economic issues still remain. Models for paying the costs of networks and services continue to be an area of discussion because of different and sometimes contradictory aims; for example, the wish to give more influence to the end-users so as to better meet their current needs, while at the same time not introducing disincentives for innovation. The disparities between the prices of network infrastructure in different parts of Europe make cost-sharing for the pan-European research and education backbone network a challenging problem. The digital divide between different parts of Europe has not gone away. EARNEST has studied the underlying factors of the digital divide, which are much broader than only the imperfections of the telecommunications markets. In addition, in the world of 'dark fibre' networks a new divide is opening up that is closely related to geographic distances. All these issues will be discussed in Sections 6 and 9.

The paradigm shift described above has also brought new technical challenges that the research and education networking community needs to address. The move to optical networking and hybrid network architectures has confronted research and education networkers with new technical issues, for example, those related to monitoring and management of networks at the lower layers, and to automated provision of hybrid networks. The increasing mobility of researchers and students, and their growing use of facilities outside their own institution, create challenges for authentication and authorisation systems, which need more development,

standardised policies and more structured collaboration across Europe. In short, also at the present time there are a large number of technical challenges. Some of these will be discussed in Section 10.

In addition to the traditional challenges related to finance and technology, there is a third challenge that should receive much more attention from research and education networkers at local, national and European level than it has received in recent years, namely the challenge to ensure that services and tools that are available to researchers, teachers and students in principle, are actually also available to them in practice, and are being used efficiently and effectively. Indeed, EARNEST has found that many beneficial services are being deployed and used to a much smaller extent than one would expect. The reports on the EARNEST study of researchers' requirements and on the study of campus issues provide a number of examples.

A remarkable example is the use of videoconferencing, a service that was developed a number of years ago, and that is considered routine by network engineers. The large-scale EARNEST survey of researchers and academic teachers found that two thirds of them never participated in a videoconference, and only 4% of researchers use videoconferencing on a weekly basis. There are some differences between research disciplines, but even in IT and computer science 45% of researchers and academic teachers never use videoconferencing.

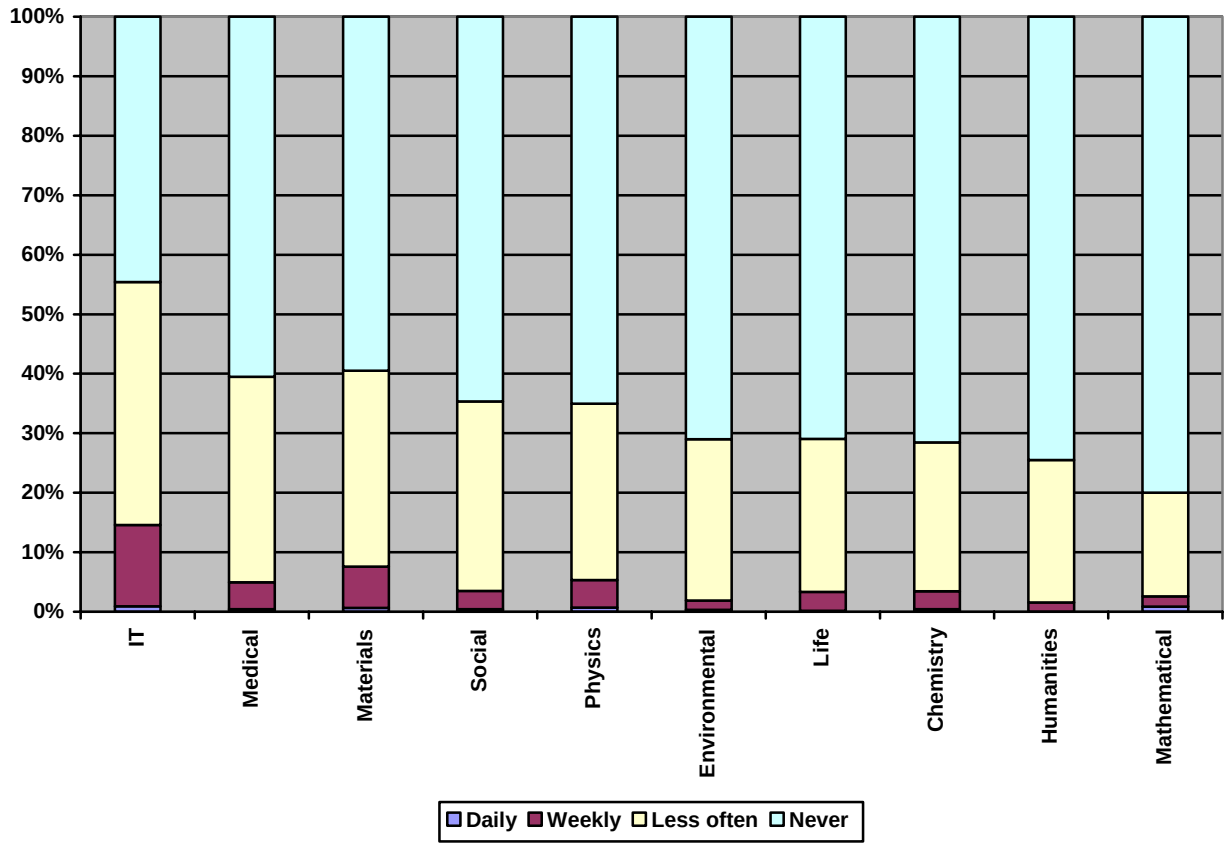

Figure 4.1: Use of videoconferencing

About one third of respondents who were currently not using videoconferencing felt that wider availability of facilities and resources would be the improvement that might encourage them to use the service. Others suggested that improvements in quality and speed, reduced costs, and better training in set-up and operation would be desirable.

More generally, 47% of researchers and academic teachers feel that they do not receive adequate training in network use that would improve the quality of their research or teaching. When a smaller number of researchers were interviewed in more depth in the second stage of the survey, many reported that they had received no training at all in the use of network-related tools and applications, and that there was no IT support staff available to help them.

The survey of researcher's requirements also showed that only a minority uses IP telephony, bandwidth reservation and encryption of data, and then only infrequently. When asked about their use of specific network-related tools, a significant number replied that they did not understand some of the terms used, implying that they were not aware of the availability of network services that are supposed to be commonly available.

The EARNEST study of campus issues has looked at a number of other services that also have a much smaller deployment than would be desirable, including multicast, IPv6 and Quality of Service.

There is a variety of reasons for the under-utilisation of network tools and services, depending on the local situation. Sometimes a service is available, but it is not publicised and many potential users do not know of its existence. Sometimes a service is available, but it is badly supported because the network support team is too small to support the service or there are no IT support staff members with the right skills. Sometimes it is technically feasible to offer a service, but it is not offered anyway, because the campus networkers know that they will be unable to cope with the demand for support. Sometimes a service cannot be offered because the network infrastructure is incorrectly configured, in some cases for questionable reasons of 'security'.

Some reasons are of a cultural nature. In many academic circles there is a culture of low expectations, which inhibits researchers and teachers from demanding new services. Sometimes the service providers at campus level have not adapted to their new role of offering services rather than only basic network connectivity, and sometimes there is a lack of customer focus in the organisation providing services.

The EARNEST reports, and in particular the reports on the two sub-studies quoted in this section, provide a number of recommendations for actions to address the under-utilisation of useful network-related tools and services. One of them is quoted below.

A cultural change in networking is taking place with the emphasis moving from providing connectivity to providing network-related services. To speed up this change of focus, and to address the under-utilisation of services, institutions should

- provide training and documentation for end-users to raise awareness of the available services and promote their use (for example, videoconferencing, multicast, video broadcasting, video on demand, IP telephony);
- provide support to users by teams that are adequately staffed and trained to keep up-to-date with fast-changing technologies.

5 Serving users

The cultural change mentioned in the previous section is indeed a major challenge, not only for campus networkers but also for research and education networking organisations at the national and international level. Research and education networking started in the infancy of data networks, and was created by visionary engineers. To this very day, research and education networks are forerunners in technological development and continuously introduce innovative technologies and services. Generally, research and education networking organisations are primarily technology-driven, and they are still in the process of becoming more demand-driven and service-oriented.

For national research and education networking organisations, meeting the demands of end-users and deploying services for them are complicated matters because the national organisation itself is not in direct contact with the researchers, teachers and students who use the services. The customers of national research and education networking organisations are first of all the connected institutions, and the communication of the NREN engineers is with the technicians at campus level rather than with the end-users.

The EARNEST reports point to a number of possible improvements in the way in which national research and education networking organisations serve the connected institutions. For example, Service Level Agreements may make the service provision more professional and measurable. As another example, knowledge transfer from national research and education networking organisations to IT service providers at campus level may help overcome the problems faced by local technicians.

NRENs should develop Service Level Definitions or Service Level Agreements in line with best practice.

NRENs should provide knowledge transfer to providers of network-related services on campus through documentation and training courses. They should promote regular meetings or working groups at national level that will enable the service providers at campus level to benefit from each other's expertise and experience.

Normally, a national research and education networking organisation will enter into direct discussions with an individual research group only in the exceptional case of very unusual and demanding needs that require special action at the national or international level. However, that does not mean that in all other circumstances the national organisation should only be in touch with its contact persons at the connected institutions.

For example, in the research community an interesting development is the emergence of so-called Virtual Organisations, groups of people at different locations and in different organisations who share certain resources that have been contributed by some of the members of the group. Sharing resources is very important in collaborative research, and their access and administration becomes much simpler when a federated Authentication and Authorisation Infrastructure is available.

NRENs should support the creation of Virtual Organisations, and provide them with tools and support (for example, authentication and authorisation mechanisms, and network tools for collaboration).

Research and education networking organisations should pay special attention to user communities that are perhaps not new, but that are 'different', in the sense that they have different working methods, constraints and needs than the research and higher-education communities that have been the dominant users of research and education networks for many years. EARNEST has looked in particular at three communities of this kind: schools, the healthcare sector, and the arts, humanities and social sciences.

For a number of reasons - often related to national policies or economic factors – national research and education networking organisations are increasingly connecting (primary and secondary) schools and are providing them with services and support. In general, this is a positive development that should be encouraged. Because schools are relatively small institutions that usually have little IT expertise, they need technical advice and support (for example, regarding their Internet connection, their local-area network or content filtering).

People working in the humanities and social sciences are usually employed by universities or research institutes, and therefore belong to the traditional target group of research and education networks. This also holds partially true for the arts. In recent years there have been important developments in these three fields. One of the EARNEST reports provides numerous examples of new applications in these fields that put high demands on the networks that they would like to use.

The healthcare sector and health research have very special demands, because they need a very high degree of reliability of networks and services, and they have very stringent requirements concerning the integrity and confidentiality of data. Most research and education networks connect university hospitals, but in general the healthcare sector in a country is not served by the national research and education network but by dedicated national or regional health data networks. In some countries it might be possible for the national research and education networking organisation to eventually include the healthcare sector in its user community. However, because of the very special character of the sector, such a policy would need to be considered very carefully before it is agreed. Nevertheless, because of its wide experience with the most advanced network technologies and services, the research and education networking community has a lot to offer to the healthcare sector.

NRENs should make a greater effort to provide or organise technical advice and support to schools.

NRENs should establish closer contacts with the arts, humanities and social-sciences communities, learn about their ideas for current and future applications, and collaborate with them to set up demonstrations of services with very demanding network requirements.

Even though they may have no ambition to serve the healthcare sector in general, NRENs should share their knowledge of the most advanced network and service technologies with the healthcare sector.

Finally, it is understandable that research and education networkers at local, national and international level are interested most in deploying and supporting services that have been developed in the research and education networking environment. For example, they are more interested in H.323 videoconferencing than in Skype. However, they should realise that the research and education networking community is no longer the only source of network and service innovation, and that products and services that are beneficial to research and education may originate in completely different environments.

The research and education networking community at local, national and international level should support the deployment and use of good-quality network-related services that are useful for research or education, whether those services originate from the research and education networking environment or from elsewhere.

6 The economic context

European research and education networking represents a significant economic activity. EARNEST found it important to analyse the costs and the cost structures of the GÉANT2 network in order to understand the relationship between the various elements. There were two main reasons for undertaking this analysis. The first was the wish to understand the geographic relationships between network costs and the provision of service to the connected countries. The second was the objective to consider how the costs can be shared fairly between the national research and education networking organisations.

There are three main categories of costs: transmission, hardware and operations. Transmission costs are the dominant component; they represent approximately 60% of the total annual costs of GÉANT2. Of the three cost components, it is the only one that varies according to geographic locations in Europe.

Historically, the situation was different. Before the liberalisation of the international telecommunications market in Europe, the cost of international connectivity was largely independent of geography. This made it easy to find a fair way to share the costs between the national research and education networking organisations. As liberalisation of the European telecommunications markets progressed in the late 1990s, large variations in the cost of international connectivity emerged, creating a significant 'digital divide'. As a consequence, a geographic element was added to the formula for sharing network costs, so that national research and education networking organisations from countries with expensive international connections paid more for the same service than research and education networking organisations from countries with cheaper connections. These issues were analysed in some detail in the SERENATE project.

Since the SERENATE report of 2003, liberalisation of the European telecommunications market has continued. Consequently, in the GÉANT2 network a significant number of connections have been implemented on fibre acquired and owned by the project, rather than circuits leased from telecommunications operators. As mentioned in Section 2, this can bring various important benefits.

However, this access to fibre for GÉANT2 does not mean the end of economic issues in research and education networking. Access to fibre is only available in certain international markets. This demonstrates that there are different markets, related to different parts of Europe and to different services, and that not all of them are competitive. Where access to fibre was not possible, leased capacity has been contracted for GÉANT2. At the time of the SERENATE study, leased capacity was the only practical available solution for a Europe-wide network. The SERENATE Summary Report documents the variation in costs between the cheapest and the

most expensive leased capacity. EARNEST has observed a similar variation four years later (see Figure 6.1). This shows that large variations in the cost of international connectivity remain an issue today.

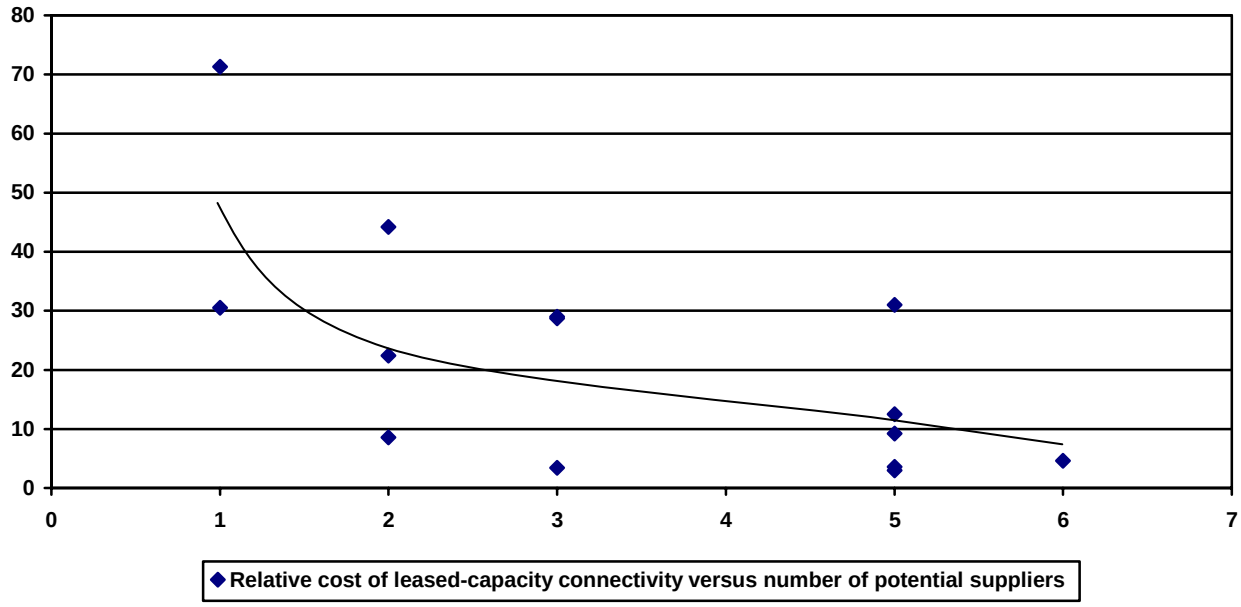

Figure 6.1: GÉANT2 procurement (2005): cost of leased-capacity connectivity versus number of suppliers

The developments in the past four years have revealed a number of new economic issues. One of them is the fact that in optical networks, costs are intrinsically distance-dependent: longer routes bring higher costs. This becomes apparent when connectivity is obtained by acquiring and lighting fibre. The consequence is a purely geographic divide in Europe, in addition to the digital divide that was already discussed by SERENATE.

For purely geographic reasons, countries at the edge of Europe are at a disadvantage, due to three main factors. The first is the very fact that they are at the edge, which means that not as much traffic flows through the connections to these countries as flows through the GÉANT2 connections in the centre of Europe. The second is that these countries are further away from other countries than is the case for countries in the centre of Europe, where distances are shorter. Thirdly, there is a concentration of population, and hence of research and education activity, in the centre of Europe, which generates even larger traffic flows in the centre.

The issue of the geographic divide is discussed further in Section 9.

The changing economic environment, and in particular issues of digital and geographic divide, make it necessary to adapt the model for sharing the costs of GÉANT2 (and its successor network) among the NRENs from time to time, taking into account both solidarity and a fair balance of sharing costs.

Next to these issues of sharing the costs of international networks between countries, i.e., between national research and education networking organisations, there is also the matter of the funding of those national organisations and their infrastructures and services themselves. The EARNEST study of organisation and

governance issues has looked into the funding of national research and education networks. It found that very different funding models are in place in different European countries. In many cases, different parts of the network or different activities are financed from different sources.

A well-known debate is the question of central funding (direct financing by the government or a government agency) versus user charging (i.e., payments by the connected institutions). It has been argued that at the early stages of the establishment of a national research and education network it is essential that the activity is almost entirely centrally funded, while once the research and education networking organisation and its services have become well-established, the organisation can be positioned more at arm's length of the government and a certain amount of user-institution funding can be introduced, thereby also giving the connected institutions more influence on decision making. EARNEST indeed found a trend towards a higher proportion of user-institution funding in a few countries, but in most countries the funding models, although mutually very different, seem quite stable. In one country, the plan was to slightly reduce the proportion of user-institution funding.

Partial funding by connected institutions is a viable model, but it needs to be treated carefully. For upgrades of the network and for the development and deployment of innovative services, a certain amount of central funding is often indispensable.

If connected institutions are charged for the connectivity and services provided by NRENs, this should be done in such a way that it is not a disincentive for innovation.

In a changing economic environment, it is important that the development and enhancement of research and education networks is planned on an appropriate timescale and that forward budget planning over several years is carried out, so that the necessary resources, both human and financial, are available when required. EARNEST found that many national research and education networking organisations only plan budgets on an annual basis. That is not sufficient for planning major network and service infrastructure developments. Involving major users of research and education networks in the planning is also important, particularly when some of them may need additional dedicated connections or services, or significant enhancements to existing infrastructure, to achieve their research and education objectives.

NRENs should re-assess their planning and budgeting periods. They should plan and budget over a period of several years, in line with best practice in the planning of major infrastructure projects.

7 Integration

As explained in Section 1, the organisational structure of research and education networking in Europe has been key to its success. Infrastructure and services are provided by technicians at the international, national and local (campus) level. The modular structure was particularly suited in the days when connectivity was the main service offered, when there were not many network-related services provided to end-users and when connectivity was based on routed IP traffic. It is an oversimplification to say that in such a situation one contact person for the European network in each national research and education networking organisation and one contact person for the national network in each connected institution were sufficient, but it contains a significant element of truth.

The consequence has been that in some countries the community of NREN engineers and the networkers at campus level have become slightly separate worlds. EARNEST found that many national research and education networking organisations do not really know the people providing network-related services in the institutions in their country. This needs to change because of technical developments and the growth of the number of network-related services. An integration of the international, national and local research and education networking worlds is required.

Earlier sections already indicated that the people who provide networks and related services at the local level are becoming more and more important. As described in Section 4, lack of training and support is a barrier for researchers, teachers and students to use various useful network-related services, and the local IT staff are the people who are expected to provide that training and support. Authentication and authorisation of users of facilities depend crucially on networkers at the campus level. End-to-end services need the involvement of network engineers at all levels. The same holds for the monitoring of network performance, to improve the quality of the connectivity that end-users receive.

For all of this, local IT teams need to be adequately staffed, trained and resourced. They need the backing of the highest authority in the institution, who should approve the institution's networking policy.

A networking policy should be defined at the highest level within each institution. The policy should cover strategic plans to meet the requirements of end-users, annual budgets, provisions for a well resourced network support team, rules for network security etc. Institutions can learn from each other in designing their policies, and NRENs should provide support to their connected institutions for drafting these policies.

As mentioned in Section 5, a national research and education networking organisation can also help its connected institutions, and institutions can help each other, through knowledge transfer relating to technology and service provision.

There are three large areas where increased co-ordination and collaboration between national research and education networking organisations and local networkers is particularly important: security policy, enhancement of network performance, and Authentication and Authorisation Infrastructures.

Most research and education networks are able to provide Gigabit line speeds that can support a variety of applications. Unfortunately, the experience of the end-users does not always live up to the potential of these networks. Operational experience shows that the majority of all reported problems can be traced to issues at end-sites or in the configuration of end-nodes.

In many cases, the problems are caused by so-called 'middleboxes', which are typically located on the exterior boundaries of campus networks or other edge networks. These include firewalls, Network Address Translators (NATs), rate-shapers, intrusion detection systems and caching devices, which were placed there to enforce security and traffic policies. In recent years, these devices have become increasingly common as vendors have offered them as convenient solutions to network management problems. Certain funtionalities (e.g., basic firewalls) are sometimes also implemented in the routers themselves.

However, these middleboxes can in turn create problems of their own. These can either be related to their intrinsic architecture (for example, public IP addresses are lost in network address translation) or be attributed to misconfigurations, but more often the problems arise because the devices are intentionally set up to behave in a particular manner. In either case, it is often not clear to the end-users, or even to the network service providers, why they are experiencing problems.

A lot of time is spent troubleshooting problems of this kind. The effects of middleboxes also prevent innovative use of the network by new applications and protocols. Moreover, they encourage circumvention of policies, for example, by encapsulating certain prohibited or restricted traffic within other traffic, or by writing applications to run over permitted protocols. In other words, devices that were supposed to help manage and secure the network, can often end up making things more complicated and less secure. Furthermore, middleboxes can hamper network performance and cause delays in upgrading networks if there are no devices available that support higher line rates.

One cannot expect certain types of middleboxes and software configurations, for example, firewalls, to disappear any time soon. However, some consideration should be given to improving network transparency between core and campus/edge networks. This might be undertaken through the use of protocols that better support NAT traversal, secure connections between trusted hosts, or dynamic management of middleboxes by trusted third parties. Another possibility is moving middleboxes closer to end-hosts, or even undertaking the functions of middleboxes on the hosts themselves. This would allow security and traffic policies to be enforced on a case-by-case basis, and would permit less restrictive policies for certain classes of users. There will obviously be concerns about increased management complexity with the latter approach, but operating systems are becoming more secure anyway and they increasingly provide better support for remote configuration.

In general, it should be recognised that networks themselves cannot ensure security that needs to be placed in end-nodes first. Any enforcement of security or traffic policies should therefore be undertaken at the campus level rather than by network operators. Research and education networks should aim to transport any traffic that originates from directly connected sites or peered networks that have similar acceptable use policies. It may be necessary or desirable to prioritise certain types of traffic in core networks, but that should only be done for reasons of traffic engineering. Nevertheless, a network operator may be in a better position to implement anomaly detection facilities to deal with events such as distributed denial-of-service attacks than campus networkers; for example, botnet attacks can be routinely filtered out by GÉANT2. Increased levels of filtering and firewalling that aim to enhance security and control need to be weighed against the resulting reduction of capabilities for innovation in the research environment.

Institutions should implement security policies that do not hinder innovative use of the network.

Increasingly, researchers have a need for services that are of an 'end-to-end' nature, involving end-sites and traversing a number of network domains. Providing such services brings challenges that are not encountered in the provision of best-effort IP-based connectivity. Intensive and well-structured collaboration between network engineers at the end-sites and at the national and international level is required to provide end-to-end services.

As mentioned above, end-users sometimes experience degraded performance of networks, and in the vast majority of cases this is caused by issues at end-sites. These problems are often difficult for users to identify and resolve themselves, and they sometimes accept degraded performance as normal. In order to trace problems with end-to-end connections, it is often necessary to contact several organisations whose management domains are traversed by the connection.

A Performance Enhancement and Response Team (PERT) was established in late 2003 as a trial in the predecessor project of GN2, and was continued as a production-level service from early 2005 in the GN2 project. The PERT was created to investigate reports from end-users whose applications are not performing as expected and who suspect a problem with a network connection. The team uses a variety of diagnostic tools to identify where problems may exist, and then contacts the responsible organisations to try to solve these. In fact, the PERT has been quite successful at tracking down and resolving issues that were reported and it has demonstrated that few problems can actually be attributed to GÉANT2 or the national research and education networks. A major source of problems is the interaction between end-systems and the connected networks, and very often changes that are made to end-systems have a significant effect on end-to-end performance.

Unfortunately, at the present time the PERT is limited in resources and scope, and does not have well-established relationships with end-sites or users. This means that cases generally only reach the PERT through a long chain of referrals, if at all. Furthermore, the multi-domain nature of most end-to-end performance problems means that successful resolution of cases often requires access to systems at user premises or information from intermediate networks.

Therefore, the PERT concept should be extended to the level of national, regional and even campus networks. That way, users will be able to raise a case with their local PERT, which will then open the investigation and escalate it to other PERTs as appropriate.

The NREN and the institutions in each country should establish structured collaboration for the provision of end-to-end services.

The central PERT should be sustained, and the process of extending the PERT concept to the national and local level should be continued. Collaboration between PERTs at European, national and local level should be organised, following either a decentralised or a federated model.

It has become increasingly common for researchers to work together while located in different places. They want to share resources such as computing time, data repositories, collaborative tools and other devices. In other words, many researchers nowadays knowingly or unknowingly belong to Virtual Organisations as described in Section 5. However, when resources are accessed remotely, there need to be mechanisms to authenticate users and to assign privileges depending on who they are and what they are allowed to do.

Authentication and authorisation on a per-resource basis becomes complicated when many resources are involved, and is impractical for users who then have a large number of credentials. Therefore, Authentication and Authorisation Infrastructures (AAIs) have been set up that establish trust relationships between institutions, which allow users to use resources at an institution after having been authenticated by their parent institution.

The Grid community was among the first to adopt such a model, but AAIs are of great use to other communities as well. Initially, AAIs were difficult to implement, but more sophisticated middleware is making this task easier and AAIs more secure.

National research and education networking organisations should put AAIs in place if they have not already done so. They should also focus on the harmonisation of AAI standards in order to improve interoperability and make management of users easier.

NRENs and institutions should develop local and national AAIs to into full services for all possible forms of use by all research and higher-education communities, based on integrated policies.

8 Collaboration between national research and education networking organisations

EARNEST found that governance, management and policy development are very different in different research and education networking organisations in Europe. This can no doubt be explained by structural, political and cultural differences between countries. However, researchers and teachers in Europe, who are increasingly involved in international collaborations, would benefit from a developed and consistent approach to governance and policy.

It is increasingly important that user requirements are well understood and that preparations to provide services that will be required in the future are made in a timely manner. This requires vigorous interaction between the national research and education networking organisation and the users, bringing information from the users to the organisation's strategy making bodies. EARNEST feels that good representation of users at the governance level and mechanisms for them to influence both business and technical directions contribute to the effectiveness of research and education networking organisations. At the present time, such representation and mechanisms are by no means universal.

At the European level, it is becoming increasingly important to ensure that researchers, teachers and students receive the best possible types of connection, which perform in an optimal manner from end to end. PERTs and other operational support teams can help resolve technical issues, but managerial and policy frameworks that enable and encourage the functioning of these structures are also vital.

Stronger collaboration between NRENs should be established on technical and business matters.

Section 5 already mentioned Service Level Agreements (SLAs), which are provided by some national research and education networking organisations to their users. In some cases, network-related services support mission-critical applications of research and education institutions, and therefore EARNEST recommends that they should be offered an accompanying SLA as a matter of practice. Users of pan-European end-to-end services rely on service provision by several national research and education networks in the path as well as the interconnecting backbone network GÉANT2. Therefore, a pan-European SLA for end-users should be explored.

NRENs and DANTE should work together in a single forum to develop Service Level Agreements and Service Level Specifications, with the ultimate goal of a pan-European Service Level Agreement for end-users.

It is important that services are offered in a standardised fashion. While standardisation needs to take place on a global scale to ensure future interoperability, it is vital that the European research and education networking community makes an active contribution, so that emerging standards will satisfy European expectations. Many individuals and organisations from the community are already contributing actively to important forums such as the OGF (Open Grid Forum), the IETF (Internet Engineering Task Force) and ITU-T (International Telecommunication Union - Telecommunication Standardisation Sector).

Europe's NRENs should strengthen their collaboration for joint contributions to standardisation, security and quality control, and participate more actively in these activities.

The development of Grid technology in all its forms originated from the view that it is more efficient to pool computing, storage and other resources than to build one's own, especially when peak demand exceeds average requirements by a large measure. Early Grid developments took place in large laboratories where dedicated connection of elements could be put in place easily. To a certain extent, the corresponding culture can still be recognised in global disciplines such as high-energy physics, which dominates the Grids field. However, Grid applications are now becoming more mainstream in other disciplines, such as computational chemistry, bio-medicine, geology and climatology, and they are starting to extend to the humanities and social sciences as well. Similar arguments apply to the area of High-Performance Computing (HPC).

This has led to a situation where the Grid, HPC and networking communities have not sufficiently engaged in collaboration to develop optimal solutions. The Grid community has sometimes had unrealistic expectations of the networks, and conversely the networking community has sometimes thought that the Grid community put unreasonable demands on the networks.

Wider and more intensive collaboration should be established between the Grids community, the High-Performance Computing community, the research and education networking community and the users of the facilities offered by these communities.

Europe's research and education networks have developed in a period of large changes in government regulations. As explained in Section 2, the regulatory developments related to the liberalisation of Europe's telecommunications markets have brought large benefits to research and education networking. Since then, regulatory changes have been continuing, and politicians have expressed that a further regulatory reform is required. In general, national research and education network organisations serve a closed user group and are therefore not subject to the regulations that hold for providers of public networks. Nevertheless, future regulatory changes could possibly affect research and education networking organisations. Conversely, research and education networking organisations with their long experience and their position at the forefront of network and service development, could contribute their expert advice to the process of regulatory change.

NRENs should co-ordinate their contributions to the process of regulatory change and hence create a forum where common positions regarding regulatory changes can be developed.

9 Digital and geographic divide

In 2003, the SERENATE study clearly demonstrated the existence of a digital divide in research and education networking between different parts of Europe. EARNEST reaffirmed that the digital divide remains a disturbing factor for European research and education networking, and, as a matter of fact, is encountered also in otherwise well-developed and well-resourced countries, at the national level and/or in some regions within a country.

Factors contributing to the existence and widening of the digital divide include relatively uncompetitive and regulated markets that lead to expensive and/or poor connectivity, uncertainty of subsequent phases of planning and support for national research and education networks, limited financial resources with the national research and education networking organisation and/or at government level, and, last but not least, the ad-hoc nature of several support actions taking place across Europe.

In addition, the EARNEST study highlighted the existence of a new phenomenon, caused by the direct relation between distance and cost in optical networks, which will be referred to as the 'geographic divide'. The three main reasons for the existence of the geographic divide are explained in Section 6. One of them is the self-evident fact that while routes from the edge of the network transverse the centre of the network, the converse is not true. As a result, in the GÉANT2 network, for example, routes in the centre of Europe are more heavily populated with wavelengths than those at the edge. The density of telecommunications links in the centre of Europe will always be higher, while the density of connections at the edges will always be lower. As a consequence of normal market forces, costs for network connections at the edge of Europe will be higher than those in the centre, even if the underlying local market is in itself highly competitive. This has a detrimental effect on the prices that have to be paid by national research and education networking organisations at the edges of Europe.

It should be noted that the geographic divide does not only affect research and education networks but also other users of international telecommunications infrastructures in countries at the edge of Europe, even though this phenomenon is more acute when an organisation lights its own 'dark fibre', because in that case it is confronted directly with the costs of the infrastructure. Similar phenomena may exist in other sectors where the costs of facilities are dependent on distance and intensity of use, for example, the transportation and logistics sector. This general problem will not go away without some intervention at a regional level.

Challenges arising due to the geographic divide should be addressed at the level of the European Union's Regional Policies.

Since the effects of the geographic divide do not only affect research and education networking but also many activities in the public sector and the national economy, there is ground for the government of a country at the edge of Europe to intervene. And because investments by owners of telecommunications infrastructure in new connections require the collaboration of the government, there is an opportunity for the government to influence the availability of infrastructure for research and education networking.

Governments of countries that suffer from the effects of the geographic divide should develop policies to obtain access to infrastructure for research and education networking, and possibly for other sectors of strategic public interest.

The EARNEST study of geographic issues has revealed that the causes of the digital divide are more complex and deeper reaching than previously understood. The effect of the liberalisation of the telecommunications markets is still the dominating feature across Europe: the more competition between telecommunication operators and Internet Service Providers, the better the situation for the country in general, and for the national research and education network and hence the national education and research communities in particular.

National governments should create a climate of favourable conditions to encourage competition between telecommunications operators as well as promote the intensive use of the Internet by the public sector, businesses and private individuals. Besides the benefits that such policies bring to the national economy and the public at large, they help the development of national research and education networking.

Even in the case of affluent countries with a liberalised telecommunications market, the level of importance that the government ascribes to education and research (and hence to research and education networking) has a large impact on the range and levels of network-related services that can be offered to the research and education community. EARNEST has shown that where a state gave a high priority to the national research and education networking organisation, it has fared exceedingly well, catching up or even surpassing its counterparts from other countries. A prime example is the case of the majority of the member states that joined the European Union in 2004, where by taking advantage of 'dark fibre' several research networking organisations have enormously increased their network capacities. When governments gave a low priority to research and education networking, researchers, teachers and students were left with little more than basic functionality equivalent to that available on the commercial market; they were disadvantaged in comparison with their peers in countries where research and education is given higher priority,

EU-funded projects stimulating the development of connectivity and services for research and education in certain regions (for example, the EUMEDCONNECT project in the Mediterranean region, the SEEREN and SEEREN2 projects in southeast Europe, the ALICE project for Latin America) can have an extremely beneficial effect. Many success stories related to these initiatives have been reported. However, the sustainability of the infrastructure after the end of the projects remains a concern.

The European Union should continue to support regional projects for the development of research and education networking, and should require that involvement of key stakeholders for long-term sustainability is an integral part of such projects during their lifetime.

The EARNEST study of geographic issues has developed the concept of a Research and Education Networking Development Index (REDI) in a relatively short timeframe, and the verification work is still in progress. It is clear from the early evaluation of the results and comparison with other indices that REDI has significant potential to become an exemplary benchmark for assessing the progress achieved over time towards closing the digital divide. In order to endorse the findings derived from REDI, further work is required to ensure its robustness. In addition, it is proposed to add indicators based on real-time performance data. While several projects have put in place monitoring nodes and beacons in the past, it would be necessary to consult with all national research and education networking organisations in order to collect and use such data in the way proposed by the developers of REDI.

Further work on REDI (including verification of data and their accuracy) is required to validate and optimise the results.

NRENs should agree to provide online measurement of traffic data, in order to facilitate the inclusion in REDI of indicators based on real-time performance data.

10 Technical challenges

The history of research and education networking is one of fast and far-reaching technological changes. As mentioned in Section 4, the revolutionary changes in the past four years have led to a number of new technical challenges that need to be addressed by the research and education networking community. The EARNEST study of technical issues has provided a broad overview, focusing on four main areas of investigation: transmission technologies, control-plane technologies, operation and performance issues, and middleware. A number of technical issues that require further work of the technical specialists in the research and education networking community were identified.

In general, it is difficult to make specific recommendations with respect to network technologies, because they evolve very quickly. Implementation decisions are also driven by issues such as the cost and availability of connectivity, the cost and availability of the next-generation equipment, and whether there is a requirement to support legacy infrastructures. All these factors vary between research and education networks. Therefore, the study focused more on the pros and cons of the various technologies that are likely to be available in the future. Nevertheless, this section highlights a few important issues that research and education networks should consider.

The current section will discuss only three of the areas for further work, namely the choice between 'faster' and 'fatter', dynamic provisioning in hybrid networks, and improved management and monitoring at network layers 1 and 2.

The discussion on 'faster or fatter' is about the question whether in the coming years increased bandwidth should be provisioned with higher-speed links or by using multiple lower-speed channels or by a certain combination of both methods.

Research and education networking organisations have traditionally run a best-effort IP service over circuits leased from telecommunications carriers, but increasingly it has become possible for them to lease or even install their own 'dark fibre'. This allows them to implement their own transmission systems and thereby they are in principle able to upgrade network capacity as demand requires, without incurring substantial additional costs.

The capacity of fibres is very high. The use of WDM (Wavelength Division Multiplexing) techniques, whereby different wavelengths of light are simultaneously transmitted over the same fibre, makes it now possible to support up to 160 channels at 10 Gb/s per fibre. Currently it is also possible to transmit data over a single

channel at up to 40 Gb/s, with 100 Gb/s promised in the next few years. However, there is a trade-off between line rates and the number of channels that can be supported, due to non-linear effects that cause interference between the wavelengths. In addition, higher-speed line rates are more susceptible to signal degradation, which reduces the distance that the signal can travel before requiring amplification or regeneration.

Typically, a premium is charged for the highest-speed router/switch interfaces, which means that using multiple lower-speed interfaces may prove to be more cost-effective for provisioning an equivalent amount of bandwidth. However, WDM systems become increasingly complex as more wavelengths are supported, and require additional equipment to handle the multiplexing/demultiplexing of channels and to add, drop and switch channels on trunk routes. In addition, WDM systems – particularly DWDM (Dense Wavelength Division Multiplexing) systems – require careful configuration and management, although this task has become easier since the advent of variable optical attenuators and electronic dispersion compensation.

Lower-capacity channels may limit the use of certain applications that can generate very large data flows. Thus far, 10 Gb/s has largely proved sufficient, but there are impending high-energy physics, radio-astronomy and multimedia applications that are likely to require higher line rates. While it is possible to concatenate multiple lower-speed channels to appear as a larger pipe, this approach is limited by the capabilities of the transmission equipment. Furthermore, for time-sensitive applications, splitting traffic over multiple physical channels can be problematic.

In contrast to the situation five years ago, it appears that many vendors see only a limited requirement for increasing the number of wavelengths that can be supported on a fibre, and they now seem to be focusing their efforts on faster line speeds. The research and education networking organisations that have access to 'dark fibre' do not yet fully exploit WDM, because few of them use more than a handful of wavelengths on each route and they tend to upgrade line speeds as a matter of preference. Of course, this is simpler to manage if one is only providing a production IP service, but equally it does not provide the capabilities to offer dedicated lightpaths to demanding users.

As a number of technological developments are expected to reduce the costs of both 10-Gb/s and 40-Gb/s router/switch interfaces, research and education networking organisations should consider whether the installation of WDM systems is cost-effective for their needs. This question may become even more pertinent as robust virtualisation techniques are developed for provisioning protocol-agnostic links over conventional IP-based networks. However, with 100-Gb/s interfaces unlikely to be commercially available before 2011, will 40-Gb/s connections still be sufficient by themselves until then?

National and international research and education networking organisations should closely follow the technical developments in WDM systems, the commercial availability of WDM products and the developing requirements of their most demanding user groups in order to make cost-effective and timely decisions on the 'faster or fatter' choice, i.e. whether to provision increased bandwidth with higher-speed links or by using multiple lower-speed channels or by a combination of both methods.

Research and education networking organisations will continue to focus heavily on production IP services, but there is also an increasing trend towards the provision of hybrid networks as 'dark fibre' becomes more widespread. Where these organisations operate the underlying transmission infrastructure, it becomes practical

to use WDM to establish dedicated point-to-point links (known as 'lightpaths') for users with specific requirements, while still providing a common IP service for general use. These lightpaths can provide dedicated bandwidth for running demanding applications or for conducting disruptive tests.

Unfortunately, while the IP routing protocols that underpin the Internet are designed to operate in an automated fashion, automated management of optical equipment is still very limited. This makes it difficult to dynamically configure circuits at the optical level, and to date, that configuration is largely done manually in research and education networks. The need for human intervention means that setting up lightpaths usually takes hours or days rather than seconds, and of course it increases the chances of misconfiguration. Another problem is that IP and optical domains largely have to be managed separately, which usually means separate management consoles and makes it difficult to track faults to a particular layer of the network.

Technologies like Generalised Multi-Protocol Label Switching (GMPLS) are designed to support not only the network equipment that performs IP routing, but also the equipment performing WDM and/or TDM (Time Division Multiplexing) switching. In principle, this allows establishing, maintaining and tearing down connections in an integrated manner, and greatly facilitates the automation of this process. Unfortunately, while there is reasonable support for establishing lightpaths within the same administrative domain, the establishment of lightpaths between or across domains remains problematic.

A more recent concept is user-controlled network resources, whereby elements of an underlying network (e.g., lightpaths, logical switches/routers) can be allocated to individual users or organisations, who can then use them to build their own network topologies for specific tasks. This would allow resources to be offered in a more flexible manner and potentially on demand, eliminating many of the constraints that exist at present. However, this requires improvements in the automated control of transmission equipment, and integration with the IP level.

Europe's research and education networking organisations have gained experience with GMPLS, among others in the research activities associated with the GÉANT2 network.

Research and education networking organisations should investigate how to improve the automation of their hybrid networks, and test and roll out appropriate technology when available. They should also consider becoming involved in the GMPLS standardisation process at the IETF.

Research and education networking organisations have a lot of experience managing and monitoring IP networks (i.e., Layer 3 and above). When they were running an IP service over leased lines, the underlying transmission system (Layers 0-2) was the responsibility of the telecommunications provider. As a consequence, there is much less knowledge of configuration, operational procedures and optimisation at these lowest layers within the research and education networking community. However, as research and education networking organisations acquire 'dark fibre', they become responsible for managing the transmission equipment as well. Up to now, they have typically outsourced this task.

Transmission systems, including switches, multiplexers/demultiplexers and attenuators, require different management techniques, and there tend to be fewer tools available for configuration and operation compared

with IP networks. These systems also need to be monitored so that faults or degraded performance can be detected quickly, and so that operators can better plan and provision their networks.

The underlying transmission protocol of choice for telecommunications providers is SDH/SONET, which has quite extensive operations, administration, maintenance and provisioning (OAM&P) features, as well as fast circuit restoration. Nevertheless, SDH/SONET can be complex to manage, and use in combination with WDM systems requires careful planning and documentation.

Many vendors are now starting to focus on Ethernet as the underlying transmission protocol, because of the cost advantages it confers. Unfortunately, as Ethernet evolved from a LAN background, it lacks many of the OAM&P features of SDH/SONET, which makes fault tracing and circuit restoration difficult. A number of vendors are working to add this functionality, but this will undoubtedly require management and monitoring platforms to be developed to support this.

The EARNEST study revealed a general lack of knowledge of Layer-1 and Layer-2 management and monitoring techniques in the research and education networking community. There also appears to be a lack of easy-to-use and affordable tools for managing and monitoring equipment, although some initiatives are underway in the research and education networking community to improve the situation.

Research and education networking organisations should improve knowledge transfer, organise training and consider supporting the development of better tools for management and monitoring at network layers 1 and 2.

11 References

EARNEST	http://www.terena.org/activities/earnest/
GN2	http://www.geant2.net/server/show/nav.749
SERENATE	http://www.serenate.org/

12 Acronyms

AAI	Authentication and Authorisation Infrastructure
ADSL	Asymmetric Digital Subscriber Line
AHSS	Arts, Humanities and Social Sciences
ALICE	América Latina Interconnectada Con Europa
CRU	Comité Réseau des Universités
DANTE	Delivery of Advanced Network Technology to Europe Ltd.
DWDM	Dense Wavelength Division Multiplexing
EARNEST	Education And Research Networking Evolution Study
eduGAIN	Education GÉANT Authorisation Infrastructure
eduroam	Education Roaming
ESF	European Science Foundation
EU	European Union
EUNIS	European University Information Systems
Gb/s	Gigabits per second
GDP	Gross Domestic Product
GE	Gigabit Ethernet
GÉANT	Gigabit European Academic Network Technology
GHz	Gigahertz
GMPLS	Generalised Multi Protocol Label Switching
GN2	Multi-Gigabit European Academic Network
HPC	High-Performance Computing
IAB	Internet Architecture Board
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	ITU – Telecommunication Standardisation Sector
kb/s	kilobits per second
LAN	Local Area Network
MAN	Metropolitan Area Network
MPLS	Multi Protocol Label Switching

NAC	Network Access Control
NAT	Network Address Translator
NREN	National Research and Education Networking organisation
OAM&P	Operations, Administration, Maintenance and Provisioning
OC	Optical Carrier
OCCASION	Organising Caucasus and Central Asian Internet Offerings to NRENs
OGF	Open Grid Forum
PerfSONAR	Performance Service Oriented Network Monitoring Architecture
PERT	Performance Enhancement and Response Team
PESC	Physical and Engineering Sciences
QoS	Quality of Service
REDI	Research and Education Networking Development Index
RENATER	Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche
ROADM	Reconfigurable Optical Add-Drop Multiplexer
SAML	Security Assertion Markup Language
SCHAC	Schema Harmonisation Committee
SDH	Synchronous Digital Hierarchy
SEEFIRE	South-East Europe Fibre Infrastructure for Research and Education
SEEREN	South-Eastern European Research & Education Networking
SEEREN2	South-Eastern European Research & Education Network
SERENATE	Study into European Research and Education Networking As Targeted by *e*Europe
SLA	Service Level Agreement
SONET	Synchronous Optical Networking
TDM	Time-Division Multiplexing
TERENA	Trans-European Research and Education Networking Association
UCLP	User Controlled Light Path
WAN	Wide Area Network
WDM	Wavelength Division Multiplexing

Appendix A The EARNEST foresight study

The EARNEST foresight study has looked at the expected development of research and education networking in Europe over the next five to ten years. The study formally started on 1 March 2006 and most of the work was completed by November 2007, although the study was only rounded off in 2008 with the publication of the final versions of the EARNEST reports. EARNEST was funded by the European Union through the GN2 project.

The aim of EARNEST was to provide input for initiatives that can help to keep the evolution of European research networking at the forefront of worldwide developments and enhance the competitiveness of the European Research Area. EARNEST prepared the ground for the planning of the development of research and education networking infrastructure and services after the completion of the GN2 project, at the local, national, European and intercontinental level.

EARNEST can be seen as the successor of the very successful study that was carried out in the SERENATE project in the years 2002-2003. The results of the SERENATE study, and in particular the recommendations in its Summary Report, have been very influential in the planning and development of research and education networking in Europe in subsequent years.

EARNEST management

The study was managed by a Panel, which met at approximately monthly intervals, either in a phone conference or face-to-face. The composition of the EARNEST Panel was as follows:

- Dorte Olesen (UNI•C, President of TERENA), chair
- Robin Arak (Archway Computer Associates)
- Patrick Bressler (European Science Foundation)
- Valentino Cavalli (TERENA Secretariat)
- Dai Davies (DANTE)
- John Dyer (TERENA Secretariat)
- Licia Florio (TERENA Secretariat)
- Sabine Jaume-Rajaonia (RENATER)

- Jean-Paul Le Guigner (CRU)
- Thibaut Lery (European Science Foundation)
- Kevin Meynell (TERENA Secretariat)
- Martin Price (EUNIS)
- Jorge-A. Sanchez-P. (J&N Partners)
- Karel Vietsch (TERENA Secretariat), activity leader
- Nikos Vogiatzis (J&N Partners).

Structure of the study

After an initial preparatory phase (March-June 2006), the EARNEST work was organised in parallel studies addressing seven areas:

- Researchers' requirements

  This study was led by Thibaut Lery and Patrick Bressler. The European Science Foundation commissioned Technopolis Ltd. to conduct a large-scale survey, which obtained responses from almost 4,400 researchers and academic teachers from across Europe, followed by more in-depth interviews with a small number of respondents.

- Technical issues

  The study was led by Kevin Meynell and Licia Florio, who were assisted by a panel of twelve experts from the research networking community. The work focused on four main areas of investigation: transmission technologies, control-plane technologies, operation and performance issues, and middleware. The findings of the study are based on a series of individual meetings with leading equipment vendors and research institutions, as well as information obtained from other sources.

- Campus issues

  The study was led by Jean-Paul Le Guigner and Martin Price. The work was organised in two phases: a fact-finding exercise to discover the current situation of campus networking on the basis of a questionnaire aimed at the heads of IT services in research and education institutions in Europe, followed by a study of strategic directions of research networking to provide a view of the possible future of campus networking.

- Economic issues

  A study carried out by Dai Davies, who looked at the GÉANT2 network and analysed its underlying cost structures. The study examined a number of cost trends, with particular reference to the relationship between costs and their geographic distribution.

- Geographic issues

The study, led by Jorge-A. Sanchez-P. and Nikos Vogiatzis, aimed to produce an enhanced, concrete and structured method of measuring the status of research and education networking development in order to contribute to a deeper understanding of the digital divide.

- Organisation and governance issues

  The study was carried out by Robin Arak, who looked into the way in which national research and education networking organisations in Europe and beyond are governed, funded and organised. The work was mainly based on the responses to a questionnaire sent to these organisations.

- Requirements of users in schools, the healthcare sector and the arts, humanities and social sciences

  This study, co-ordinated by Sabine Jaume-Rajaonia was a compilation of three separate case studies. Requirements of schools were investigated by Andrew Perry (Department for Children, Schools and Families, United Kingdom). A report on networking in the healthcare sector was compiled by Christina Wanscher from MedCom in Denmark together with Henrik Søndergaard and Martin Bech (UNI•C). Finally, networking requirements in the arts, humanities and social sciences were studied by Sabine Jaume-Rajaonia and Cătălin Meiroşu (TERENA Secretariat).

Reports have been published on each of these sub-studies, as well as an additional report on regulatory issues, produced by Robert Milne and Claire Milne of Antelope Consulting, a consultancy firm specialising in this area. The EARNEST study was rounded off by the current Summary Report.

The third phase of the EARNEST study started in June 2007. Draft versions of the sub-study reports and draft recommendations were presented at the EARNEST Final Workshop, to which prominent representatives of all stakeholders were invited.

Taking into account the feedback received, the EARNEST Panel formulated its conclusions and recommendations to be included in the Summary Report. The various reports were finalised, approved by the Panel and published in the period from September 2007 to May 2008.

EARNEST workshops

A number of workshops played an important role in the EARNEST study:

- EARNEST Initial Workshop, Berlin, 23-24 May 2006

The main objective of the workshop was to obtain input from the attendees concerning the issues that were considered important for the future of networks and network-related services for research and education in Europe, as this could help to define the study areas. The event was attended by more than 80 representatives of all stakeholders in research and education networking in Europe: national government authorities and the European Commission, other funding bodies, NRENs, management of universities, research institutes and educational institutions, equipment vendors and telecommunications operators, and, last but not least, the users of research and education networking facilities and services.

- EARNEST Workshop on Schools, Paris, 10-11 February 2007

The event was organised by TERENA to collect additional input for the study on the requirements of users in schools. The workshop was attended by teachers and other persons from a number of European countries with special expertise regarding the use of information technology and networks in schools.

- EARNEST Workshop for NREN Managers, Bratislava, 27 April 2007

The objective of this event was to present the intermediate findings of the various sub-studies to representatives of national research and education networking organisations at management level, and to receive their feedback.

- EARNEST Workshop for Funders and Policy Makers, Amsterdam, 8 May 2007

This workshop was organised for representatives of governments and government agencies as funders and policy makers in the area of research and education networking. The objective was the same as that of the Bratislava workshop: to present the intermediate findings of the various sub-studies and to receive feedback from the workshop participants.

- EARNEST Final Workshop, La Hulpe, 25-26 September 2007

The event addressed the same set of stakeholders as the Initial Workshop, and was attended by a similar number of representatives. Draft versions of the sub-study reports and draft recommendations were presented and discussed in lively debates with the workshop participants. The feedback from this workshop has played an important role in the formulation of the final conclusions and recommendations.

- EARNEST Workshop at the European Parliament, Brussels, 2 April 2008

The event presented the main findings and recommendations of the EARNEST study to Members of the European Parliament and other policy makers. It explained about the great importance and achievements of European research and education networking, and pointed at a number of issues that deserve political attention.

EARNEST publications

In total, EARNEST has published nine public reports. All these reports are available from the EARNEST website at www.terena.org/activities/earnest/publications.html. Printed copies can be ordered from the TERENA Secretariat.

The list of reports is as follows:

- *EARNEST Report on Researchers Requirements*, by Thibaut Lery and Patrick Bressler
- *EARNEST Report on Technical Issues*, by Kevin Meynell (editor), Luca Deri, Sergi Figuerola, Licia Florio, Alexander Gall, Leon Gommans, Paola Grosso, Gigi Karmous-Edwards, Simon Leinen, Athanassios Liakopoulos, Diego López, Cătălin Meiroşu, Milan Sova, Stig Venås and Klaas Wierenga
- *EARNEST Report on Campus Issues*, by Jean-Paul Le Guigner, Martin Price, Rogelio Montañana and Michael Nowlan
- *EARNEST Report on Economic Issues*, by Dai Davies
- *EARNEST Report on Geographic Issues*, by Jorge-A. Sanchez-P. and Nikos Vogiatzis
- *EARNEST Report on Organisation and Governance Issues*, by Robin Arak

- *EARNEST Report on the Requirements of Users in Schools, the Healthcare Sector and the Arts, Humanities and Social Sciences*, by Sabine Jaume-Rajaonia and Karel Vietsch (editors), Andrew Perry, Cătălin Meiroşu, Christina Wanscher, Henrik Søndergaard and Martin Bech
- *EARNEST Report on Regulatory Issues*, by Robert Milne and Claire Milne
- *EARNEST Summary Report*, by Dorte Olesen, Robin Arak, Patrick Bressler, Valentino Cavalli, Dai Davies, John Dyer, Licia Florio, Sabine Jaume-Rajaonia, Jean-Paul Le Guigner, Thibaut Lery, Kevin Meynell, Martin Price, Jorge-A. Sanchez-P., Karel Vietsch and Nikos Vogiatzis.

Appendix B Researchers' requirements

The EARNEST study of researchers' requirements was carried out by the European Science Foundation (ESF) through its Physical and Engineering Sciences (PESC) unit. The ESF commissioned Technopolis Ltd. to undertake a two-stage survey and to provide a statistical evaluation of the results. Stage 1 consisted of a single large-scale online survey directed at more than 11,000 professional scientists working across Europe. Stage 2 followed on directly and was smaller in scale but more focused than the earlier part of the study. It involved follow-up interviews with 30 respondents to examine more thoroughly the issues arising from the first stage.

The survey achieved a high response rate. Responses were received from 4,392 researchers and academic teachers from across Europe, representing 39% of the persons approached. The wide spread of respondents over countries and disciplines, and the high total number of responses give a good level of robustness to the survey results.

Use of network-related services and tools

The study provides evidence of the increasing importance that the development of research and education networks and related services has had in recent years for the work of researchers in Europe:

- The use of network-related tools and services has become increasingly common among the overwhelming majority of European scientists in the last five years. Still, considerable growth in awareness of these tools and their use is anticipated over the next decade.
- The most commonly and frequently used tools are email, distribution lists, wireless access and transfer of large files.
- The most commonly and frequently used services are access to digital libraries and to remote databases.

However, there still appears to be a widespread lack of (detailed) knowledge of many of the main network-related tools and services among 'light users'. Future growth may be dependent on better dissemination of technical information regarding available resources and services.

The survey respondents indicated that scientists spend an average of fifteen hours each week interacting with other researchers and academic teachers via a range of different media. The majority of this time is dedicated to face-to-face meetings and email interaction. However, the use of other media, such as videoconferencing, is still increasing and already more frequent in certain fields. Results also showed that a large proportion of time is

spent actively using data networks for research or teaching, with a majority of researchers spending over an hour each day on such activities.

Among researchers, three categories of users are identified, which can be linked to the majority of users in a scientific field:

- light network users: environmental, mathematical and social sciences;
- moderate network users: humanities, life and medical sciences;
- heavy network users: physics and related sciences, materials science and mechanical engineering, IT and computer science, chemistry and chemical engineering.

Lack of knowledge and awareness of national research and education networks and of GÉANT2 is widespread among researchers. Overall, only 5% of all respondents knew that the network at their workplace was connected to the pan-European network. However, this can also be seen as an indication of how smoothly and transparently the NRENs and GÉANT2 provide services: typically, awareness of the technology and related services rises when the services fail.

Developments in network-related services over the last five years are seen to have had a (very) positive effect on a number of aspects of research and teaching. In particular, for more than 60% of respondents, access to publications and other information needed for their research has increased very considerably over the last decade. A large number of examples and explanations were provided as to the positive benefits that have been experienced as a result of network developments, while few drawbacks were identified.

A very large number of respondents mainly use research and education networks for simple applications such as Web browsing and email. A smaller number of end-users use applications that require streaming media or Virtual Private Networks. Their bandwidth requirements exceed ADSL and extend up to Gigabit Ethernet. Finally, there is a third category of researchers who use special scientific applications such as Grid computing and virtual presence. They need network capacities of one or more Gigabits per second.

Researchers expressed the view that network providers should increase the flow of information - including road maps of future service developments - to their end-user communities. Likewise, network providers should make more educational material available. They should take into account the growth of the expectations of users, who require more sophisticated services. They should also plan 'broadband' network access for researchers at work, at home or away.

Current and future requirements

In the next 5-10 years, considerable changes are anticipated in the way in which researchers and academics work. These changes are expected to have implications for the development of networking and related services. Most respondents expect international collaboration and participation in large-scale collaborative projects to increase substantially in the coming decade.

Comments on how people envisage their future use of data networks suggest that there is a widespread interest in increased use of network-related tools and services for research and teaching activities. Overall, respondents are satisfied with the network infrastructure at their workplace. However, nearly half of the

respondents desire more adequate training in network use to improve the quality of their research and teaching. Researchers in environmental sciences and life sciences expressed a striking lack of training in network use. Researchers in IT and computer science expressed great dissatisfaction regarding privacy and, especially, security issues. In general, the use of computing Grids, Virtual Organisations and, in particular, lightpaths is hampered by a widespread lack of information and knowledge of what they are.

It appears that improvements needed to provide better network services are not so much networking improvements but technical improvements: higher, guaranteed bandwidth, and easier, more user-friendly interfaces and infrastructure. Over 60% of the respondents do not use nor expect to use large computing facilities and large storage facilities within the next five years. The majority is unaware of the size of these large facilities. In consequence, the facilities appear to be adequate to users' needs today. Nevertheless, a majority of respondents does indeed expect large computing facilities as well as large storage facilities to be inadequate for their needs in 5-10 years' time.

An important part of the study was to investigate the future networking requirements of members of the European research community. There is substantial evidence that the network is becoming an essential element in the scientific landscape in all areas of research. There is a distinctly high level of satisfaction as regards the services provided today. The study shows that e-Infrastructure is generally accepted as a major facilitator for research and teaching.

The expectations of network users are evolving beyond the provision of pure bandwidth towards the supply of more complex services. There are now concerns about the lack of user knowledge of existing services, tools and software.

General expectations relate to incremental improvements of current technologies and trends. This can be taken as an indicator that networks and Grids have passed through the phase of expansive technological innovation and have now entered a phase of vigorous implementation, in which services are improved and used for a wider range of applications.

Another trend is a growing demand for network facilities to support scientific collaboration. In this context, standardisation, quality control and security issues should be addressed. It is foreseen that effective exploitation of trans-national connectivity and the resulting capability to make the correct decisions will become increasingly critical to the success of individual projects and research strategies.

Recommendations

According to researchers and academic teachers, the research and education networks in Europe are delivering an excellent service, which must be enhanced further. There are several issues of concern, which relate to sustainability, awareness, user support and training. Below is a list of recommendations regarding services, co-operation and capacities, based on the comments from respondents to the survey and amended following various discussions with respondents and with participants in workshops and meetings.

Services

a. **Quality services and security.** There is a need to update and improve usage policies, security and quality control of data as well as knowledge and information management.

b. **Awareness.** More user awareness of network technology and services must be created. Researchers are asking for better training and higher levels of support for many of the network tools and services currently available. Wider and better awareness of network technology and services must be reinforced nationally and at a European level, e.g., by establishing so-called Service Knowledge Centres.

c. **User friendly services.** Services and support should also be directed towards 'light' or infrequent users. This would increase the access and use of network-related tools and services.

Co-operation

d. **Simplification and adaptation.** New standards, protocols and interfaces need to be defined and developed for better communication between researchers and for new tools, including data repositories and databases.

e. **Interdisciplinary approach.** There is a need to build and extend interdisciplinary federation-based, decentralised (or even virtual) infrastructures to support an expanding and diverse community of researchers.

f. **Training.** Researchers and all the other users need continuous training in the use of existing and upcoming tools. Transfer of knowledge and tools for e-teaching are particular topics to address.

Capacities

g. **Sustainability and interdependency.** It is important to enhance the interoperability of facilities and services with network control and management and to develop common operational models to accommodate new and secure services. Many institutions or network-related facilities do not have enough human resources to exploit fully the benefits of their level of investment in the technology. Moreover, career development for researchers in this field has so far been neglected and needs fresh consideration. Therefore, not only is it necessary to sustain investment in the infrastructure, but it is also crucial to invest in long-term career plans for the most competent experts.

h. **Virtualisation.** Users want to have services delivered and do not really want to bother with the exact location or technology of connectivity of the network service. As a consequence, Europe should promote the virtual provision of services, including computing resources, storage services, data-repository services, collaborative tools and communication services in the most convenient way for researchers. Simultaneously, issues of security standards and data integrity are of high importance as a protection against misuse of virtual services. It is necessary to design a robust distribution of facilities across Europe that can interoperate and bridge the gap of the digital divide. This would create a rich ecology of dedicated facilities for European researchers. Europe can then become a hub for virtual communities.

i. **Support.** Institutions must be able to provide complete technical support to end-users, especially to inexperienced or occasional users, as a way of promoting the network service. This should include not only the network-related aspects of the service but also the provision of modern equipment and tools, and guarantee high security and data standards. Modular and decentralised development of tools and services should be implemented via dedicated European virtual organisations and communities. Existing and emerging services, tools and software require structured financial support for development, maintenance and use at both national and European levels.

Appendix C Technical issues

The EARNEST study of technical issues focused on the technologies that are currently used to build research and education networks, identified the problems associated with them, and considered how technological developments may change the way in which these networks are provisioned in the next five years and beyond. The study was split into four main areas of investigation: transmission technologies, control-plane technologies, operation and performance issues, and middleware. The study examined in particular technologies that are likely to be suitable for national and pan-European research and education networks, although it also took into account research and education networking at the regional, metropolitan and campus level.

The findings of the study are based on a series of separate meetings with leading equipment suppliers and research institutions, as well as information obtained from other sources such as technological briefings and research papers. The relevant organisations were identified and interviewed with the assistance of a panel of technical experts drawn from the research and education networking community.

Transmission technologies

Increasingly, research and education network organisations have access to 'dark fibre' and in some cases they are now managing all aspects of transmission themselves. This means that issues such as fibre quality and the capabilities of transmission equipment have become much more relevant than before. Nevertheless, most research and education networks are likely to be limited to existing fibre installations for the foreseeable future.

The fastest currently available transmission equipment is able to support 40 Gb/s using SDH/SONET (OC-768) over a limited number of wavelengths, but this is currently perceived as prohibitively expensive for most research and education network organisations. Although prices for SDH/SONET interfaces are expected to drop significantly soon, it would seem that next-generation Ethernet will become the transmission technology of choice for those networks that do not have legacy telecommunications issues.

Most vendors appear to be focusing on 40 and 100 Gigabit Ethernet (GE) for next-generation transmission systems, and are adding carrier-class features such as OAM&P and virtual-circuit functionality. It is anticipated that the first implementations of 100 GE will arrive around 2010 or 2011, with 40 GE perhaps providing an alternative to OC-768 by 2009. For both 40 and 100 GE, improved modulation techniques are eventually expected to allow these technologies to support long-haul links.

Most vendors see a limited requirement for provisioning more than about 80 wavelengths over a single fibre. 50-GHz channel spacing appears to provide a good trade-off between faster line rates and longer reaches, although this is likely to be of limited concern to research and education network organisations that currently only use a fraction of the potential capacity of their fibres. However, the availability of ROADMs and wavelength-selectable interfaces on switches and routers will make WDM systems simpler and cheaper to provision and operate.

Control-plane and routing technologies

Research and education network organisations will continue to focus heavily on IP services, although the trend towards hybrid networks is likely to continue as network organisations move increasingly towards operating the underlying optical infrastructure. At the present time, the IP and optical domains largely have to be managed separately, but the introduction of GMPLS and virtualisation frameworks such as UCLP promise a more integrated approach. It is possible that production IP services may eventually become just one of many other services provisioned over a dynamic lightpath infrastructure.

With respect to IP services, there are some concerns over the future scalability of the routing system. Although these problems are not imminent, the IAB and IETF recently started to investigate whether addressing and routing could be made more efficient so that it becomes less reliant on hardware developments. In addition, there are revised predictions saying that IPv4 address space may be exhausted within the next five years, which is sooner than expected earlier. IPv6 has already been widely adopted by NRENs, which should be well-placed to support the transition from IPv4, but campuses should start developing migration strategies if they have not already done so.

Operations and performance

It is likely that most NRENs and international backbones will continue to rely on overprovisioning to ensure reliable performance. There is currently limited demand for premium services and there is little value in devising complex bandwidth allocation models when additional links can be established over 'dark fibre' at marginal cost. Where customers or users have very demanding requirements, lightpaths can be used to provision dedicated private networks, and this should become a more dynamic process as better control-plane and virtualisation frameworks are developed. However, recognising that some edge networks may still have bandwidth limitations, QoS transparency should be supported in core IP networks in order to allow QoS and other traffic engineering mechanisms to be deployed over them.

Unfortunately, hybrid networks complicate network management because the IP and optical layers have evolved somewhat separately, and therefore have different management protocols, tools and operational procedures. There are a number of initiatives in the research and education community to develop tools for monitoring and managing optical networks, but these are at quite an early stage of development and offer limited integration with the IP layer. In addition, more comprehensive network monitoring is needed for understanding and managing networks, although it remains hampered by a lack of standards and is challenging to undertake at line rates above 5 Gb/s.

Another important issue for network management is that operational experience shows that around 90% of all reported problems in modern networks are due to issues at end-sites, many of which are attributable to so-

called ‘middleboxes’ such as firewalls, NATs, rate shapers and intrusion detection devices. These devices that are supposed to help manage and secure the network, can often end up making things more complicated and less secure, as well as hampering performance and delaying network upgrades. Therefore, consideration needs to be given to better placement and management of such devices.

The PERT of the GN2 project has successfully traced many of the problems that afflict users of GÉANT2 and other connected networks, in most cases demonstrating that the problems are at the end-sites. Unfortunately, it currently has a limited scope, and if the PERT concept is to evolve, it needs to be extended to NRENs and possibly to regional and/or campus levels as well. This should be accompanied by the establishment of standard operating procedures and common informational and tracking systems.

Middleware

In the middleware area, identity federations are becoming increasingly important for handling and supporting user access to remote (e.g., Grid) or roaming (e.g., wireless) services. The majority of the NRENs in Europe either already have a federation or are in the process of establishing one. Those without a federation should plan to have one in place within the next couple of years.

As NRENs are the natural candidates for providing technical and organisational co-ordination for research and education communities, they are also in a good position to co-ordinate the deployment of AAIs and federations (either directly or through outsourcing). Support for multiple trust infrastructures should therefore be considered in order to use AAIs for different purposes. In addition, as identity federation implementations mature, consideration should be given to ways of supporting new features such as integrating federations with Grid applications, facilitating inter-federation peering and interoperating with other technologies.

SAML 2.0 is expected to gain more momentum as a mechanism for exchanging identity assertions within identity federations and for Web-based applications. As identity federations make more use of attributes for authorisation, it appears that SAML is becoming the standard exchange protocol. Nevertheless, other models, such as the user-centric OpenID, seem less keen to adopt SAML. Furthermore, other services (e.g., Grids) still make wide use of digital certificates, which are not much used by identity federations.

To facilitate interoperability it is important that efforts are directed towards developing syntax and semantics for exchange of attributes. Initiatives like eduPerson and SCHAC can play an important role, although there are other methods such as attribute certificates or signed tokens. Unfortunately, there is still no well-established standard for communicating identity data to applications; this is an area in which NRENs might be proactive.

Other AAI models such as user-centric identity management or the abstract identity framework may yet prevail beyond the academic community and NRENs should continue to monitor these developments. However, users might still be able to use their federated identities with services that support these models.

Appendix D Campus issues

The EARNEST study of campus issues looked at networking arrangements at institutions of higher education and research in Europe.

The importance of campus networks

Higher-education and research communities in Europe and across the world are working more closely together, and they depend increasingly on top-class networks for effective communication. GÉANT2 and national research and education networks deploy leading-edge technologies to support these communities. To ensure high-quality services for end-users, it is vital that the networks within institutions deploy matching capabilities.

In 2003, SERENATE indicated that there were network bottlenecks at the campus level, but responses to the EARNEST surveys of both campus IT managers and researchers show that this is no longer a problem. In the last four years there has been significant investment in the network infrastructure within institutions and there are now few persistent bottlenecks. However, there is still scope for improvement. Some bottlenecks will disappear when the remaining examples of outdated equipment and cabling are replaced. Other bottlenecks appear to be caused by unnecessarily restrictive security arrangements. This sometimes happens because network support staff find it easier to eliminate risk by imposing a total ban on some services. Institutions should carefully assess the risks associated with their campus networks and adopt only the most appropriate and, whenever possible, less elaborate security measures.

The involvement of institutional management

The importance of networks in institutional strategic planning is growing rapidly, as research institutes and institutions of higher education become increasingly dependent on network services for so many activities. Effective institutional network strategies are essential; they should be established following consultations between the institution's senior managers, the user community and the network support staff. Too often end-users are not involved in policy making.

The EARNEST study of campus issues found that the network infrastructure in institutions is generally satisfactory. However, in many cases this seems to have happened by accident rather than by good planning, because a coherent policy for networking does not appear to exist. It is especially important to have effective policy-making mechanisms where there are demanding applications and projects.

It is also important that institutions provide sufficient resources to meet policy objectives and growing demand. In many institutions the network support team is too small to meet present-day demands. As a result, team members spend much of their time 'fire fighting', and they dare not risk offering new services to their user community because they believe that they would not be able to cope with the extra workload. Often there is not sufficient staff or expertise to provide the appropriate level of training and support.

End-users

There is a strong message from the EARNEST surveys that significant numbers of end-users are not aware of the availability (or even the existence) of many network and network-related services. Steps should be taken to promote greater awareness and provide appropriate training. A typical example is videoconferencing.

There is an important paradigm shift now taking place in networking, from only providing connectivity to offering and supporting network services. Institutions should carefully assess whether they are sufficiently equipped to support the rapidly changing nature of networking, and take appropriate action where necessary.

It has also emerged from the EARNEST surveys that many institutions do not have formal mechanisms to identify the networking requirements of end-users. If the needs of the user community are not known, especially for innovative and demanding projects, it is extremely difficult to plan ahead. In many institutions end-users should be much more prominently involved in network policy making.

Network support

Research institutes and institutions of higher education need well-trained and resourced network teams to support the major cultural change in networking as the emphasis moves from providing connectivity to providing network services. To remain competitive it is important that institutions accomplish this change quickly and effectively.

First of all, institutions should ensure that their networking infrastructure has a sound basis to meet the increasing demands placed upon it. Measures that they might take include:

- setting aggressive replacement policies for equipment with a maximum life expectancy of five years;
- adopting institution-wide specifications for network infrastructure, including elements controlled by departments or faculties;
- ensuring seamless end-to-end connectivity where a particular quality of service is required;
- providing support and training for performance optimisation, especially to demanding users;
- providing IPv6 services at network level, and taking the appropriate steps to migrate to IPv6 at transport and application level.

Institutions should also take steps to help their support staff and end-users adapt to the changing network environment, including:

- making arrangements for network support teams to be re-trained in order to keep up with fast changing technologies;
- establishing strong, formal arrangements for collaboration with other management domains, e.g., NRENs, intermediate networks, other institutions;
- encouraging network teams to share their expertise with colleagues in other management domains;
- providing training courses and good-quality documentation for end-users to raise their awareness of the network services available and promote their use; examples include videoconferencing, multicast, video broadcasting, video on demand and IP telephony.

The area of security requires special attention, because the impact of security failures grows enormously as users increasingly rely on the network for mission-critical activities. Sometimes it is not easy to assess the potential risks involved in providing the more contentious network services (for example, those using peer-to-peer technologies), but absolute bans are not the answer. Institutions should adopt effective security measures that are appropriate for the purpose and do not hinder the effective use of the network. They should also create a formal security team with a wide remit and a considerable degree of independence from the institution's central IT service.

An important role for NRENs

NRENs have an important role to play in assisting research institutes and institutions of higher education to develop more effective networking services. Areas where NRENs and institutions would benefit from closer collaboration include:

- developing guidelines for institutional network policies;
- sharing strategic information;
- obtaining a better understanding of the requirements of high-end users;
- deploying key services;
- organising training for innovative services;
- providing support and training about performance optimisation for end-users with demanding projects;
- supporting a smooth transition to IPv6;
- co-ordinating working groups for network staff to share expertise.

Technologies

Some warnings are in order. In the first place, it is notoriously difficult to foresee future trends in IT and EARNEST believes it is impossible to predict with confidence which new network technologies will become commonplace in a few years' time. Secondly, several major innovative uses of the Internet have taken place at the application layer using existing technologies. Nevertheless, they have resulted in significant increases in network traffic and a need for greater bandwidth. Because these developments were not technology-driven, they were not considered in the context of the survey of technologies conducted by the EARNEST study of campus issues.

No radical technology developments, but constant evolution

The survey on technologies showed that there was no convincing evidence of emerging technologies that were likely to have a major impact on campus networks in the near future.

This conclusion could bring some comfort to institutional IT managers and network teams, but it would be a great mistake to become complacent. Most areas of technology are evolving incrementally and some of them at a relatively fast pace. Change is ongoing and requires very close attention and serious planning to keep the technical infrastructure on campus up to date. This is especially important for institutions hosting end-users with very demanding requirements.

Underlying drivers for the deployment of technologies

Several criteria should be taken into account when choosing technologies to upgrade the network infrastructure. These include improving connectivity and services for end-users, increasing the bandwidth to the NREN, making the network more transparent and user friendly while keeping security under control.

Introducing technologies that will help to provide high-performance end-to-end services is extremely important for collaboration in the areas of research and teaching. Close co-operation between institutions and NRENs should help the coherent deployment of several of these technologies, improve interoperability levels between NRENs, MANs, regional networks and campus networks, and ensure seamless end-to-end services with improved quality of service.

Intelligent network architectures to reconcile innovation and security

Often, the main technological components are already in place on campuses for providing high speeds and the basis for end-to-end services. However, inflexible security architectures often deny end-users with demanding applications access to the functionalities needed for innovative use. Institutions should pay greater attention to the architectural design of their network with the aim of facilitating better end-to-end connectivity for innovative uses, while at the same time continuing to enforce the appropriate information system security policies. More security functionality should be applied at the end-node level instead of being concentrated at the edges of the network.

When there need to be firewalls between campus networks and national research and education networks, they should not unnecessarily lower the performance of the network.

Higher bandwidth for all; dedicated capacities for specific demands; guaranteed performance

Research institutes and institutions of higher education must be prepared to meet the requirements of demanding applications and projects by deploying appropriate technologies. All end-users should obtain appropriate bandwidth without undue limitation, and specific requests coming from very demanding applications should be fulfilled, such as end-to-end dedicated connectivity with guaranteed bandwidth.

- Optical infrastructures (quality of fibre) need to be upgraded so that end-to-end wavelengths or circuits at speeds of 10 Gb/s or higher can be established on demand. Where there is a lack of fibre, WDM equipment should be installed to alleviate this problem.

- It is too early to advocate the implementation of forthcoming OAM&P Ethernet technologies. Nevertheless, attention should be paid to their evolution since they could soon be at the heart of wide-area community networks and facilitate the deployment of high-performance end-to-end circuits. They could replace some of the MPLS infrastructures and avoid the need to deploy too many wavelengths.

- Network resources are not unlimited and they have to be shared between multiple end-points. Consequently, there is a need for environments allowing demanding applications to share requested resources without coming into conflict with other applications. Most NRENs offering dedicated network resources run different variants of MPLS associated with Traffic Engineering and class of services, on top of IP networks. These technologies can also be implemented at the campus level, although there is evidence that their main advantage is on WANs.

- Configuration and management tools (GPMLS, UCLP) for dynamic allocation and control of the bandwidth (based this time on IP networks, Ethernet or wavelengths) are still under development, and it is not yet clear whether campus networks will have to integrate and master these technologies. Different variants of MPLS are commonly in use today by NRENs.

- Campus network teams will have to deploy monitoring tools, such as PerfSONAR. These are crucial for end-to-end control of quality of service.

Collaboration between NRENs and institutions will be vital to ensure proper deployment of most of these technologies. There will also need to be some co-ordination of test beds, either at national or European level.

Secure networking - anytime, anywhere

Wireless connectivity is now well established and end-users expect to gain access to their usual network services while they are visiting other institutions. It is common practice for only authenticated and authorised end-users to be granted access to network resources for connecting to the Internet or an intranet. In order to facilitate the authentication and authorisation process for roaming users, AAI technologies like eduroam are being deployed and institutions should integrate such technologies into their portfolio and become part of a global landscape.

On their own, basic authentication and authorisation mechanisms, such as those implemented by eduroam, do not provide sufficient security when mobile users request access to intranets. There is also a need for NAC-like (Network Access Control) technologies to perform 'sanity' checks on the remote device, and for more granularity in the authorisation process so that a different service package could be offered to the connected end-user, depending on his or her profile and the security risks introduced by the connecting device.

Distributed remote resources

The way to find and access relevant resources for research, teaching or learning has very much changed over the last decades, with much scientific, technological and cultural content accessible online. Some resources are freely available. Others require authentication and authorisation as a preliminary step. Researchers are also making extensive use of collaborative platforms, Grids, remote high-performance computing, remote scientific equipment etc. Again, authentication and authorisation are normally needed before access is granted. In order to help their end-users to access remote resources as easily as possible, institutions should consider using trusted Authentication and Authorisation Infrastructures, for example those based on identity-federation technologies. It is important to note that successful use of trusted AAI implies that an institution runs an effective identity management system covering all end-users within its own information systems.

Anticipate new requirements and new technologies

Institutions should have a policy of actively tracking possible new developments in their research communities, especially those requiring specific network services which entail upgrading the network infrastructure and possibly the architecture of the network.

For institutions to install, configure and run appropriate technologies, they must have the right expertise available at the right time. Vigorous collaboration between NRENs and institutions would assist greatly in achieving this.

Appendix E Economic issues

The EARNEST study of economic issues examined the costs of pan-European research networking based on a cost analysis of the GÉANT2 network. The analysis concentrated on the different types of cost and the way in which these costs vary across the geography of the network.

Three types of network cost are identified: transmission, hardware and operations costs. The transmission costs are the dominant ones, representing some 60% of the total annual cost of the GÉANT2 network. Transmission costs are also important because they are the only costs that vary geographically within Europe. This variation of costs has historically been due to the relative competitiveness of the market for international connectivity (transmission) to a country. GÉANT2's predecessor network (GÉANT) was entirely based on connectivity that was leased on an annual basis from telecommunications service providers. GÉANT2 differs from its predecessor because in GÉANT2 connectivity is also provided by lighting fibre, leased on a long term basis and equipped with hardware to provide wavelength capacities. Therefore, a specific analysis has been carried out of the costs of acquiring and lighting fibre.

The digital divide

In 2003, the SERENATE study described the issue of the digital divide – specifically, varying telecommunications costs across Europe for the same service - that was affecting European research networking. The EARNEST study of economic issues has shown that, far from disappearing, that digital divide in Europe is alive and well.

Figure E.1, which also appears in Section 6 of the current report, shows the cost of connectivity in GÉANT2 in 2006 for capacity leased from telecommunications service providers versus the number of potential suppliers. The figure is very similar to the picture showing the situation in 2001 that was published in the SERENATE Summary Report.

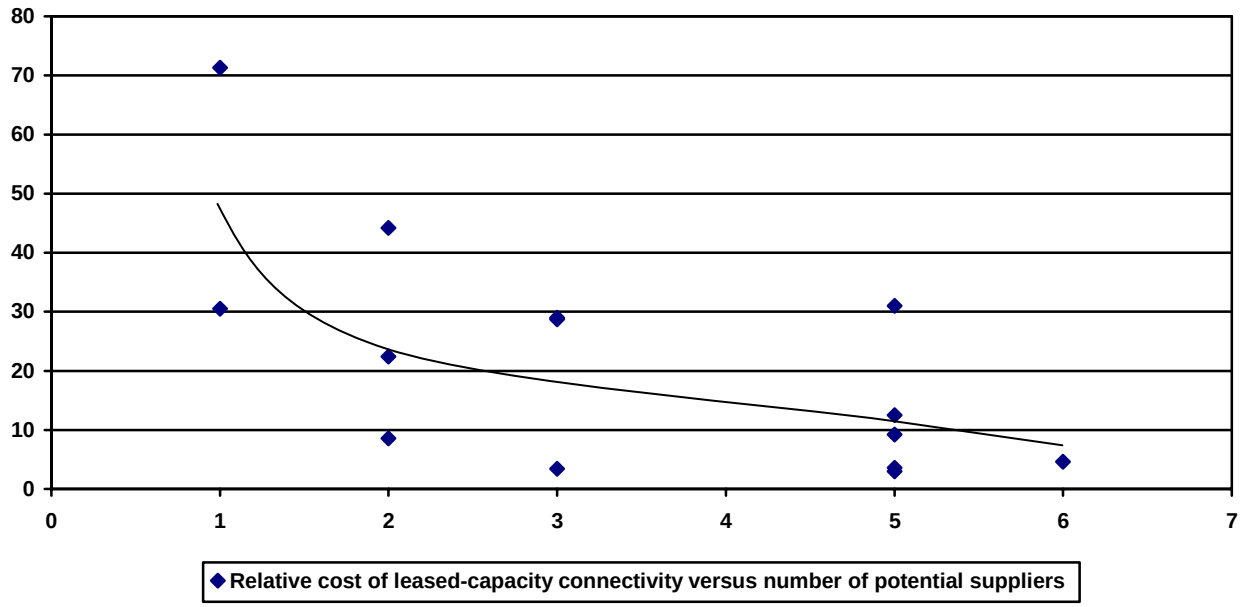

Figure A5.1: GÉANT2 digital divide

It shows a strong correlation between the cost of leasing international connectivity within Europe and the number of potential suppliers of that connectivity, indicating that lack of market competitiveness for international connectivity remains a significant issue for certain parts of Europe today.

The geographic divide

In addition to the digital divide related to the competitiveness of the telecommunications markets, a new geographic divide is appearing in Europe as investment in fibre has replaced leased circuits for much of the transmission in the GÉANT2 network. There are four factors involved in the geographic divide:

- Firstly, there is a division between countries where international fibre is available and those where it is not.
- Secondly, even where fibre is available, the cost of connectivity provided via fibre is heavily dependent on geographic factors, notably route length. The length of a route will have a strong influence on its construction costs. The cost of equipping a route with transmission equipment is also dependent on route length, because the technology requires equipment to be sited at regular intervals along the route (typically around 80 kilometres). Thus, even if the market for leased fibre is very competitive, longer routes will necessarily be more expensive.
- Thirdly, the reality is that the market for leased fibre in Europe is not uniformly competitive. Analysis of route costs on a 'cost per kilometre' basis, thereby eliminating to some real extent the distance component, shows that there is considerable variation (as illustrated in Figure E.2). Nevertheless, in practice less competitive locations with shorter international routes are cheaper in absolute terms than more competitive locations with longer routes.
- Finally, looking at the geography of routes, those in the centre of the network have a higher population of wavelengths than those at the edge and are therefore cheaper per wavelength, as the investment cost is shared by a larger number of wavelengths. Table E.1 below illustrates this. The average wavelength cost on the route Dublin-London will be a factor of 6 higher than between Frankfurt and Geneva, solely because of the location of the route in the network (edge versus centre).

In summary, things have changed over the last five years, but they have not improved for the most expensive or least central locations. Indeed, there is a danger that the digital and geographic divides are becoming institutionalised, as the political focus has moved away from telecommunications liberalisation.

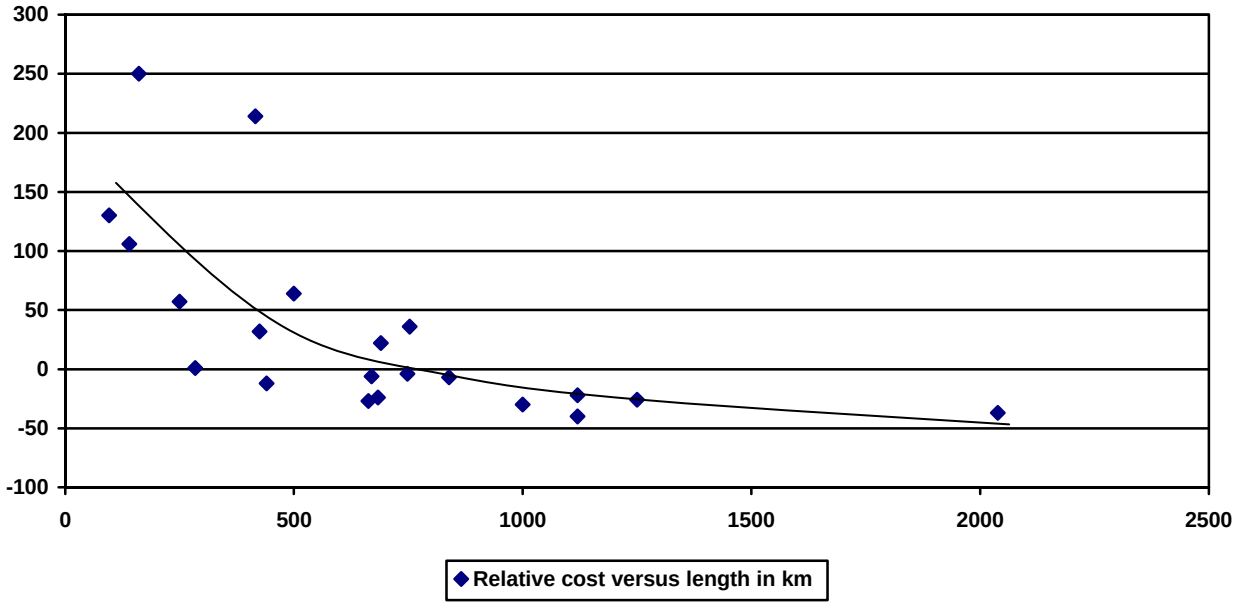

Figure A5.2: Comparison of GÉANT2 routes: variation (in %) of cost per kilometre versus route length (in km)

Route	Leased capacity GÉANT (2003)	Lit fibre GÉANT2 (2006)
Dublin-London (edge)	1	2
Frankfurt-Geneva (centre)	1	12

Table A5.1: Edge versus centre: number of wavelengths

Pricing principles

The variation in the cost of international connections to a country became a factor as liberalisation proceeded at different speeds in Europe. This variation was reflected in the prices that NRENs paid for service from the pan-European research network. As the variation could then reasonably be attributed to a lack of competitiveness of the telecommunications market of a country, this was a reasonable approach to pricing.

Another factor affecting pricing principles is the service portfolio provided. A best-effort IP service is a resource that is shared by all NRENs connecting to the pan-European network. In GÉANT2 the service portfolio has been extended to the provision of point-to-point connections between pairs of NRENs. In contrast to a best-effort IP service, the resources consumed by point-to-point services are dedicated to the end-points. The point-to-point services are currently provided at incremental cost, with the major cost of GÉANT2 being funded by IP service subscriptions. If all NRENs had equivalent access to, and demand for, point-to-point services, this

would not be a serious issue. However, the digital and geographic divides militate against this universal provision of services.

With the investment in fibre, underlying transmission costs are now much more strongly related to geography than to market competitiveness. Indeed, because of distance-dependent costs, more competitive links on a per-kilometre basis can be more expensive when distance is factored in. From a policy point of view, pricing on the basis of geography raises a number of issues. These, coupled with the fact that point-to-point services are effectively subsidised by the more general European IP service, imply that the historic approach to pricing based on market competitiveness of international connectivity is no longer feasible and that a new approach to pricing principles needs to be developed.

Expensive routes

Another factor is the problem created by fibre investment in locations with high prices. Where leased wavelengths are very expensive, it may still be possible to justify investment in fibre. This may potentially save money, but it is likely to freeze route costs for the routes concerned for a period of several years. That institutionalises the non-competitiveness of connectivity and extends the time scales for creating a more competitive environment in Europe. Figure E.3 illustrates this point.

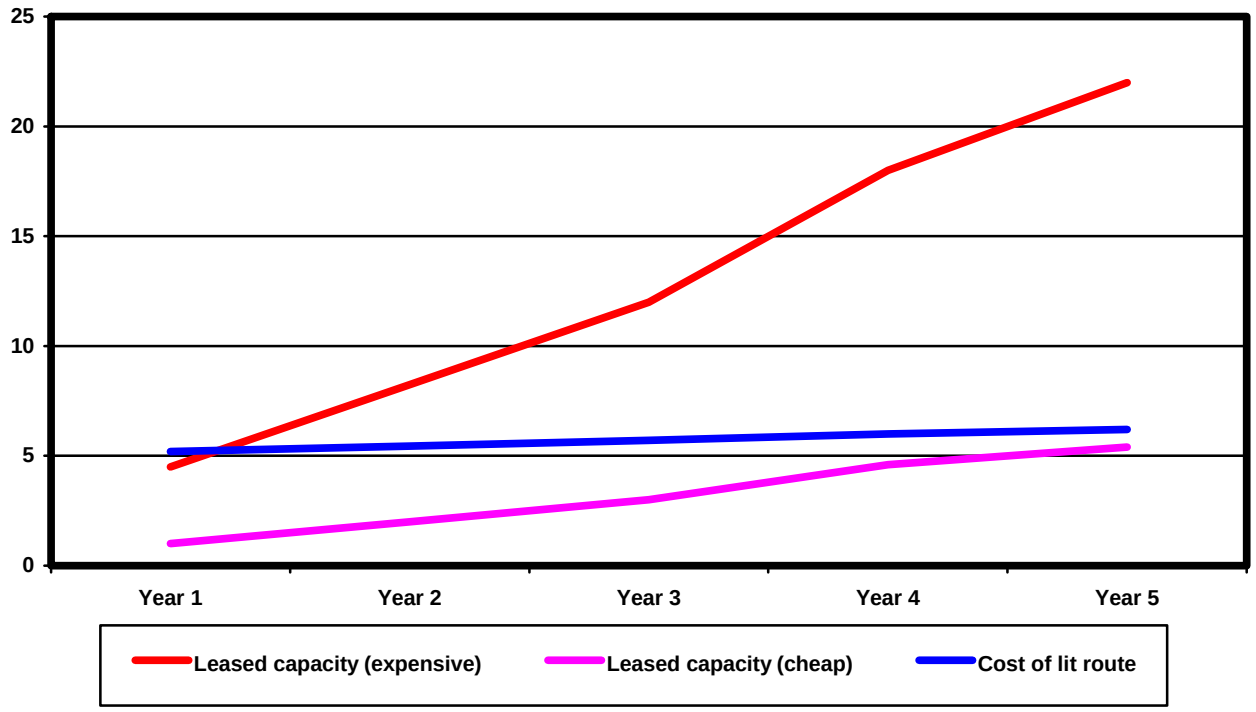

Figure A5.3: Breakeven analysis for a given route: relative costs for expensive and cheap leased wavelength

The figure shows that an investment in fibre would never break even if leased capacity was competitive, but where a leased circuit is 400% more expensive than the norm, a business case can be made. However, this has the effect of maintaining an uncompetitive route cost.

Conclusions

The cost of connectivity remains the most significant cost in the operation of the pan-European research network GÉANT2. It has a significant geographic element that can be directly related to the provision of service to a country. Historically, this geographic element was related to market competitiveness. GÉANT2 differs from predecessor networks in that a significant part of the connectivity is provided using fibre acquired and lit by the project. For those areas of Europe where fibre is not available, an analysis of connectivity costs in GÉANT2 has shown the continuation of a digital divide, earlier identified in the SERENATE report. An analysis of costs of fibre routes has shown that geography, rather than market forces, plays a significant role in the cost of connectivity, with countries further from the centre of Europe having higher connectivity costs in absolute terms, even if these costs may be relatively competitive when distances are factored out. The evolution of the portfolio of connectivity services, which now includes dedicated connections between NRENs, is an additional development, which together with the geographic issues associated with costs identified above, should lead to the examination of pricing principles for pan-European networking to ensure that equitability and cohesion are encouraged.

Appendix F Geographic issues

The EARNEST study of geographic issues looked at the disparities in the available infrastructure and network-related services for researchers and academics in different parts of Europe. Its aim was to produce an enhanced, concrete and structured method of measuring the status of the development of research and education networking in order to contribute to a deeper understanding of the digital divide.

It is generally difficult to gain an overall understanding of the digital divide. There are multiple definitions of the concept, conflicting reports on whether the digital divide is widening or narrowing, and a range of opinions about what the key factors are that affect the digital divide. There are also different approaches to addressing the problem of the digital divide and there is no single solution that could make a major difference in this respect. EARNEST has found that the disparities between the 'haves' and the 'have-nots' are clearly growing, and that the potential impact on society may be exacerbated by technological breakthroughs and/or novel business and operational models.

In fact, the digital divide is a complex problem that manifests itself in different ways in different countries. It may be due to infrastructural, social, economic, educational, regulatory and other causes. These include unavailability of digital resources and technologies, difficulty in accessing them, unawareness of their availability or capabilities, and lack of understanding of how to access and use them. The digital divide presents both practical and policy challenges. Moreover, it is apparent that solutions that work in developed countries cannot simply be transplanted to the environment of a developing country: solutions must be based on an understanding of local needs and conditions. Real disparities exist both between countries (the 'international digital divide') and between groups or regions within countries (the 'domestic digital divide'). There is a wealth of statistics and anecdotal evidence to support this statement.

The most frequently encountered factors contributing to the digital divide in research and education networking include limited budgets, relatively uncompetitive telecommunications markets, uncertainty about subsequent phases of planning and support for the national network, an ineffective NREN management structure etc. If these factors remain unaddressed, they will continue limiting the prospect of digital inclusion for the regions that are still lagging behind.

Ongoing actions to reduce the digital divide

There have already been various actions to reduce the digital divide in the regions investigated by the EARNEST study of geographic issues, which addressed in particular, but not exclusively, the NREN

environment. These efforts have covered a wide spectrum of activities, focusing primarily on two main lines of action:

- studies, including: digital divide studies, monitoring of NREN development indicators, international workshops, and other 'recommendation-oriented' types of actions, resulting in declarations, expressions of solidarity and commitments to action plans;

- projects, including EU-funded regional projects that aim to address the digital divide in developing parts of Europe and the world (SEEREN, EUMEDCONNECT, Porta Optica, SEEFIRE, OCCASION, ALICE etc.), as well as other projects funded by international organisations and other 'subsidy-oriented' types of actions that in most cases entail building of human networks, connectivity fees or infrastructure development and deployment.

These actions have had a significant impact in easing the digital divide. Such initiatives should continue, but they should involve all stakeholders and identify at the start champions who may guarantee the sustainability of what is achieved by the initiative after the end of its lifetime. There is also a need for co-ordination between national governments and EU institutions to orchestrate an umbrella initiative incorporating EU Structural Funds, Neighbourhood Policy Actions, focused calls for proposals in EU Framework Programmes and other elements to leverage the sustained impact of NREN development activities. Furthermore, there would be a lasting impact and sustainable structure if – instead of continued short-term interventions on a project basis – a more permanent institutionalised model for NREN development would be established, with a national budget that would be guaranteed for a period of 5-7 years.

REDI: the Research and Education Networking Development Index

Defining, measuring, quantifying and tackling the digital divide is a multi-faceted challenge. EARNEST has produced an enhanced, concrete and structured method for measuring the development of research and education networking in a country, in order to contribute to a deeper understanding of the challenges posed by the digital divide and digital inclusion, and of digital opportunities. It also suggests ways of addressing these challenges and opportunities in a more effective way.

The Research and Education Networking Development Index (REDI) is a framework that can help quantify several elements related to the digital divide. Following international best practices and in order to be able to reveal specific aspects in the development of research and education networks, the REDI indicators are assembled in five homogenous groupings/sub-indices, namely 'affordability', 'infrastructure', 'quality', 'knowledge' and 'usage'. Each one of them is composed of several indicators. Main selection criteria for the indicators that combine into the REDI's sub-indices are the availability and quality of data.

Overall initial REDI findings indicate that, as far as REDI's main sub-indices and the main REDI index are concerned, there is a disparity of more than three orders of magnitude between the countries investigated in the EARNEST study of geographic issues. These findings reveal that researchers in a large number of countries on the wrong side of the digital divide encounter significant difficulties in accessing cutting-edge applications and services for research and education over the network infrastructure.

Correlation with economic prosperity

For the majority of the countries studied, there is a correlation between the wealth of countries (as expressed, for example by the Gross Domestic Product (GDP) per capita) and the stage of development of the NREN, but there are several cases where the correlation is not as strong as one would expect. Nordic countries and the countries that joined the European Union in 2004 score high in NREN development compared to their GDP per capita. This could be attributed to, among others:

- Faster adoption of technological breakthroughs, which makes it possible even for greenfield regions and developing countries to catch up with, or even surpass, developed regions. For example, by taking advantage of access to 'dark fibre', several NRENs in the European Union have significantly increased their network capacities. This points to a course of action to address the digital divide: technological breakthroughs and new business models should be facilitated and sponsored, including research and field trials.

- Recognition of the importance of research and education networking. The low priority given by national authorities to research networking is the single most important hurdle that NRENs still face and need to overcome, irrespective of whether they are based in a developed or a developing country. Usually, the misperception of the importance of research and education networking originates in the national government, but there is only limited effort from the side of NRENs and at the European level to address this misconception.

Correlation with market competitiveness and liberalisation

There is also a very strong correlation between the development of research and education networking and the average Internet tariffs in a given country. Indeed, Internet tariffs can be seen as a strong indicator of market competitiveness in a country. Therefore, governments should proceed to implement national policies that create a favourable climate for stability, predictability and fair competition at all levels, including first and foremost the total liberalisation of the telecommunications market and open access to affordable 'dark fibre' routes.

Correlation with the development of the commercial Internet

There is also a digital divide in the commercial Internet, but it is smaller than in the research and education networking domain. In general, one would expect research networks to have a significantly better performance than commercially provided networks, given their cutting-edge infrastructure and the need to meet the requirements of applications in the research and education sector. However, this is not always the case in terms of, for example, the available international bandwidth per user, even in large and advanced countries with a high GDP. NRENs have to upgrade their infrastructure continuously in order to stay on par with the highest network performance, robustness and resilience. They have to provide state-of-the-art, competitive and user-friendly services to the research and education community to remain highly competitive.

Use of REDI

Overall, REDI can provide policy makers with a comprehensive statistical framework to monitor the development and prospects in research and education networking, including a frame of reference for comparisons over time and between regions. This effectively constitutes a powerful benchmark for monitoring internal disparities in indicators for research and education networking infrastructure, use, affordability, knowledge and quality. It can, in a straightforward way, evaluate the impact of applied research and education networking policies. It must be stressed that REDI is a work-in-progress and caution should be applied in using REDI until further verification and fine-tuning has been carried out.

The following aspects of the REDI framework can be highlighted:

- The overall REDI score (the master index) should be used mainly for assessing and monitoring the overall development status and digital opportunities in a certain country or region. It could also be used as a cross-check benchmark for the five main sub-indices, in order to identify intra-indicator correlations and deviations, for example, by revealing unusually low or high values of one of the five sub-indices compared to the master index.

- Because the five main sub-indices are focused and reveal elements of a more specific nature than the value of the composite master index, they should be used mainly for identifying and delivering measures and policies to tackle the deficiencies in a particular (sub-index) field. In particular, the sub-indices enable more specific benchmarking and quantification that can help shape detailed action plans to address low-ranked attributes.

- From a practical point of view, the development over time of REDI and its sub-indices is significantly more important than a one-year snapshot. Monitoring REDI trends for a region requires a period of at least 3-5 years. Dedicated resources, commitment and consistency of measuring methods are then required in order to carry out the proper process of data collection, validation and analysis.

- Online network measurements may provide an additional tool to identify disparities. It is recommended that NRENs ease access and accommodate homogenised online data measurements across their network infrastructures through online measurement tools and methods.

- The 'TERENA Compendium of National Research and Education Networks in Europe' is currently accepted by the research and education networking community as a reference point of data gathering and archiving. This should be used to build the base of the values of the indicators and to enhance the links between TERENA and its member organisations by providing a value-added incentive to NRENs to provide accurate and prompt figures. The current data-validation mechanism in the production of the annual editions of the TERENA Compendium should adopt a more systematic approach in order to ensure higher accuracy of data. A systematic data-validation mechanism will also encourage further co-operation and co-ordination by including in the communication between NRENs and TERENA other key stakeholders for reducing the digital divide, such as national research and academic organisations, government agencies, ministries and other parties.

Appendix G Organisation and governance issues

The EARNEST study of organisation and governance issues looked into the way in which NRENs in Europe and beyond are governed, funded and organised. The study was mainly based on the results from a questionnaire sent to NRENs, which focused on several areas:

- funding;
- governance, organisation and policy setting within NRENs;
- general operational support for the national research and education network;
- provisioning and support of end-to-end services;
- support and funding for special projects and developing new strategic services;
- connection and support of primary and secondary schools.

The study also used information from other EARNEST sub-studies and information from the 'TERENA Compendium of National Research and Education Networks in Europe'.

As mentioned in Appendix A, two consultation workshops were organised, one with NREN managers and one with representatives of the funding bodies of NRENs. In these meetings, some of the key results obtained in the study area were presented, and feedback was received. In addition, modifications to the recommendations were made as a result of feedback obtained from participants at the EARNEST Final Workshop.

NRENs are part of a multi-level network and support structure that serves the research and education community in Europe and beyond. The SERENATE study recognised that NRENs have become key players in supporting many areas of research and education. The NRENs throughout Europe and beyond have been created to support their communities of research and education institutions by providing networking services and increasingly by developing and providing other, value-added services as well. On the whole, EARNEST found that the NRENs have been effective at providing networking services and often provide new services ahead of those that are available cost-effectively in the commercial market. NRENs have supported some areas of scientific research that would be impossible without the use of advanced networking services. Staying at the leading edge of the provision of networking and related value-added services brings challenges to NRENs, particularly when there are often many competing demands for resources, both financial and human.

Governance models

The study found that there are many different governance models in place for NRENs, with different stakeholders represented in the governance structures of the NRENs. Most NRENs have governance structures that have representation from the research and higher-education communities, which is a healthy sign that NRENs are closely connected to the main communities that they serve. However, the study found that representation from other communities that use NREN services is not always embedded in the governance structures of NRENs. In some instances this could become a contentious issue, particularly if these other user communities provide significant funding for the NREN and feel that they want more influence on the running and development of NREN services.

Approximately two thirds of NRENs are legal entities or part of a larger legal entity. This legal structure gives NRENs considerable scope for making their own decisions and entering into contracts for the provision of services, and it enables them to develop policies, plans and services effectively. The majority of NRENs can make policy decisions autonomously along with their governing bodies and key stakeholder representatives.

Funding and charging mechanisms

The funding and charging mechanisms and the methods of making decisions within NRENs are also diverse, but it is clear that in many cases the government has a good deal of influence on the NREN by providing some funding for the provision of services to support the country's research and education.

Many NRENs do not have budget planning in place for more than one year ahead, which potentially could lead to problems when planning medium- and long-term programmes for network service development and upgrade. This situation is not ideal, because the development and running of networking infrastructures needs to be planned and budgeted over a period of several years. Some NRENs and their funding bodies need to consider how longer-term planning might be improved.

NRENs must ensure that charging mechanisms do not discourage the uptake and use of networking services that support collaborative research and education. If charging mechanisms financially discourage collaborative research, but still have to be in place for economic or policy reasons, then special provisions will need to be made to facilitate collaborative research.

NRENs and European collaboration

NRENs strongly support the view that GÉANT2, the pan-European research and education backbone network, and its successor should continue to be 50% funded by the European Union, with the rest of the funding being provided by the NRENs that connect to the network. A significant number of NRENs are involved in pan-European research and education network policy setting, but there is only a small minority of NRENs that as a matter of course implement the policies.

Many NRENs only implement European policies if they are in-line with their country's existing or future research and education networking policies. The majority of NRENs clearly wish to remain autonomous with respect to implementing European policies, even when they fully participate in European research and education networking policy discussions and agreements. This may pose a problem, particularly if certain policies are needed to enable the effective delivery of end-to-end services.

It is clear that further collaboration in setting, agreeing and implementing policies is required so that the necessary policies are in place to support the development and delivery of end-to-end services across Europe and beyond. It is also important that the policies are not developed in isolation by European policy-setting groups, without the wider reference to global policy development. If end-to-end services are to be delivered effectively, the focus for NRENs in the next few years needs to be on developing and then implementing appropriate polices that will allow networking services to be delivered across multiple network domains in Europe and beyond.

It is important that effort is not wasted by supporting parallel, alternative developments that result in incompatible policies and processes, because that would inhibit the roll-out of collaborative research and education activities on a European and global scale.

Service portfolios and Service Level Agreements

Different NREN organisations provide very different levels of technical and operational support for their networks; different parts of the networks are often supported to different degrees, using different combinations of NREN staff, outsourced services and staff from universities and research institutions. The hours of guaranteed support are very different among the NRENs, which could become an issue as more collaborative research is conducted using multiple NREN infrastructures. If some NRENs cannot provide the necessary level of support, it may be difficult to assure users that they can rely on all NREN infrastructures for conducting their collaborative research with different countries. It is clear that this is an area that needs to be looked into thoroughly when planning collaborative research and education projects between countries with different NREN support arrangements.

Only a small minority of NRENs deliver services in line with an agreed Service Level Agreement (SLA), whereas many of the commercial telecommunications operators that provide services to many different types of users do offer SLAs. The lack of the use of Service Level Agreements or Service Level Specifications by NRENs does not mean that they deliver poor services or that they are not effectively monitoring and maintaining services. However, the lack of SLAs could be a point of weakness or even a threat when having to justify using NRENs rather than commercial providers, particularly to new potential user communities, which are not familiar with the ethos of the way NRENs function and provide services. These communities might expect some formal commitment to agreed service levels in return for providing funds.

Several NRENs are delivering or aspiring to deliver end-to-end services, which allow projects to be supported that require more than just a commodity network service, and take away the need to build separate network infrastructures for such projects. Some NRENs are planning the automated set-up of end-to-end services, which will allow network services to be configured quickly and cost effectively. However, the variability of existing arrangements to support end-to-end services will pose some challenges in certain areas when collaborative research projects are being planned. The research projects will need to liaise closely with all the NRENs involved in order to ensure that end-to-end services can be reliably set up and delivered.

The wider role of NRENs

NRENs are all taking a wider role in the support of their country's national research and education programmes by getting involved in strategic projects in addition to continuing to provide high-quality networking services.

This move by NRENs to take a broader role is building on the success of the provision and support of networking services to the research and education communities. It shows that the education communities that are stakeholders in NRENs have confidence in their NRENs to broaden their remits to include additional support and services.

Several NRENs have already connected a wider range of institutions than just universities and research institutes, and others are planning to do so. These institutions can include primary and secondary schools, tertiary and professional institutions, organisations supporting health services and government departments.

Awareness of NRENs and GÉANT2

EARNEST revealed that there is very little awareness in the research community of the existence of the pan-European network backbone, GÉANT2. However, this can also be seen as an indication of how smoothly and transparently the NRENs and GÉANT2 provide services. The lack of awareness of GÉANT2 in itself is not a problem, but if support for the funding of a pan-European research and education network backbone is to be maintained, it may become more important that the research community is made aware of the importance of GÉANT2 for facilitating collaborative research.

Conclusions

The EARNEST study of organisation and governance issues has resulted in several recommendations, which if implemented, should improve the governance and organisation of NRENs and the support that they can offer to the research and education communities. In particular, it is clear that further policy development, agreement and implementation are required so that end-to-end services can be delivered.

The challenge for NRENs is to support more complex services across Europe and beyond, so that collaborative research and education can continue to flourish and expand. The delivery of reliable and supported end-to-end services is going to be essential for major projects.

The development of best-practice models for NREN governance was started as part of the study, but it is the NRENs themselves that need to put in place the appropriate structures that will allow them to better plan, develop, implement and support the state-of-the-art services that will be needed to support collaborative research and education throughout Europe and beyond.

NRENs have an excellent opportunity to continue to provide crucial support to the research and education community. However, they cannot do this by acting alone. They need to increase collaboration on policy making within the NREN community but also with the research and education communities. This can be done by building on existing successful collaborative structures such as TERENA, and by ensuring that they make best use of work carried out elsewhere, to avoid duplication of effort.

Appendix H Requirements of users in schools, the healthcare sector and the arts, humanities and social sciences

One of the seven EARNEST sub-studies has looked into the requirements of 'other' users. Increasingly, research and education networks (at the national, regional and local level) connect not only researchers, teachers and students in research institutes, universities and other institutions of higher education, but also other kinds of users (in the public sector). This greater 'inclusiveness' of research and education network infrastructure and services in Europe is a development of strategic value, both for the research and education networking community and for the 'other' users themselves.

EARNEST has focused on three user communities, namely schools, the healthcare sector, and the arts, humanities and social sciences.

It is important to note that it is now quite well understood how to connect schools and therefore EARNEST focused on the actual use of networks by schools. The arts, humanities and social sciences are also a community where networking plays an important role. Similarly, EARNEST has studied the network use of this community and the services that are being requested. By contrast, the healthcare sector is a very new area for the research networking community. EARNEST has collected more detailed information about this sector and its needs; that information will be useful for those research and education networking organisations that wish to establish a plan or strategy to work with this community of (potential) users.

Schools

In recent years, NRENs all over Europe have increasingly brought Internet connectivity to schools. The different technical and organisational options for connecting schools and their pros and cons are now well understood. The exchange of information between NRENs in the past 3-4 years has enabled NRENs to learn from each other and find the best solution for their own countries.

It is now time for research networking organisations to go one step further and to look systematically at the services that can be provided to schools by NRENs (and others) and at the actual use that schools make of the Internet and the resources available via the Internet for the teaching and learning process.

This is the subject of a study report written by Andrew Perry (Department for Children, Schools and Families, United Kingdom).

This study provides qualitative information based on interviews and feedback from practitioners about the use of network connections. For those interested in figures and comparisons between countries, the study provides references to interesting quantitative studies. Indeed, one surprising remark in the study is that virtually every school in Europe has access to the Internet: in most countries the rate is 100% or almost 100%. Here we must note carefully that a school having access to the Internet does not mean necessarily that the Internet connectivity is used for teaching and learning. For example, it may even be that there is one PC connected in a school's administration. The report on schools concludes that the use of network connectivity in the classroom is not yet ubiquitous.

Not only are an increasing number of NRENs now providing network connectivity to schools, but also a number of services are provided to schools to support their use of this connectivity. The services that are offered vary, but there are some that are offered by almost all NRENs.

The way in which connectivity is provided to schools varies across Europe, as does the level of bandwidth available to schools. There are a number of reasons for this. Political will has had some influence, but it is likely that NRENs would have connected schools anyway.

The evidence gathered shows that network connectivity is widely used in schools, and that it can make a real difference to the way teachers teach and pupils learn. When used effectively, network connectivity has a positive impact on pupils' attainment and achievement levels. When used in the right way, it can be a valuable pedagogical tool. Network connectivity opens up a wealth of possibilities to teachers. Potentially it may result in a radical change in their teaching methods, but more commonly, it will be used to enhance already effective teaching methods.

Schools need to have confidence in their infrastructure before they will use network connectivity in the classroom. Simply put, if it does not work reliably, then teachers will not use it. Effective technical support is therefore very important to them.

From the point of view of educational needs, the services offered need to be linked to the educational aims of schools. For example, schools cannot be forced to use videoconferencing if there is no educational benefit for them.

From a pedagogical point of view, the use of network connectivity is linked to the teachers' understanding and knowledge of their subject. As pedagogical practice changes, so the use of information and communication technology needs to change accordingly, in order to ensure that educational goals are met.

To develop their value for schools in the future, NRENs should look into offering additional services to schools. However, this has clear implications in terms of staffing and finances, and some of the possibilities might be a long way off.

The arts, humanities and social sciences

The Arts, Humanities and Social Sciences (AHSS) communities are not totally new users of research and education networks. Indeed, many people active in the social sciences and the humanities are employed by universities and research institutes, which are the original core target group of NRENs, and this also holds true in part for the arts. However, new applications are appearing in the humanities and social sciences that make particular demands on research networks and on the services provided by them. In the arts – for example, in the performing arts – innovative and very demanding network applications are also being developed.

These developments are described in a study report written by Sabine Jaume-Rajaonia (RENATER) and Cătălin Meiroşu (TERENA Secretariat).

Their report contains a large number of examples of novel network applications and looks at the services provided by NRENs to satisfy the needs of this user community.

Based on their interactions with artists, researchers and academics involved in the fields of arts, humanities and social sciences, the authors conclude that these domains have intensified their use of Internet technologies compared to the interval covered in the SERENATE reports. The diversity of the technologies employed and the persistence of the infrastructures signal an important paradigm shift towards online collaborations.

As yet, the work in this community does not show any strong links to Grids. However, this is expected to change. Currently, the use of Grid technology is limited to authentication and authorisation middleware. Projects such as TextGrid open the way to a wider adoption of these technologies in AHSS. Although quite radical, this conclusion is necessarily logical taking into account the global evolution of society and technology. It is also in line with responses to a short survey conducted by the authors.

There is an increase in the number of multi-disciplinary scientific projects that involve people in the humanities and social sciences working together with researchers from computer-science and engineering departments. At the same time, computer scientists, software developers and engineers are employed to support the work of projects in the humanities and social sciences. Concurrently, the number of scholars in the humanities and social sciences with knowledge of modern computing and network technologies is growing. There is a need to provide specific training in these technologies to scholars. Centres dedicated to promoting and supporting the use of eScience in the arts, humanities and social sciences have been established in several European countries.

Extrapolating the technical requirements for services provided by NREN infrastructures, five major areas can be identified:

- bandwidth and quality of service;
- high-quality collaboration services;
- authentication and authorisation infrastructures;
- support and training for using new Internet technologies as they arrive;

- raising awareness in the AHSS community of how new services developed by the NRENs could transform their work, and also raising awareness in the NREN community of the problems that are being approached within AHSS.

NRENs provide both infrastructure and services needed by the AHSS community; it is perceived that they serve the community very well. An increase in network use by the AHSS is expected in the coming years.

NRENs have to be aware that this community of users is very demanding, both in terms of infrastructure and in terms of services, and they should consider dedicating special outreach and training to them in the future.

The healthcare sector

Although NRENs usually connect university hospitals and in some European countries a small number of other hospitals as well, in general, NRENs do not serve the healthcare sector. There are a number of reasons for that. However, because in many countries the need for a high-level information and communication infrastructure is now appearing high on the agenda of the healthcare sector, there is an opportunity for that sector to learn from the experience of the research networking community, while for an NREN the healthcare sector could be a prime candidate for a large extension of its 'inclusiveness'.

These issues are described in a study report by Christina Wanscher (MedCom), Henrik Søndergaard (UNI•C) and Martin Bech (UNI•C). Their report describes the complex context as well as recent initiatives in a large number of European countries to establish a network and information infrastructure for the national healthcare sector. The report focuses on general healthcare networks, and not on diverse projects that may include some hospitals in some countries.

The key findings are:

- Most health data networks in Europe are mainly regional. National solutions exist in the Scandinavian countries, as well as in the Netherlands, Austria and the constituent countries of the United Kingdom. Throughout Europe, a large number of advanced regional applications are using networks to exchange information between hospitals, generalist doctors and specialist doctors.

- The healthcare sector has significant political and legislative constraints, which means that the situation in a country or region will not change rapidly even when technological development offers opportunities to make changes that would lower costs and provide better care.

- The sector is application-driven but still rather immature, with a large number of different applications even within one hospital and a relatively low level of interoperability at this stage.

- Existing operational applications are not, in general, limited by the currently available bandwidth. However, there are emerging applications that require significant bandwidth, such as tele-diagnostics, remote radiology with exchange of high-resolution images and video streaming for the transmission of surgical operations with a view to teaching or monitoring remotely.

- The NRENs are generally not involved in the healthcare sector. Exceptions are mainly the Scandinavian and Baltic countries, the United Kingdom and Serbia, where the NRENs are involved in a few projects.

- The pharmaceutical industry and clinical-research organisations generally use closed, rented networks. They have relatively little demand for high-speed connections and are very demanding regarding the service levels agreements and guarantees offered by their contractors.

The authors also discuss the barriers that NRENs face to deliver their services to the healthcare sector and they make recommendations on how to overcome these obstacles should an NREN wish to serve this community.

The main demands that NRENs might be able to meet would seem to be:

- providing parts of network security infrastructure for health research and the health sector;

- exchanging large volumes of information between collaborating hospitals mostly for tele-diagnostics, medical education, clinical research or monitoring of surgical interventions;

- running cross-border pilot projects within Europe, federating a number of motivated healthcare actors in a test of scalability at the international level for the purpose of network capacity improvements.

The main strong point of NRENs in the health context is the excellent international high-speed connectivity that they offer at reasonable cost, including to countries outside Europe.

The main obstacles for NRENs to get involved in the health sector are probably:

- the perception that they would not adequately protect the confidentiality and integrity of the sensitive personal data involved, and their lack of knowledge of the health sector;

- the limitations in the guaranteed service levels offered;

- the restrictions in serving other communities that are imposed by the connection policies of some NRENs.