serenate

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ISBN-90-77559-01-9

Production: TERENA Secretariat
Design: Eva de Lange
Printing: GraphicResult

The SERENATE project was an Accompanying Measure in the Information Society Technologies programme of the Fifth Framework Programme for Research and Technological Development, and was supported as such by the European Community.

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Summary of Major Recommendations

Research networks are a national asset

National governments should be aware that research and education networking in their country, and in particular their National Research and Education Network organisation (NREN), is an asset for economic growth and prosperity. It is a source of innovation and provides fast and widespread technology transfer to society and industry. Promoting such technology transfer should be an explicit goal of NRENs.

NRENs and industry should ensure that collaboration between research teams in industry and teams in universities and publicly funded research centres can be supported effectively.

Optical networking is coming and everyone can and should participate

All stakeholders in European research and education networking need to reflect on the rapid move towards optical transmission technologies for communications and networking, and urgently consider its implications. In particular, in countries where the national fibre-optic infrastructure is not available at competitive prices and on a transparent basis, steps should be taken to remedy that situation.

The European Commission and the national regulatory authorities should establish an annual census of installed optical fibre and ducting, and the resulting information should be made publicly available.

The European Commission should, by the end of 2004, consider under what conditions, and for which parties, it would be reasonable to introduce a right of non-discriminatory access to optical-fibre infrastructure at equitably negotiated pricing.

In general terms, all European governments, politicians and national regulatory authorities should strive hard to introduce a truly competitive environment for the provision of Gigabit network services.
More specifically, it is very important that governments across the whole of Europe, including those beyond the borders of the European Union, ensure that their NREN, should it so wish, be empowered to install, or lease, its own optical-fibre transmission infrastructure.

Very demanding applications are coming and need careful attention

The NRENs, both acting nationally and acting internationally through DANTE in the development of GÉANT, should support the new, very demanding applications and encourage the researchers concerned to use the common research network infrastructure. The groups generating such demanding applications should collaborate with their NRENs and DANTE in order to obtain under reasonable conditions, including financial conditions, the services that they require. National and European funding bodies should work together to integrate these new, very demanding groups with the rest of the user community of research networks.

In order to support very demanding applications, NRENs and DANTE should explore the use of hybrid network architectures, in which switched optical paths are introduced alongside the traditional general-purpose routed network.

There is a digital divide inside the European research and education community

The institutions of the European Union and governments in Europe should:
- **recognise that, at the present time, a digital divide exists inside the European research and education community**
- **take energetic measures to reduce, and preferably eliminate, this digital divide.**

The institutions of the European Union should determine the approach to be adopted by the Union with respect to the digital divide that exists between its research and education community and that of the neighbouring European countries. Even if those countries are neither EU members nor are likely to obtain EU membership in the short term, policies and advice from the European Union carry significant weight. The European Union also has a political interest to ensure stability and to strengthen democracy in these countries.

The European Commission should monitor annually the state of the digital divide between the European Union's research and education communities, also including the neighbouring European countries, and publish the results. The monitoring should cover the availability and cost of Gigabit communication services and the functionality and performance offered by the various national research and education networks.

The European Union and the governments of the EU member states and the accession states should encourage the use of Structural Funds to finance investments in the field of research and education networking, including investments in communications infrastructure, such as optical fibre.
Governments of countries without access to the Structural Funds of the European Union should actively seek alternative sources of finance for such investments.

The campus is often the weakest link in the network chain

In Europe, campus networks are now often the weakest link in the chain of the end-to-end services needed for research and education. Therefore, universities and research institutes and their supervisory and funding authorities need to ensure that their campus networks are appropriately resourced.
In general, expenditure for ongoing technical upgrade in campus networks is best treated as a budget expense on an annual basis.

Research and education institutions should consider acquiring their own fibre infrastructure between their Local Area Network(s) and the point(s) of presence of key service and/or infrastructure providers, if necessary by commissioning its construction.

Users need end-to-end service quality, a compatible European Authentication and Authorisation Infrastructure, and value-added services

All providers of research and education network services, including the NRENs, DANTE and the campuses, need to select and develop tools and to provide 'single-stop' facilities for the rapid diagnosis of problems of end-to-end performance and/or reliability. In view of the number of organisations involved in the provision of such services, the co-ordination will be a significant management challenge.

The NRENs and those responsible for academic IT services at the national and campus levels need to develop much closer co-ordination of their services in several areas, especially the co-ordinated access to content, such as distance-education material and commercial databases.

We recommend to the European Commission and to the multiple other actors involved (universities, academic authorities, governments, funding agencies, hardware and software suppliers) that a major project should be set up with the objective of implementing and validating a coherent pan-European Authentication and Authorisation Infrastructure.

Inclusiveness of the user community of an NREN can only be determined nationally, but obvious economies of scale exist in smaller countries

If network connections and services for primary and secondary education are to be provided through the NREN in a given country, then adequate resources must be allocated, additional to those needed to support the research and higher-education communities.
Whatever detailed organisational and funding arrangements are made, it is essential to have excellent co-operation between all organisations providing network connections and services for primary and secondary education, for lifelong learning, for higher education and for the research community.

There is a crucial role for the European Union

The European Council and the European Parliament should ensure that the European Commission continues to play a significant role in enabling Europe's research and education network facilities to remain competitive at the global level. 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.

Executive Summary

Introduction

European universities and research institutions were early adopters of data networking. In most countries in Europe, national networks interconnecting the universities in the country were established in the 1980s. These national networks, which are in turn interconnected at the European level, provide operational services to research and higher education.

Many technologies and services that are developed and tested in the research network environment, later find their way to the commercial Internet. More generally, research networks are an excellent source of technical innovation.

The liberalisation of the telecommunications markets in Europe has had a major impact on the environment in which National Research and Education Network organisations (NRENs) operate. In many parts of Europe, the prices to be paid for the components of networks have been reduced enormously. Europe is now a world leader in several aspects of research networking. However, progress has not been uniform.

The organisational model

In Europe, the provision of network services to research and education is organised at three levels: the Local Area Network to which the end-user is connected, the national infrastructure provided by the NREN, and the pan-European level provided by GÉANT.

This organisational model, with one NREN per country and close collaboration at the European level, has been a success factor for the development of research and education networking in Europe. We expect this model to remain in place and to continue to be a key to success for at least the next 5-10 years.

Optical networking is coming and everyone can and should participate

The move towards the use of optical techniques in data transmission is a fundamental change that will not be reversed. It offers enormous opportunities for research and education networks, regarding cost and management and in relation to the network capacities and services that can be provided.

As a consequence, optical-fibre infrastructure becomes an asset of crucial importance, not only for research and education, but also for the economy and society in general. A competitive market for fibre infrastructure should therefore be promoted, and access to fibre at reasonable prices should be ensured.

Very demanding applications are coming and need careful attention

There is a growing diversification of the network requirements of researchers. The most demanding scientific applications now require very high network capacities and put heavy demands on network availability and end-to-end performance.

Recent technical and market developments will enable the existing research network organisations to serve the needs of these most demanding users. This will maintain the coherence in European research and education networking, which is in the interest of all stakeholders and of great importance for continued innovation. However, in order to achieve this goal, research network organisations will need to introduce new infrastructures, technologies and network architectures. Moreover, funding and cost-sharing models for research network facilities will need to be adjusted to accommodate the increasing diversity in network use.

There is a digital divide inside the European research and education community

One of the main objectives of the European Research Area and of the *e*Europe Action Plans is to provide equal opportunities to researchers, teachers and students independent of location. Widespread and cost-effective access to research and education networks is therefore of crucial importance to the success of these two policy initiatives.

Unfortunately, there is a significant divide between countries in Europe with respect to the network infrastructure and services that are available to the national research and education communities. The institutions of the European Union and national authorities should recognise the existence of this digital divide and take energetic measures to reduce, and preferably eliminate, the divide.

Creating a truly competitive telecommunications market and ensuring access to fibre infrastructures at reasonable prices are important in this context. In addition, investments in research and education networking will be needed, including investments in communications infrastructure such as optical fibre. The use of the European Union's Structural Funds for this purpose should be encouraged.

In order to measure the effect of the actions, it will be important to monitor regularly the state of the digital divide in research and education.

The campus is often the weakest link in the network chain

Because, in recent years, research and education networks at the national and international levels have achieved substantial improvements in network capacity and service quality, it is perhaps not surprising that the local level of network facilities is now seen to produce the most significant bottlenecks. Investments need to be made, and universities and research institutes need to ensure that adequate annual budgets are available for their campus networks.

Users need end-to-end quality, a compatible European Authentication and Authorisation Infrastructure, and value-added services

The expectations of network users have evolved beyond the provision of pure bandwidth towards the supply of more complex services. There are concerns about security, privacy and confidentiality. There will be a strong demand for authentication and authorisation services. Increasingly, researchers and teachers want to be able to access networks and their own usual set of network and information services wherever they happen to be. The establishment of a pan-European Authentication and Authorisation Infrastructure will be an important contribution to meeting these requirements.

Inclusiveness of the user community of an NREN can only be determined nationally, but obvious economies of scale exist in smaller countries

Several national governments in Europe have initiated projects to provide network connections and services to schools, libraries, museums and other public institutions. Some of these initiatives involve the NREN, but others do not. Such initiatives, and the way they are implemented, have to be decided at the national level.

However, several countries – the United Kingdom is a notable example - are launching national initiatives to improve the coherence and delivery of the full range of their education services, including continued education ('lifelong learning'), based on the use of their NREN infrastructure. These developments should be observed carefully in order to determine if there could be possible synergies at the European level.

It should be mentioned that greater 'inclusiveness' is particularly important for small countries. By extending their user community beyond researchers, teachers and students in higher education, NRENs in such countries can achieve a critical mass and economies of scale that are obtained naturally by NRENs in large countries.

There is a crucial role for the European Union

The NRENs and their pan-European organisations DANTE and TERENA need to intensify their collaboration in order to meet the new challenges to research and education networking.

In recent years, the European Commission has acted as a uniting force. The European Council and the European Parliament should ensure that the European Commission continues to play a significant role in enabling Europe's research and education network facilities to remain competitive at a global level. 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.

1 Introduction

The Internet had its origins in the world of research and universities. It is often described as a network of networks. Today, those networks that provide connectivity and services to users in research establishments and institutions for higher education are still the most advanced part of the entire Internet. Those networks - commonly referred to as ***research networks*** or ***research and education networks*** - offer very large network capacities and various advanced services that are not available generally.

Research networks and their user communities form an environment that is an important source of innovation. Many of the technologies and services that are developed and tested in the research networking environment, later find their way to the general Internet that serves companies as well as individuals who use the Internet for business and leisure. The World Wide Web is no doubt the largest and most famous historical example, but many more technologies and services have been carried over from the research and higher-education network environment to the rest of the Internet - ***the commercial Internet*** - and this transfer of innovation is continuing and increasing today.

There have been many dramatic changes since the pioneering days of the Internet when researchers formed the majority of network users. Whereas in the early days network speeds were measured in kilobits per second, nowadays they are measured in Gigabits per second, a million times faster. Services like videoconferencing or end-to-end quality were inconceivable in the early days of the Internet, but have become common in the research networks of today, although perhaps not yet in the commercial Internet.

Despite the enormous changes, research networks have remained at the forefront of developments worldwide. The history of research networking has not been one of constant evolutionary growth. Rather, periods of revolutionary change have alternated with relatively quiet periods of consolidation. At this moment, research networking, particularly in Europe, is once again entering a period of dramatic changes. This is caused by new network and service opportunities offered by technological developments, new economic opportunities made possible by telecommunications liberalisation and market developments, and new requirements from users in the research community.

The SERENATE studies have addressed these challenges by investigating the strategic aspects of the development of research and education networking in Europe over the next 5-10 years, looking into the technical, organisational and financial aspects, the market conditions and the regulatory environment. The SERENATE project (Study into European Research and Education Networking As Targeted by *e*Europe) was carried out in the period from May 2002 to December 2003. It was funded by the European Commission as an accompanying measure in the Information Society Technologies programme of the European Union's Fifth Framework Programme for Research and Technological Development. The project partners were TERENA, DANTE, the Center for Tele-Information at the Technical University of Denmark, the Academia

Europaea and the European Science Foundation[1]. The studies have benefited greatly from the active involvement of all stakeholders: research and education networking organisations, governments and funding bodies, network operators and equipment vendors, and, last but not least, the users of research and education networks.

1. *More information about these organisations is given in Appendix A.*

2 Structure and Organisation of European Research and Education Networking

2.1. The multi-level structure

Network services that are provided to users in the European research and education community are organised at various levels with different geographical domains. These levels are managed by separate organisations.

The level closest to the researcher, teacher or student is the Local Area Network (LAN) at the site (for example, the university campus) where they work. This level is the responsibility of the organisation (i.e., the research institute, university, college, school etc.) that runs the campus. Normally, the LAN will be a component of the information technology environment provided by that organisation.

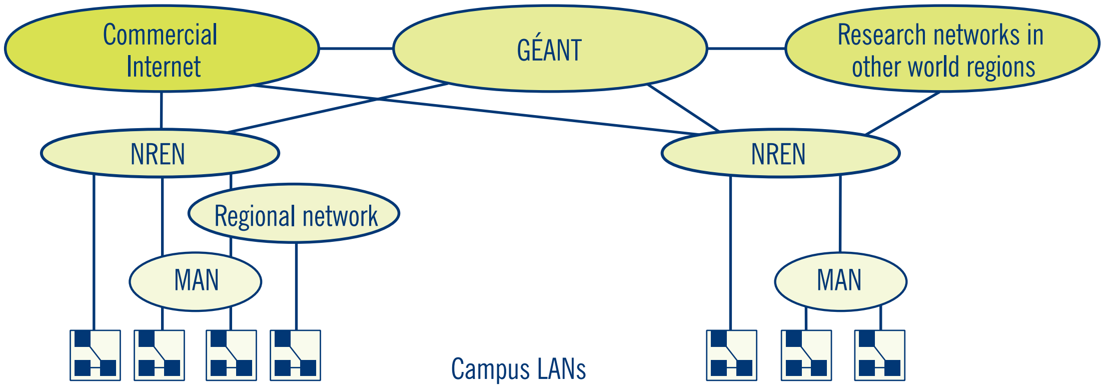
The next level consists of the national research and education network that provides the connectivity between the local networks of research and higher-education institutions in a country. This level is the responsibility of the National Research and Education Network organisation (the NREN) of that country. Traditionally, NRENs have acquired their own hardware (routers, switches, servers etc.) to operate an IP (Internet Protocol) service over a set of communication paths leased from one or more national or regional operators. Recent years have seen a trend where some NRENs start to own (or obtain long-term access to) their own optical-fibre infrastructure, as an alternative to leasing such paths from operators.

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 a number of the 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) pursues four main categories of activities: fostering new initiatives; supporting joint work in developing, evaluating, testing and integrating new technologies through the TERENA Technical Programme; organising conferences and workshops, and promoting knowledge transfer to less advanced networking organisations; and representing the common interests and opinions of its membership.*

The third level of the research and education network infrastructure provides international connectivity between researchers in Europe. It is essentially provided by the GÉANT network, which interconnects the national research and education networks. GÉANT is managed by DANTE on behalf of the NRENs.

Connectivity to research networks in other continents is either obtained directly by the NREN via its own links to key destinations, or provided by DANTE via GÉANT. 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 at the GÉANT level.



A network session between research establishments in two different European countries therefore depends on facilities provided by at least five different organisations: two campuses, two NRENs and DANTE.

Moreover, in some countries campuses are not directly connected to the NREN's national network but via Metropolitan Area Networks (MANs) or regional networks. Obviously this makes management even more complex.

When trying to understand European research and education networking and its development, one cannot simply concentrate on just one of the levels described above to the exclusion of others. It is important to consider the totality of the infrastructure and its organisation, including all levels.

2.2. National Research and Education Networks

At first sight, it is not obvious that the national network infrastructure for research and education should be provided by special, dedicated organisations – NRENs – nor that there should be only one such organisation per country.

Indeed, when in the 1980s data communication networks moved beyond pioneering efforts to a wider user group in the European research community, many predicted that in due course general commercial service providers would enter the business of providing advanced network facilities to research establishments and institutions for higher education. Some predicted that dedicated research networks would disappear. This has not happened, despite the emergence of many commercial Internet Service Providers. The reasons are clear. The research and education community represents the most demanding network users. Satisfying their needs requires large investments, not only in infrastructure facilities but also in the testing and deployment of new technologies and the development of new services. Moreover, research and education is not a community with a very significant purchasing power. Therefore, research and education network services do not offer a compelling business case for commercial companies; for them it is more interesting to concentrate on providing services to businesses and the general public, a market that requires less investment and offers a faster return on investment.

The situation sketched above justifies intervention by government. In addition, education and research are areas of government responsibility in their own right. In the 1980s and 1990s, NRENs have therefore been created in almost all countries in Europe, usually with financial support or at least active encouragement from the national government or funding bodies for research.
In the early days of European research networking, some fields of research, such as particle physics

and space research, were early adopters of the network technologies and created their own discipline-specific networks. However, as NRENs and their international collaboration developed, it soon became apparent that the economies of scale offered by these general research networks made it more attractive for all disciplines to join that research-network infrastructure than to continue separate developments. In a few countries, organisational issues, such as different funding streams, have initially led to the creation of more than one research network organisation operating at a national level. However, the economies of scale and the need to concentrate scarce expertise and financial resources have in each country in Western Europe eventually led to the establishment of a single NREN.

Although some countries in Europe are quite small, there are no examples of an NREN serving more than one country. There are various reasons for this. NRENs need to provide assistance to their connected institutions and in some cases to the end-users; this communication requires the use of the national language of the country. Institutional collaboration in research and higher education is primarily organised on a national basis. Funding for research is largely, and funding for education is almost entirely, provided by national sources. Despite harmonisation of regulations, the markets for telecommunications services are still largely national markets. Despite increased international collaboration, network traffic patterns in research and education are strongly influenced by national borders. The organisation of research and education networking in NRENs and their European collaborative organisations follows the organisational pattern of their user communities and their funding bodies.

There are large differences between the NRENs of the various European countries[2], in size, legal structure, funding, budget, staffing, services etc. However, the commonalities between these organisations prevail; they share the same objectives and are well positioned to collaborate in pursuing their common goals.

The organisational model of a single NREN per country is an important success story. It is one of the factors that have enabled Europe to position itself at the forefront of developments worldwide in a number of aspects of research networking. The model is increasingly being copied in other continents, for example in the Asia-Pacific region and in Latin America.

The SERENATE studies have led to the conclusion that the organisational model of research networks in Europe, with different levels related to geography, a single NREN per country and close collaboration at the European level, can be expected to remain essentially unchanged at least for the next 5-10 years and to be a success factor for the further development of European research networking. However, as described later in this report, developments such as the emergence of network users who require end-to-end services with very large network capacities and guaranteed service levels pose significant new challenges to the model.

2.3. Funding of research networks

In most European countries, educational establishments are funded almost entirely from public resources and research institutions are funded to a large extent from public resources. Hence, in the end, research and education networks are basically funded by taxpayers' money. However, the paths along which the funds are channelled from the government to the responsible organisations may vary.

Different funding models are used at the various levels of research networks described in section

2. *The TERENA Compendium of NRENs offers a large amount of data on National Research and Education Networks in countries in and around Europe. See http://www.terena.nl/compendium/ .*

2.1. In most countries, funding of the local network facilities within an institution is considered to be the responsibility of the institution itself, as the LAN is considered part of the environment provided by the relevant research or education organisation.

At the national and international levels of research networking there is a variety of funding models.

Central funding can be very appropriate in three cases. When an NREN is in its start-up phase, it can be helpful if all necessary funding is provided centrally, since decisions can then be taken quickly. There may also be an argument for central funding of research networks in countries that are economically less developed or where funding for research and/or education is under strong pressure, because there may then be particular problems to strike the correct balance between essential network infrastructure and equally important improvements to other poorly funded activities. Finally, central funding may be appropriate for the testing of new technologies and the development of new services that are for the long-term benefit of users in general, but bring no direct short-term return to individual connected institutions.

Funding through the connected institutions, either on the basis of their access capacity or on the basis of actual use (or a combination of both), has the advantage that it provides a strong incentive to NRENs to keep adapting the services that they offer to the actual needs of users.

In practice, there are large differences between countries in the way the national and international levels of research networking are funded[3], varying from total central funding to substantial funding via the connected institutions. The optimal solution clearly depends on national circumstances. A large majority of countries has a mixed system, which can work well if expenditures of long-term benefit are centrally funded and some of the services whose costs can be directly related to individual connected institutions are funded through those institutions.

Funding by connected institutions, if any, is usually provided from the central budgets of those organisations. In general, it is not desirable to introduce charging at a lower level in the organisation, such as institutes within a university, research groups or even individual end-users. For one thing, the total annual expenditure of an NREN divided by the number of end-users is typically in the range of 20 to 40 euro; in case of end-user charging the costs of accounting and billing would therefore lead to a very substantial increase of the overall costs.

However, the emergence of classes of network users with very high requirements may mean that the model of charging at the level of institutions may no longer scale. As will be explained later in this report, there are already examples where a single end-user application created more traffic on GÉANT between two countries than the whole of the research communities in those countries taken together. New funding mechanisms will need to be developed to enable the provision of services to end-users of this kind.

As to the European level of research networking, GÉANT is partly funded by the European Commission but the larger part of the GÉANT costs is covered from national contributions. Those costs are shared between the countries on the basis of an algorithm that has been agreed by the participating NRENs and can be updated by them as needed. One of the effects of the chosen algorithm is to smooth the very large differences between the costs of communication services to individual countries. We will discuss the cost issues in more detail in chapter 5. Again, this cost-sharing model may not be adequate to cover the costs caused by new network applications that generate extremely large amounts of traffic between a small number of

3. *Details about the current situation are given in the TERENA Compendium of NRENs.*

locations, and it may be necessary in the near future to develop alternative financial models to cover that form of network use.

2.4. User communities

The initial user communities of NRENs consisted of researchers, teachers and students in research centres and universities. There are differences between countries, for example in the extent to which students are given access to the network facilities, the inclusion of institutions for higher education other than universities, and the inclusion of research institutes that are not part of universities or that are even partially or entirely funded by the private sector. Increased collaboration within higher education and between publicly funded and privately funded research is a priority in science and education policy. The inclusion of all higher-education institutions and publicly and privately funded research centres is, therefore, probably desirable. However, in practice there may be impediments in some countries because of the policies of national authorities or funding bodies.

In some countries, the user base of the NREN has been extended in the last decade by the inclusion, to a greater or lesser extent, of higher-education colleges offering training for specific vocations and schools for further education, secondary education or even primary education. Other examples of user communities that, in some countries, have been connected to the national research and education network are students at home, libraries, museums and government institutions. One of the SERENATE reports[4] contains a number of case studies on the inclusion of these user groups. We will discuss the issues involved in more detail in section 8.4.

2.5. Acceptable Use Policy and commodity traffic

All NRENs have Acceptable Use(r) Policy documents[5] that define the users that are eligible to be connected to the national research and education network and the use that they are allowed to make of the network. Because NRENs are either directly or indirectly financed from public resources, they do not wish to enter into competition with commercial Internet Service Providers.

An officially established and published Acceptable Use Policy and strict adherence to that policy are important instruments for an NREN to avoid complaints about competition. If an Acceptable Use Policy clearly limits the type of users that will be served and the kind of traffic that will be carried, and if new user communities connected are evidently within that limited group, then fears of commercial companies about unfair competition can be prevented.

It is part of the professional activity of any researcher, teacher or student to access not only research networks but also the commercial Internet, for example to obtain publicly available information or services in relation to his or her work. It is the general policy in Europe that NRENs should off-load traffic with a destination in the commercial Internet onto the networks of commercial Internet Service Providers at the earliest economically viable opportunity. Unless the campus network is interconnecting directly with the commercial Internet, this usually means that such ***commodity traffic*** is carried over the national research network to some national Internet Exchange Point[6], from where it is carried further by a commercial service provider.

4. *SERENATE deliverable D15 "Report on examples of extension of research networks to education and other user communities"*
5. *The Acceptable Use Policies of all NRENs currently connected to GÉANT are available from the GÉANT webpages: http://www.dante.net/geant/connect.html .*
6. *An Internet Exchange Point is a location where several networks that are part of the Internet are present and exchange traffic. Many NRENs have a close relationship with the national-level Internet Exchange Point(s) in their country.*

The SERENATE studies have found that there are often real network service problems when research collaboration involves not only persons who are connected to research networks but also individuals who are dependent on the commercial Internet. An important example is the collaboration between researchers on university campuses and industrial researchers, in those cases where the industrial research laboratories are not connected to the national research network. One cause of these problems is that the commercial Internet is normally dimensioned to provide reasonable performance for electronic mail and Web-related traffic, while collaboration on a research project requires much greater bandwidth for fast file transfer and the deployment of tools for collaborative work. The problem is aggravated by the growing deployment of firewalls and other security measures that as an unintended side-effect produce obstacles for end-to-end collaboration between users on different networks.

NRENs and industry should ensure that collaboration between research teams in industry and teams in universities and publicly funded research centres can be supported effectively.

2.6. The wider value of research networks

The primary goal of any research and education network is to deliver connectivity and associated services of high quality to its user community. There are many dimensions to the high quality that research network organisations aim to provide, for example:

- cost-effectiveness
- reliability
- offering very advanced services to users with high-level requirements
- wide connectivity via the research network infrastructure as a whole, reaching very large numbers of relevant locations worldwide
- providing good user support
- integration with the research and education communities, including the provision of support for interesting applications and services.

In the context of European policies, the research network infrastructure at its local, national and pan-European levels provides effective support for the European Research Area. The European Union's political vision of a single European community of researchers where scientific collaboration is not hindered by distances and national borders requires a very high-quality research network infrastructure. NRENs have been engaged in efforts to provide pan-European interconnection since the early 1980s. In recent years, substantial progress has been made, thanks particularly to the opportunities offered by the developments in the telecommunications markets and the increased support from the European Union through the Fifth Framework Programme. All European Union member states have a professionally managed NREN, and the same is true for most of their neighbouring countries in Europe. Research networking is at the cutting edge of building an effective European Research Area. The research and education network infrastructure is also making rapid progress in delivering pan-European connectivity and services for the education community, as required by the European Union's *e*Europe Action Plans.

The findings of the SERENATE studies underline, once more, that all researchers, teachers and students require cost-effective, reliable, widespread and advanced network services, regardless of their geographic location or subject discipline. Some have additional requirements, but there are common network services that all feel should be as available and as reliable as the electricity supply or the telephone service.

Research networks are an excellent source of technical innovation. The research community is eager to use the most advanced services possible and is more tolerant than commercially oriented user communities to the teething troubles that are unavoidable when services are at the forefront of technical developments. The work performed in research networking and the services developed in that environment are carried over to society as a whole, and especially to high-technology industry. The users served by research and education networks are - in majority - young, very well educated and dynamic. Many people move every year from the fields of education and research to industry and commerce.

Research network organisations, and the NREN in particular, are therefore an important asset for a country, driving innovation and the dissemination and wide adoption of new technologies and services, thereby eventually contributing to the development of industry and commerce and to economic prosperity.

As a particular example, NRENs and their users form a community with considerable knowledge and experience of very advanced network applications. That community is able to play an important role in stimulating telecommunications operators and Internet Service Providers to develop new services, especially those that involve the use of high-capacity networks. The willingness of operators and service providers to engage in collaborative projects with NRENs and their users can have a strong enabling effect on the speed with which such new technologies and services are taken up in society in general.

National governments should be aware that research and education networking in their country, and in particular their NREN, is an asset for economic growth and prosperity. It is a source of innovation and provides fast and widespread technology transfer to society and industry. Promoting such technology transfer should be an explicit goal of NRENs.

2.7. External factors influencing European research and education networking

Europe can now look back on two decades of organised provision of network services to researchers, teachers and students. There has been a tremendous growth and many things have changed during these years, while only recently a really wide deployment of research and education network services has been achieved. Nevertheless, history can provide some interesting observations about the barriers and enablers to achieving the goals of research and education networking.

A first observation is the important enabling role of political support, and of government subvention. In section 2.2 we have indicated briefly why the development and deployment of research and education network infrastructure and services should be a field of government concern. It cannot be left entirely to market forces, and although the development of a national and international infrastructure and services need the support of the individual research and education institutions, progress will be slow and difficult without a stimulus from national governments or funding bodies. The development and deployment of research network facilities have been fastest and most successful in those countries where national authorities realised their responsibility earliest. Those countries where governments were also quick in realising the economic potential of research networking have been even more successful, as they could combine education and research policies with industry policy.

The intervention of government can take various forms. One particularly important form is of course funding, as lack of adequate funding is the most obvious barrier for network development. In recent years, authorities have been able to translate their political support into financial subvention, both at the national and at the European level. There are unfortunately still regions in Europe, areas within individual countries, and categories of institutions in certain countries, where lack of funding means that it has proved impossible to bring network facilities up to the level that is generally considered acceptable in Europe as a whole. As was briefly indicated in section 2.3, there are many different options for financing schemes, and each country should develop the financial model that is best suited for its own situation and provides the necessary incentives to achieve the most effective use of funds.

Governments can also assist the development of research and education networking in other ways. One particularly important area of government policy is telecommunications regulations. Much of the history of European research networking has been dominated by the barrier of very high prices for communication services charged by monopoly or quasi-monopoly telecommunications operators. Market liberalisation has in recent years created unprecedented opportunities for research networks; the introduction of real and effective competition is no doubt a significant enabler. The same holds for other aspects of a liberal regulatory regime, such as the possibility for NRENs to obtain some form of 'ownership' of the telecommunications infrastructure that they use. However, the SERENATE studies have found that, although in theory the new EU regulatory regime has been introduced in all member states and accession states of the European Union, in practice the situation in a number of countries leaves much to be desired. We will discuss these issues in some more detail in chapter 5.

In some countries, the overall state of the national market for telecommunications and network infrastructure can be a barrier for development. If there is a lack of investment in telecommunications infrastructure in a country, because of an insufficient de-facto liberalisation of the market or because of general economic circumstances, then it is difficult for an NREN to deploy its services. Conversely, in countries where large investments have been made in the telecommunications infrastructure there may be a wide choice of options for the NREN.

Finally, the existence of a strong high-technology industry or other economically strong potential users of the fibre-optical infrastructure in a country can have an important positive influence. It will be easier to make progress if communication and network operators can have some confidence that the services and infrastructure requested by the NREN will indeed come into wider use on the timescale of just a few years.

3 The Evolution of User Needs

3.1. Growing needs and new requirements

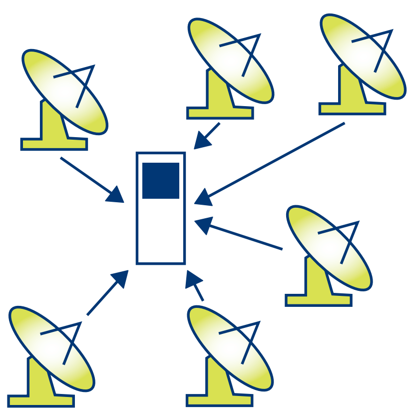
It has been an important part of the SERENATE studies to investigate the future networking needs of members of the European research community[7].

In general, researchers appear to be satisfied with the progress that has been made in recent years. In many parts of Europe, researchers have a reasonable environment of research and education networking facilities. However, the situation in several regions in Europe is far from satisfactory, and arguably getting worse in relative terms. To a large extent, these problems are related to the 'digital divide' issues that we will discuss in chapter 6.

Satisfactory network performance for end-users depends on an adequate infrastructure at three levels: on the campus, nationally and internationally. For many European researchers, the major source of limited network performance is primarily at the campus.

There is impressive evidence of growing network requirements from all areas of research. These needs will grow dramatically over the next 5-10 years, in all disciplines and in all countries. At the same time as many of the natural sciences are pushing towards a very broadly based deployment of Grid computing, we have been shown compelling examples of how research in the humanities could benefit greatly from advanced networking, while the aspirations of social scientists, ecologists, musicologists and geographers are also very challenging. There is absolutely no 'divide' in the field of user requirements.

At the SERENATE workshops and in their replies to SERENATE questionnaires, researchers have given examples where their research would become much more efficient if network capacities could be increased by one or two orders of magnitude. Examples were also given where there is a possibility of starting completely new research activities that were prohibited until now by lack of very high performance network facilities.



Starting in the early 1990s, radio telescopes in Europe have joined forces to deploy a fascinating new technique called Very Long Baseline Interferometry (VLBI). Signals from the telescopes are correlated using specially designed dedicated high-performance computing facilities, leading to extraordinary precision when studying celestial objects. The huge amounts of data were transported from the telescopes to the computing facilities at JIVE (the Joint Institute for VLBI in Europe) in the Netherlands using tapes carried by planes and vans. As a consequence, interpretation of observations could start only many days after the recording date. Now that national research networks and GÉANT have reached Gigabit capacities, it has become possible to transport the data much more quickly and if required even in real time. This will allow radio astronomers to work interactively with the 'instrument' - an 'instrument' consisting of the network and several radio telescopes -, which offers unprecedented opportunities for observations / measurements when interesting astronomical events occur.

7. *The results of that investigation have been summarised in SERENATE deliverable D10 "Report on the networking needs of users in the European research community". See also Appendix B of the current report.*

The SERENATE studies found a remarkable interest and involvement of researchers in Grid computing. Such involvement was reported from astrophysics and astronomy, particle physics, computer science, earth sciences and oceanography, protein modelling, photonics, chemistry and many other disciplines.

The state of computer and network technology today makes the seamless sharing of computing resources on a European or even global scale achievable. For scientific applications, the vision is that such computing Grids will integrate large, geographically distributed computer clusters and data storage facilities, and provide simple, reliable and round-the-clock access to these resources. The benefits will include large increases in both the peak capacity and the total computing power delivered to various scientific projects, as well as new ways for scientific communities to share and analyse very large data sets. These benefits will result in an increase of the quality and quantity of scientific output across a broad spectrum of computing-intensive fields, ranging from bio-informatics and climate simulation to the nanoscale design of new materials and integration of large engineering projects involving many partners. The EGEE (Enabling Grids for E-Science in Europe) project aims to create a seamless European Grid infrastructure. EGEE will deliver production-level Grid services, carry out a Grid middleware re-engineering activity, and ensure an outreach and training effort providing the necessary education to enable new users to benefit from the Grid infrastructure.

The expectations of network users have evolved beyond the provision of pure bandwidth towards the supply of more complex services. There are concerns about security, privacy and confidentiality.

Actually, it should be noted that generally research and education networks provide more and better security-related services to their users than users of the commercial Internet can expect to receive. Research networks are better monitored than the commercial Internet and almost all NRENs have an incident response team - known as CERT (Computer Emergency Response Team) or CSIRT (Computer Security Incident Response Team) - for early detection of security threats, dissemination of security alerts and patches, detection of, and response to, denial-of-service attacks, and support and advice to users. The research networking community is also very active in developing refined monitoring and measurement tools, which will help to further improve the quality of networks and to foster a secure network environment.

The SERENATE studies have also found that there is likely to be a strong demand for authentication and authorisation services in the research and education area. There will be a growing demand for researchers to be able to access networks and their own usual set of network and information services wherever they happen to be.

There is general pressure from end-users that research and education network organisations should give more attention to the end-to-end aspects of communication, including issues related to quality of service. The organisations responsible for research networks at the various levels should co-operate to put in place a service that deals with performance problems. When a user believes there is unusually bad network performance, this service will determine whether the performance is indeed degraded, and if so, take responsibility for correcting the situation. This will be a challenge of management integration since, as pointed out in section 2.1, any network communication between researchers in two different countries involves services provided by at least five different organisations.

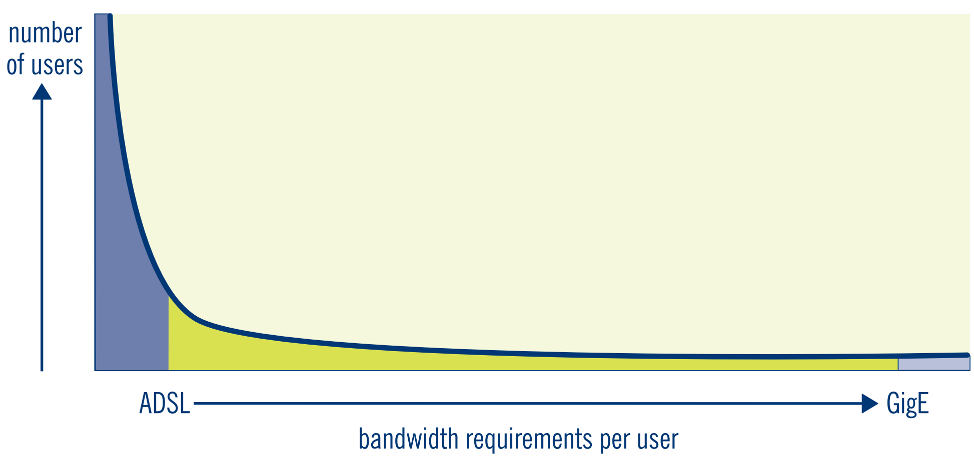
All providers of research and education network services, including the NRENs, DANTE and the campuses, need to select and develop tools and to provide 'single-stop' facilities for the rapid diagnosis of problems of end-to-end performance and/or reliability. In view of the number of organisations involved in the provision of such services, the co-ordination will be a significant management challenge.

Another trend is a growing requirement for network facilities to support scientific collaboration at a global scale. While maintaining their interest in countries such as Australia, Canada, Japan and the United States, European researchers have over recent years become more interested in collaboration with colleagues in, for example, China, India, Korea and Russia. The background appears to be that some of those countries are now deploying state-of-the-art research networks, thereby making it feasible to build collaborative relationships between research groups in those countries and their European colleagues. As regards connectivity to Latin America and to countries south and east of the Mediterranean, DANTE has, with financial support from the European Commission, recently started projects that are expected to result soon in a significant improvement of the facilities for network communications between researchers in Europe and in those world regions.

3.2. Applications with very high network demands

One of the demonstrations at the iGrid event[8] in Amsterdam in September 2002 featured an application that generated more traffic between two European national research networks than the total traffic between those two countries produced by all other research network users at that time. Indeed, during the past year there have been more cases where a single instance of a new application, such as a Grid file transfer, a remote immersive virtual-reality session or the transmission of very high definition images, has exceeded the aggregate flow that we usually see from a whole country with thousands of simultaneous users.

This illustrates the strongly growing diversification of the network requirements of users in the research community. As far as bandwidth requirements are concerned, this is illustrated by the following graph[9].



8. *The iGrids are biennial international testbed events, with special emphasis on Grid and virtual laboratory applications and e-Science in general.*
9. *This graph was presented by Dr. Cees de Laat (University of Amsterdam) at the Initial Workshop of the SERENATE project*

There are very large numbers of users of research and education networks whose network use is mostly limited to simple applications such as Web browsing and email. Their individual bandwidth requirements can be met satisfactorily by the equivalent of ADSL[10] or less. A smaller number of end-users is involved in applications that require streaming media or the use of Virtual Private Networks; their bandwidth requirements exceed ADSL and extend up to Gigabit Ethernet. And finally there is a third category of users who work on special scientific applications such as Grid computing and virtual presence; they need network capacities of one or more Gigabits per second.

It is expected that, over the next few years, the applications that put very heavy demands on networks will grow in number and importance, especially as Grid applications move from the advanced prototype phase to full exploitation. These applications not only require very large network capacities but also put heavy demands on network availability and end-to-end performance. However, the number of end-users involved can be expected to remain small as compared to the total number of network users. They also tend to be concentrated at a limited number of locations. Together with the technical and market developments that will be discussed in the next two chapters, this will allow the existing research and education network organisations to serve the needs of these most demanding users, provided that those network organisations take adequate measures to adjust their technical infrastructure and their managerial and financial arrangements. We will discuss this challenge to the research and education networks further in section 8.1.

10. *Asymmetric Digital Subscriber Line, a technology used to upgrade the connection between a local telephone exchange and the customer's premises from the version needed to support conventional voice telephony, in order to carry data traffic, typically at 512 kb/s.*

4 Technical Developments

The Internet is evolving continuously as a result of innovative technological developments. Research networks are at the forefront of those developments; they are among the first to test new technologies and to introduce new services. Some of the current technical developments in the research network environment are the introduction of Internet Protocol version 6, the deployment of multicast services and the growing importance of wireless technology for local connectivity. A very fundamental change has been introduced by optical techniques in data transmission. It is expected that the move to optical networking will have an enormous impact on the services that research networks can offer and on the way that research networks are managed.

4.1. Internet Protocol version 6

The Internet Protocol lies at the heart of the Internet, as it defines the structure of each packet of data that is transmitted. The Internet, as we have known it, operates using version 4 of the Internet Protocol (IPv4). For a number of reasons, related to the range of addresses that can be used as the source and destination of Internet packets, as well as to issues of security and quality of service, IPv4 needs to be replaced by a newer version of the protocol. It is to be expected that within a decade the whole of the Internet will be operating using IPv6.

In Europe, the deployment of IPv6, both in research networks and in the wider Internet, is very much promoted by the European Commission, which sees the widespread use of the IPv6 protocol as a competitive advantage in the use of the Internet for industry and commerce. GÉANT and most of the national research and education networks in Europe are already IPv6 capable. We expect the further deployment of IPv6 to happen quite smoothly over the next one to three years, although very considerable work is still required.

4.2. Multicast

During normal (unicast) Internet sessions, a source and a destination are in communication and exchange data on a one-to-one basis. If a television station or an educational institute broadcasts a programme or a lecture to thousands of subscribers using unicast protocols, then there will be thousands of identical streams being transmitted from the source to the destinations. The purpose of multicast protocols is to ensure that, in such a case, all of the identical sessions on one route are merged into a single stream, which is then broken out to multiple destinations only when necessary, by multicast-capable routers.

Real-time and on-demand broadcasts to a large number of users are particularly important in education. Such applications take up large parts of the available network capacity, and the deployment of multicast technology is one of the very few ways to reduce this bandwidth consumption. However, multicast is a complex technology to implement. Although the multicast protocols have been available for many years, they have not been very widely deployed. In the research community, organisations that have tried to deploy applications that depend on multicast protocols have frequently experienced delays of up to several months while a whole range of minor incompatibilities between the equipment of different vendors was investigated and eventually resolved.

The conclusion is that either a significant effort should be made to achieve a wide and uniform deployment of multicast technology across the research and education networks in Europe, or efforts to deploy multicast should be abandoned altogether, relying on the provision of very high capacity networks as an alternative solution to the problem of current bandwidth limitations.

NRENs should develop a coherent strategy concerning the deployment of multicast protocols across Europe.

4.3. Wireless connectivity

Ethernet is the dominant technology used in Local Area Networks. It is clear that wireless Ethernet[11] is moving into mainstream use. It has a growing importance on the campus, because it can be deployed there more rapidly and with greater flexibility than wired Ethernet. Its increasing availability in 'hot spots' such as railway stations, airports and cafes is proving very useful in providing Internet access, and thereby access to research networks, to researchers and students who are away from their regular place of work.

The current situation is that a fraction of users can obtain useful service from 'islands' of wireless connectivity, but it is expected that within a few years researchers, teachers and students will be able to use wireless connectivity more generally as they travel around. This evolution will increase the need for research and education networks to support these ***roaming*** users. The security requirements - one needs to be very sure that the people trying to access the servers at institutes are indeed who they claim to be - highlight the need for a rapid deployment of a pan-European Authentication and Authorisation Infrastructure. We will discuss this topic further in section 8.3.

Some people predict a gradual merger of mobile telephony and wireless Ethernet technologies. While we can only adopt a 'wait and see' approach as far as this possible development is concerned, it seems clear that such a convergence could be very useful for researchers and students whenever they need to travel.

4.4. The move to optical transmission

The basic service that NRENs offer to their users is a best-efforts IP service. The equivalent service is extended across Europe, and to research networks in other world regions, via the GÉANT network. The characteristic of a best-efforts IP service is that it offers ubiquitous connectivity, but without guarantees of performance.

The best-efforts IP service is normally provided by routers interconnected by leased circuits. Historically, both nationally and internationally within Europe, leased circuits were provided by monopoly telecommunications operators, who were reluctant to provide access to leading-edge technology. The liberalisation of the European telecommunications market has changed this

11. *Also referred to as Wi-Fi or as IEEE standards 802.11b and 802.11g.*

picture dramatically in the last four years. For many locations in Europe, it is now possible to gain access to leased circuits that offer the maximum performance technically available today (currently 10 Gb/s). In addition, liberalisation has, in some locations, allowed direct access to physical connections, typically fibre-optic cables. This has enabled some NRENs to implement their own transmission infrastructure rather than relying on services provided by telecommunications operators. These factors are changing the technical options available for constructing research networks in Europe.

A further factor of importance is the emergence of groups of users with potentially very large demands for connectivity between a limited number of locations, as described in section 3.2. As a consequence, the simple model of a basic, best-efforts IP service provided by routers is no longer sufficient to meet the service requirements of an environment where there may be very large flows of data between a limited set of locations, and which requires predictable and defined performance. In addition, the option of a direct implementation of transmission technology, as an alternative to leasing capacity from telecommunications operators, opens new technical opportunities for the provision of service.

The steady move towards the use of optical techniques in data transmission is a fundamental change that will not be reversed. The fact that lasers can be used to transmit signals through very thin optical fibres over very long distances is already impressive, because of the simplicity and economy of the equipment. However, the multiple possibilities that have opened up for future technological improvements, in areas such as improved laser construction, fibres with lower loss and/or lower dispersion and the transmission of more and more wavelengths along the same fibre, indicate that we may only be at the start of a major change.

Many people predict scenarios where most data will be carried across networks from source to destination along (switched) optical paths. Two major uncertainties will determine if and when these scenarios will move from a test environment to real-life operational networks. One is of a technical nature: although in principle the technology for optical switching devices is known, the management of switched optical networks crossing multiple administrative domains is still an issue that requires further investigation. The second uncertainty relates to finance: the extent to which, in the opinion of investors, these technical innovations, when they are realised in production-quality hardware, can form the basis for successful and widespread business.

In view of the increasing diversification of the network requirements of users, as described in section 3.2, there are strong indications that we are reaching the point where it is no longer efficient to route each and every packet that is part of a high-throughput flow. Economics may now well favour the introduction of hybrid architectures, where long-lived high-throughput flows are switched rather than routed, leaving the more traditional fully routed Internet architecture to provide for the far higher number of smaller sessions.

In order to support very demanding applications, NRENs and DANTE should explore the use of hybrid network architectures, in which switched optical paths are introduced alongside the traditional general-purpose routed network.

An important consequence of the move towards optical transmission is that access to optical fibres will become a critical resource for the provision of network services.

All stakeholders in European research and education networking need to reflect on the rapid move towards optical transmission technologies for communications and networking, and urgently consider its implications. In particular, in countries where the national fibre-optic infrastructure is not available at competitive prices and on a transparent basis, steps should be taken to remedy that situation.

In one of the SERENATE studies[12] we have examined the way telecommunications technology is likely to develop in the next five years, its ability to meet user demands, and the effects this can have on the implementation of research networking in Europe. The study has focused on four areas of technology: routers, optical switching devices, transmission equipment and network control techniques.

Transmission technology developments have demonstrated that speeds of 40 Gb/s, and higher, are technically possible. Offering 40 Gb/s, commercially, at attractive prices is a different matter, influenced by numerous factors. These include general market conditions and mass production, which will influence the level of market prices, as well as many technical details. At the level of switch and router interfaces, a 40 Gb/s single channel is much more complex to implement than 10 Gb/s. The various technical factors will all increase the price for integrated systems operating at 40 Gb/s in a full operational environment.

The conclusion is that equipment manufacturers have undertaken considerable prototype development for equipment operating at 40 Gb/s and higher speeds, but are hesitant to commit resources to producing products until they have recognised a sizeable and firm demand. For the research and education networks, this slow move to 40 Gb/s transmission does not pose any significant problems in the short term.

The financial consequences of the move to optical networking need to be considered as well. As speed of operation of equipment increases, so does the cost of the equipment. Unlike transmission costs, which show economies of scale as speeds rise (i.e., quadrupling transmission speeds is likely to result in only a doubling of transmission costs), interface costs appear to rise more or less linearly with speed. As a consequence, router hardware costs, which used to be trivial when compared with transmission costs, can now be in excess of 30% of the cost of a link. The fact that routers operate on a 'per packet' basis accounts for elements of the increased cost as speed of transmission increases. If traffic flows are large and predictable, there is little relevance is using a per-packet decision-making mechanism to control flows. Switches, which operate on a 'per flow' basis, are much simpler devices and have interface costs of around 10% of the equivalent router interface cost. By combining routers and switches in a hybrid architecture, it should be possible to build more cost-effective networks.

12. *The results of that study have been published in SERENATE deliverable D9 "Report on the availability and characteristics of equipment for next-generation networks". See also Appendix G of the current report.*

5 Economic and Regulatory Developments

5.1. Development of the regulatory situation

The history of European research networking has been dominated by the barrier of very high prices for communication services charged by monopoly or quasi-monopoly telecommunications operators. In large parts of Europe and for a large number of telecommunications services, the liberalisation of the telecommunications markets has resulted in substantial improvements of the situation. The development of the regulatory situation has therefore been one of the topics of investigation in the SERENATE studies.

All member states of the European Union are required to adhere to the common regulatory framework laid down in EU directives. However, these directives have to be transposed into national laws, and the detailed implementation of those laws is supervised by national regulatory authorities. As a consequence, there will always be (minor) differences between the rules and regulations in different countries.
At the present time, the fifteen current member states of the European Union are in the process of implementing a new regulatory package, which was adopted by the European Union in April 2002 and was to be implemented in the member states by July 2003. However, there have been significant delays in almost all countries. The ten countries that will join the European Union in May 2004 have for some years been in the process of aligning their regulatory regime for telecommunications with that of the European Union. That alignment will be complete when each of these countries formally implements the new regulatory package, by 1 May 2004 at the latest.
A few countries, such as Norway and Switzerland, that currently do not wish to become EU members have explicitly or implicitly aligned their telecommunications regulation with that of the European Union. Bulgaria, Romania and Turkey are at various stages of the process of accession to the European Union, which brings the obligation to move towards the EU regulatory framework. The situation in other European countries varies considerably. Many of them have a rather unreformed regulatory approach in which the incumbent operator retains very strong market power.

There are direct and indirect implications of the regulatory situation. The indirect implications relate to the state of competition in the telecommunications markets, which affects the price and quality of services, and therefore the conditions under which research networks can get access to connectivity. For DANTE and for the NRENs the prices of national and international leased circuits are of particular importance. We will describe the development of those prices in section 5.2.

The most important of the direct implications is the basic right to establish self-owned networks. Under an 'infrastructure monopoly' regime, only the monopoly provider has the right to build infrastructure. When infrastructure provision is liberalised, NRENs and any other organisations have the right to provide communication services – either for their own use or as a business. Under the previous EU regulations, obligations to obtain licenses and the conditions under which such licenses were awarded may have put limitations on the establishment and operation of networks in various countries. However, with the new 'light-handed' type of authorisation in the new EU regulatory package, NRENs and other entities operating communication networks are not required to obtain permission but only to notify their national regulatory authority. We will discuss the opportunities offered by the right to establish self-owned networks in section 5.3.

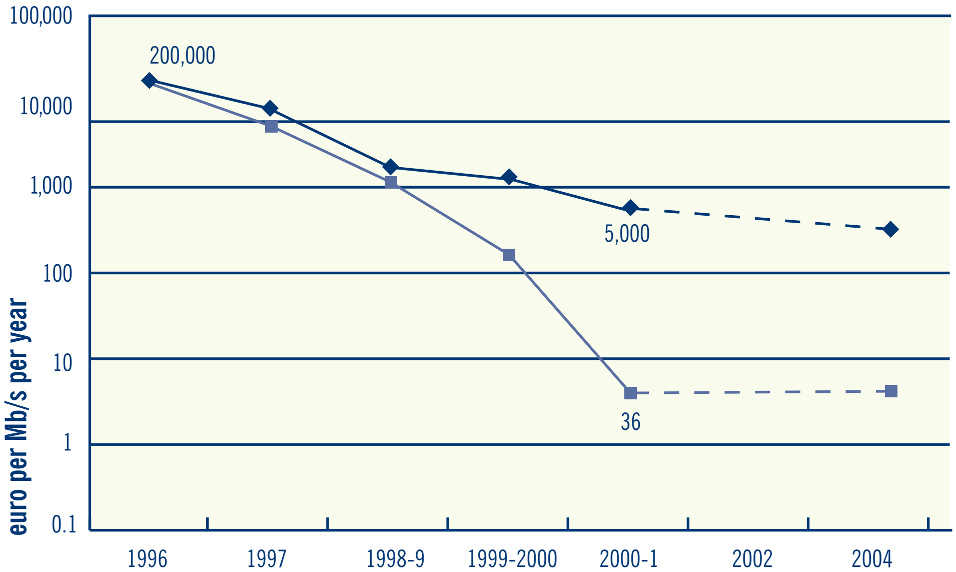
The SERENATE studies have found that the reality in some countries can be very different from the official situation as described above. In some accession states the reality of the situation is that the regulations are only weakly applied. Especially when a country is small it can be difficult to implement an effective separation of powers between the government, the national regulatory authority and the dominant telecommunications operator. We know of cases where the incumbent operator has adopted policies that seem to be in clear breach of regulatory requirements, but where the NREN was unwilling to file a formal complaint, so as not to create problems for itself.

The result of such weak application of the formally enacted regulatory regime is that there is little effective competition in the telecommunications marketplace and that prices remain considerably higher than in the most competitive regions of Europe. Moreover, in such circumstances it may be very difficult for a research network organisation to exercise its right to establish self-owned networks.

5.2. Communication costs for European networks

During the last six years, the international market for telecommunications in Europe and many of the national markets have changed significantly. The most comprehensive set of data available for studying that change are the prices that DANTE has paid for the procurement of international circuits for the pan-European backbone network (GÉANT and its predecessors). Our data sets for the prices of national circuits are not so comprehensive, but they show much the same evolution as the international trends. Perhaps the only surprising point is that the prices of national circuits are often higher than those of comparable international circuits. Prices depend significantly on the demand for circuits on the given route – routes that generate a large demand attract several suppliers and the resulting competition keeps prices low.

The figure on the next page illustrates the development of prices for international circuits as measured by the response to tenders for connectivity for GÉANT and its predecessors. It can be seen that in 1996 prices for international circuits in Europe were uniform and high. Over the next five years the picture changed dramatically. By 2001, the price of the cheapest circuit had gone down from 200,000 euro per Mb/s per year to 36 euro per Mb/s per year. From this factor of almost 6,000 a factor of 30 can be attributed to general economies of scale, representing the differences between the much larger capacities that were available in 2001 as compared with offers in 1996. Therefore, in real terms, after correction for economies of scale, prices have dropped by a factor of 200 in the most competitive parts of the European market.



The graph shows the development of international connectivity prices in the period 1996-2001 as measured by the response to tenders for the various pan-European research network backbones that have been implemented during this period, with an estimate for the later years. Prices are expressed in the simple measure of euro per Mb/s per year. The upper line shows the average offer price, and the lower line shows the lowest offer price. Note that the graph is on a logarithmic scale!

This has to be compared with the average trend line in the same figure, which shows a much more limited general reduction in prices, from 200,000 euro per Mb/s per year to 5,000 euro per Mb/s per year before correction for economies of scale. In other words, the trend is not uniform across Europe and an extremely large gap has opened up between the most competitive routes and those where competition is limited[14] or non-existent.

Much of the price reduction in the period from 1996 to 2001 has been the result of the changing market structure. In 1996 the market was still dominated by traditional operators. A key development in the creation of a competitive market for international connectivity has been the emergence of alternative service providers who built there own pan-European networks and whose business was focused on the provision of international connectivity.

The recent downturn of the telecommunications industry has made predictions about future developments very difficult. A number of pan-European carriers have been declared bankrupt and others left the market for international data communications. There are diverse reasons for this state of the market. The enormous premiums paid for Third-Generation mobile telephony licenses have taken very large sums of money from the industry. The general over-optimism about the opportunities for Internet services and e-commerce has proved to be unfounded. It should also be noted that none of the alternative service providers are yet profitable.

This sudden change of the market has had a dramatic effect on the development of prices in the most recent period. After the enormous decline of prices in previous years, the total price reduction for high-capacity circuits in GÉANT between 2002 and 2003 has been only about 3%. Prices (in euro per Mb/s per year) for international circuits in the most competitive parts of Europe are expected to remain largely unchanged. Recently there have been some attractive offers for international connectivity in the most expensive regions, thereby lowering, albeit to a

14. *An analysis of the relative prices of circuits offered in response to the GÉANT tender in 2001 shows that prices are only really competitive if the number of suppliers making an offer is at least four.*

15. *Synchronous Digital Hierarchy, the international telecommunications standard for data transmission at rates (typically) between 2 Mb/s and 622 Mb/s. Equivalent in many ways to the primarily US-based SONET standard.*

limited extent, the average offer price. Nevertheless, the gap between the most competitive routes and those where there is little competition is expected to remain very significant.

Another way to convey the complexity and range of pricing is to analyse the present communication costs of GÉANT, which amount to 30 million euro per year. Of this sum, 14 million euro is used to pay for 140 Gb/s of wavelength service (14 circuits at 10 Gb/s), while 16 million euro is needed to pay for only 3 Gb/s of classic SDH15 service in locations where wavelength services are not available or would not represent a sensible solution. If all circuits could be procured at the per-kilometre cost of the cheapest wavelength, then the 14 million euro of annual expenditure for the wavelength service would be reduced to about 4 million euro. If all over Europe communication costs would drop to the level of the most competitive areas, then the communication costs for GÉANT would not be 30 million but less than 5 million euro per year.

Expensive regions not only exist in the market for international circuits but also within countries. Even in countries that are well endowed with optical-fibre infrastructure and have competitive pricing, there can be islands of fibre penury. For example, connecting university campuses in Lancashire and Kent (United Kingdom) and in Brittany (France) to the national research network at high speeds has proved difficult because of high pricing or the absence of fibre infrastructure in those regions.

5.3. Self-owned networks and related cost

The current economic and regulatory situation allows research network organisations to obtain some form of 'ownership' of the telecommunications infrastructure that they use. This can offer them an attractive alternative to leasing circuits from telecommunications operators in those cases where the prices offered by operators are excessive. The various alternative forms of infrastructure acquisition may also offer research network organisations greater control over the networks and services. In the discussions in Canada the term 'customer-empowered networks' has been introduced.

The move to optical transmission that was described in chapter 4 has led to an unbundling of communication services. This exposes the costs of the individual elements of what was previously a single unbundled service. These components include access to the optical-fibre infrastructure; the deployment of transmission equipment, including any equipment needed for amplification and regeneration of optical signals; the arrangements for reconfiguration in case of a disruption of the service; and the service operations. The research network organisation needs to understand the financial impact of each unbundled component in order to develop a strategy for the way in which it wishes the overall service to be delivered. In the discussions in the SERENATE workshops the evolution to unbundled communication services has been characterised as a major element of the 'new complexity' that now faces research network organisations.

Research network organisations that wish to acquire some form of infrastructure 'ownership' have to make choices between a number of options. One aspect of the choice concerns the extent to which the organisation wants to take responsibility for the physical infrastructure on which its network will be implemented. A second aspect relates to the extent to which the organisation wishes to have protection against any disruption of service. The third aspect concerns the nature and the duration of the commitment that the organisation should make.

Dark fibre is optical fibre dedicated to use by a single organisation – in our case a research network organisation – where the organisation is responsible for attaching the transmission equipment to 'light' the fibre. Professional companies who specialise in dark-fibre systems take care of the installation of the fibre and may also maintain it on behalf of the research network organisation. Some additional management complexity appears in long-distance fibres, when in-line optical-signal amplification or regeneration is necessary. In such cases, the research network organisation must take responsibility for remote management of in-line equipment and the company maintaining the fibre may provide some local assistance.

Fibre owners do not normally sell their fibre but offer IRUs (Indefeasible Rights of Use) for up to twenty years for unrestricted use. The up-front cost for the purchase of a 20-year IRU can be a one-time investment. It will normally be associated with ongoing obligations for shared maintenance. Usually, the IRU can be considered to be a physical asset, which can be resold, traded or used as collateral. As such, the cost of an IRU can be depreciated over its lifetime, which results in a monthly cost that can, where the market is not competitive, be considered lower than the cost of traditional telecommunications services.

The potential advantage of such a long-term commitment is that the research network organisation then has control over exactly when and how new equipment is deployed to increase the transmission capacity on the fibre in response to evolving needs. A disadvantage is that it is not possible to exclude that technology will evolve so quickly that the fibre will become obsolete before the end of the lifetime of the IRU.

Because of legal rules in some countries, or because of the funding horizons of the organisations concerned, it is in some cases not possible to depreciate the cost of the IRU over its lifetime. For this reason and for reasons of competitiveness, some fibre owners offer long-term lease with a regular monthly fee and, in some cases, an additional one-off installation fee. A small number of NRENs have had positive experiences with this arrangement, having the possibility to decide which dark-fibre lines to lease and for how many years.

An organisation that wishes to have access to an optical-fibre infrastructure can decide not to operate the transmission equipment itself but to outsource that task to a professional company, for example to the fibre owner. In such cases it must of course be carefully defined who is responsible for which aspects of the correct functioning of any equipment. With arrangements like these, one usually speaks about ***managed fibre*** instead of dark fibre.

Currently, and in the foreseeable future, research networks will use only a very small number of wavelengths in a single fibre. Therefore, for longer distances buying ***wavelength services*** from carriers is likely to be cheaper than using dark fibre, where the market is competitive. This depends of course on the actual business offer, but in principle a higher level of fibre sharing is necessary to reduce expenses, and carriers have better opportunities to organise fibre sharing for long distances than NRENs[16].

Quite apart from these financial considerations, if a research network organisation does not want to acquire a deep technical understanding of optical-fibre infrastructure and does not want to take responsibility for the operation of transmission equipment, then it may prefer to lease - for a shorter or longer period - one or more wavelengths between a set of locations.

In that case, the fundamental decisions concern the specification of the interfaces at the source and destination, and the arrangements in case of a service breakdown. The most common interfaces to wavelength services are based on SONET/SDH transmission. They offer speeds of 2.5 and 10 Gb/s. There is also a growing interest in the campus-to-campus transmission of

16. *As far as international connectivity is concerned, the GÉANT procurement in 2004, which seeks offers for dark fibre, managed fibre and wavelength services, is expected to provide an objective view of this uncertain area.*

Gigabit Ethernet streams, which are normally multiplexed and transported over wide-area SONET/SDH services at 2.5 and 10 Gb/s.

In addition to the connectivity costs, the budgets needed for routers, switches and/or transmission equipment are also part of the overall financial picture. In section 4.4 it was already pointed out that hardware costs are no longer negligible, and can actually amount to more than 30% of the transmission cost. The most powerful modern routers - capable of handling multiple 10 Gb/s line interfaces and switching packets at line speed without loss - provide a good illustration of the trend. The cost of a basic installation is around one million euro and adding one new 10 Gb/s interface can cost some 200,000 euro.

In order to improve our understanding of the underlying costs, the Center for Tele-Information, one of the SERENATE project partners, has developed a financial model for telecommunications services running over an optical-fibre infrastructure. The model takes account of the cost of the link itself, the transmission equipment (including any equipment needed for amplification and regeneration) and routing and switching equipment. Using figures obtained - typically on a non-disclosure basis - as part of the SERENATE studies, the model was used to calculate the underlying costs for a broad range of links. A generic version of the tool has been made available on the SERENATE website[17].

The conclusions of this work confirm the distance-related nature of the cost of optical transmission. Significant extra costs are incurred for amplification as the distance involved exceeds 200 km and for regeneration as the distance exceeds 800 km. The work also highlights that physical construction is very expensive unless the costs can be shared with others. Actually digging trenches normally only makes sense for telecommunications operators, which make a business out of having many customers pay to share long-distance capacity, and for institutions on short routes between their campuses and local exchange points in case no other organisation is likely to take responsibility. However, the work also emphasises that optical transmission, although it requires some specialist skills during construction and operation, is a relatively simple and economic technology. This holds in particular if the spans involved are shorter than approximately 200 km.

One of the few instances where NRENs or organisations responsible for campus networks should actually consider physical construction is when short distances need to be bridged between isolated institutes and the points of presence of key service and/or infrastructure providers. Because the construction costs of optical-fibre infrastructure are dominated by civil-engineering costs and are only marginally affected by the number of fibre pairs installed, the cost of building local loops can be high. In these cases one should try to minimise the distance involved and look for partners with whom the cost can be shared.

Research and education institutions should consider acquiring their own fibre infrastructure between their Local Area Network(s) and the point(s) of presence of key service and/or infrastructure providers, if necessary by commissioning its construction.

5.4. The strategic importance of optical fibre

The optical-fibre infrastructure is likely to be the infrastructure that will have the most direct impact on national economic performance in the 21st century. With a cost per kilometre (for cables of approximately 100 fibre pairs – and hence an enormous available capacity) that is

17. *http://www.serenate.org/*

only 5% of that of motorways, this infrastructure is not expensive. And it is most certainly not expensive if Europe indeed wishes to become the most competitive and dynamic knowledge-based society in the world.

While cost-effective access to this infrastructure is very important for NRENs and other research and education network organisations, we are convinced that optical-fibre communications will also have a very broad impact on society in general. The fate of two specific major European policy initiatives, the European Research Area and *e*Europe, will depend strongly on the widespread deployment of the optical-fibre infrastructure and on the cost of access to that infrastructure.

One may be optimistic that in the economically most prosperous parts of Europe investment in the fibre infrastructure will be sufficient to achieve competitive pricing for customers. However, it is not obvious that all countries, especially those with less economic strength and/or little high-technology industry, will automatically attract sufficient investment in that infrastructure. The governments concerned will need to address the issue and find appropriate sources of investment. The European Union's structural and regional funds could provide a contribution.

Over the next few years, many research network organisations will acquire 'ownership' of optical fibre assets. Seen from the point of view of small players, entering a complex market largely dominated by a few operators with strong capital backing, success is likely to depend on market transparency - so that research network organisations can understand who has fibre assets available on the routes of interest - as well as on fair pricing - so that the fibre pairs can be acquired at reasonable cost. We make two specific recommendations in this context, one related to reporting on fibre availability and one related to right of access at equitably negotiated pricing.

When, in previous centuries, entrepreneurs invested in building roads, railways and canals in the hope of making a profit over time, those infrastructures were visible to all passers-by. That is not the case with optical fibres – they are thin and many fibres fit easily in a duct of small dimensions. Such ducts run along many European motorways, pipelines, railway tracks and sewers, but their presence, and above all the number of installed fibres and whether they carry traffic, is not known to anyone but the owner. Since optical fibre will be the key communication infrastructure of the next decades, this present lack of transparency is likely to be a serious impediment to creating an open and competitive market for communication services in Europe.

The European Commission and the national regulatory authorities should establish an annual census of installed optical fibre and ducting, and the resulting information should be made publicly available.

To achieve the objectives of the European Union's regulatory framework for electronic communications it will be necessary that a vigorous market for dark (and managed) fibre comes into existence in all European countries and on a pan-European basis. However, currently NRENs, or indeed any small market players interested in leading-edge services, have no guarantee that they will be able to obtain access to optical fibres at reasonable prices. Since we would like to avoid any specific regulatory exemptions for research and education networks, we would ideally like to see a regulatory approach that will give all small players and perhaps even all market parties a non-discriminatory right of access to installed fibre at equitably negotiated pricing. By 'equitably negotiated' we mean prices freely negotiated on the basis of accountable costs incurred by the supplier - plus a reasonable profit margin. The national regulator would only need to intervene in cases where parties are unable to reach agreement.

However, we recognise that this is a complex area and that the regulatory framework of the European Union can only be modified after wide consultation and with appropriate care. We therefore make the following recommendation:

The European Commission should, by the end of 2004, consider under what conditions, and for which parties, it would be reasonable to introduce a right of non-discriminatory access to optical-fibre infrastructure at equitably negotiated pricing.

It would perhaps be reasonable to limit this right of access to those small market parties that are not in a position to assemble the engineering effort and/or the capital required for building their own long-distance infrastructure. Alternatively, or additionally, it might be wise to exempt certain infrastructures from the obligation, such as those that have only recently been constructed or those that carry traffic that occupies a reasonable part (for example, at least 33%) of their total capacity.
We would hope and expect that at some point in time the need for this right of access would no longer exist, when the markets have become fully competitive. That could be demonstrated by pricing surveys and the census mentioned above.

5.5. Competition in high-capacity network services and access to optical fibre

Effective competition in the provision of network services at speeds of 1 Gb/s and more, and access to dark and managed optical fibre, will be vital for the healthy development of research and education networking in Europe. As NRENs have experienced during many years, unacceptably high prices are the immediate consequence of a lack of real competition. Such pricing – often several orders of magnitude higher than market prices in competitive parts of Europe – creates an insurmountable barrier, often setting back progress by many years and preventing the user communities from integrating into the global research community.

If such high prices for Gigabit services are sustained over long periods, in any parts of Europe, they will also have a strong negative impact on the economic competitiveness of those regions and on Europe's overall regional and social cohesion.

National governments and national politicians have a major role to play in ensuring that the spirit of the EU regulatory framework for electronic communications infrastructure and associated services is actually implemented, also for networking at Gigabit speeds, that a truly independent regulator is in place, and that effective competition is enabled. During the SERENATE studies we were continuously confronted with the reality that in a surprising number of countries where the EU regulatory regime applies, there is extremely little competition in the supply of communication and network services, while in practice the supply of advanced services, such as networks at Gigabit speeds, often remains a de-facto monopoly.

In the fifteen current EU member states and in the ten countries that will join the European Union in May 2004, NRENs and any other organisations have the right to establish self-owned networks, in line with the new EU regulatory package. What is additionally needed in some of those countries is pressure to ensure that the regulatory regime is effectively applied. Occasionally some active encouragement for new market entrants will also be necessary.

Many of the other countries in Europe find themselves with a regulatory regime that is very far from ideal. The governments of those countries should be strongly encouraged to adopt a regulatory regime in line with the European Union's regulatory framework, thus strengthening competition, including competition for the supply of Gigabit network services, and for providing access to dark and managed optical fibre.

Looking at Europe as a whole, some research network organisations may be able to lease circuits or to obtain wavelength services at very competitive prices. They may not feel much pressure to establish self-owned networks. Others may refer to the option of establishing their own infrastructure in their negotiations with telecommunications operators in order to receive lower price offers. There is a third group of research network organisations, which are confronted with unacceptably high prices and find themselves in such a situation that they will only be able to provide state-of-the-art services by deploying their own infrastructure.

In general terms, all European governments, politicians and national regulatory authorities should strive hard to introduce a truly competitive environment for the provision of Gigabit network services.
More specifically, it is very important that governments across the whole of Europe, including those beyond the borders of the European Union, ensure that their NREN, should it so wish, be empowered to install, or lease, its own optical-fibre transmission infrastructure.

6 The Digital Divide

6.1. Recognition of the digital divide

There is clear evidence that there is a significant divide between countries in Europe with respect to the network infrastructure and services that are available to the national research and education communities. This digital divide has been investigated in some detail in one of the SERENATE studies[18].

Network capacities are one indicator for the extent of the digital divide. The SERENATE study on geographic issues has compared figures for three groups of countries in Europe: the European Economic Area (the current fifteen member states of the European Union, Iceland, Norway and Switzerland), the ten countries that will join the European Union in May 2004, and a number of other countries neighbouring the European Union (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, FYR Macedonia, Romania, Serbia and Montenegro, and Turkey). It turns out that on average the typical core capacity of the national research network is five times smaller in the second group of countries than in the first group, while on average it is 25 times smaller in the third group of countries. The same ratios hold for the average total capacity of the international connections available to the NRENs in each of the three groups. However, there are also significant differences between countries in each of the groups. The situation is most discouraging in Albania and in Bosnia and Herzegovina, where there is currently no operational national research and education network, and in FYR Macedonia, where the network capacities are very small.

The consequences of this digital divide are serious. The international research community is moving rapidly to adopt Grid-based research and other forms of collaborative e-science. In future, only those researchers who have access to a high-capacity research network will be able to take part. Consequently, the countries without an adequate research network will suffer from 'research exclusion'.

The institutions of the European Union and governments in Europe should:
- recognise that, at the present time, a digital divide exists inside the European research and education community
- take energetic measures to reduce, and preferably eliminate, this digital divide.

In principle, policies set by the European Union can be expected to affect only the EU member states, and to a certain extent the countries that are candidates for EU membership and the other countries of the European Economic Area. However, on several occasions during the SERENATE studies we received the strong message that in the areas of telecommunications, networking and related fields any technical and organisational advice and recommendations provided by the European Commission carry very much weight in other European countries as well.

18. *The results of that investigation have been published in SERENATE deliverable D16 "Report identifying issues related to the geographic coverage of European research and education networking". See also Appendix F of the current report.*

The institutions of the European Union should determine the approach to be adopted by the Union with respect to the digital divide that exists between its research and education community and that of the neighbouring European countries. Even if those countries are neither EU members nor are likely to obtain EU membership in the short term, policies and advice from the European Union carry significant weight. The European Union also has a political interest to ensure stability and to strengthen democracy in these countries.

6.2. Monitoring

It is very important that the existence of a digital divide between the research and education communities in different European countries is officially acknowledged. It is equally important that the European Union accepts overall responsibility to reduce, and ideally to eliminate, the divide between the (current and future) EU member states, as well as to assist the other countries in Europe to address the problem of their own divide. In order to measure progress in these actions, it will be vital to establish a series of specific measurements.

The European Commission should monitor annually the state of the digital divide between the European Union's research and education communities, also including the neighbouring European countries, and publish the results. The monitoring should cover the availability and cost of Gigabit communication services and the functionality and performance offered by the various national research and education networks.

Determining the availability and cost of communication services is related to the annual census of ducting and fibre that is proposed in section 5.4, but covers a wider field and should, preferably, be conducted separately.

The annual editions of the TERENA Compendium of National Research and Education Networks already provide important data as regards the functionality and performance of NREN services. The European Commission's financial support to this publication should definitely be continued. In addition, it would be highly desirable to monitor performance on a more continuous basis and especially to report on the performance as experienced by individual end-users. An example is the end-to-end performance monitoring that has been conducted since 1997 by the Stanford Linear Accelerator Center[19].

At a policy level, there is an additional opportunity for monitoring the progress towards eliminating the digital divide for those countries that are candidates for membership of the European Union. The term 'acquis communautaire' refers, in the strict sense, to the entire body of European legislation, including all treaties, regulations and directives passed by institutions of the European Union as well as judgements laid down by the Court of Justice. Countries that are candidates for EU membership must adopt, implement and enforce all the 'acquis' to be allowed to join the European Union. The term is also used with a broader connotation, and the Regular Reports that the European Commission publishes annually on the progress that candidate countries have made towards reaching the standards of the 'acquis' deal with a variety of topics. They contain sections on science and research and on education and training.

The Regular Reports on the progress towards accession that are published annually for each of the countries that are candidates for EU membership should report on the overall status and performance of the national research and education network in the country.

19. *See http://www-iepm.slac.stanford.edu/*

6.3. Government actions

As was pointed out in chapter 2, national governments have the responsibility to ensure that researchers, teachers and students in their country can use appropriate network facilities. This responsibility should weigh heavily in those countries that are in danger of remaining on the wrong side of the digital divide.

There are many actions that governments can undertake. In countries where a national research network organisation does not yet exist, the government should help to create one, and ensure that it is recognised inside and outside the country as the single official NREN. Governments should ensure that adequate funding is allocated to the NREN and also that universities and research institutes receive adequate funding for their network facilities. This should include funds to cover the payments of those institutions to the NREN, if any.

As mentioned in chapter 5, there is a surprising number of countries where in reality there is very little competition in the supply of advanced telecommunications and network services, even though, in some cases, in theory the EU regulatory regime has been adopted. It is not surprising that that set of countries coincides largely with those countries where researchers, teachers and students find themselves on the wrong side of a digital divide. Governments can remedy that situation by promoting a truly competitive environment, for example for the provision of Gigabit network services. More specifically, they should ensure that the NREN in their country has access to optical-fibre infrastructure. We refer to the recommendation in section 5.5.

Besides measures related to the regulatory situation, funding and investments are what is needed most to improve the situation in research and education networking. In some of the countries concerned, this may be difficult to achieve because of the general economic situation. Financial support from the European Union can play an important role here.

Where a member state of the European Union or an accession country wants to make investments in research and education networks, especially investments in communications infrastructure such as optical fibre, it is appropriate to apply for the use of EU Structural Funds (either via the European Regional Development Fund or via the Instrument for Structural Policies for Pre-Accession (ISPA)).

The European Union and the governments of the EU member states and the accession states should encourage the use of Structural Funds to finance investments in the field of research and education networking, including investments in communications infrastructure, such as optical fibre.
Governments of countries without access to the Structural Funds of the European Union should actively seek alternative sources of finance for such investments.

7 Local and Regional Networks

7.1. Campus infrastructure

The many end-users who provided contributions to the SERENATE studies pointed, in large numbers, to the campus infrastructure as the weakest link in the chain of research network provision. Historically, this may have been different. For many years the development of research networks at the national and international levels has been limited by the high prices charged by telecommunications operators. That situation has changed dramatically in recent years, and national research networks and their international interconnections have moved to much higher speeds and the provision of more advanced services. In many cases, Local Area Networks have not been upgraded in the same way, mostly because the level of ongoing investment provided by the responsible authorities is insufficient. Universities, colleges and research centres all need to make regular investments to maintain their campus LANs at an appropriate level.

Many details of the required campus infrastructure, and its costs, will depend on local circumstances as well as on the rapidly evolving technology. We plan to publish in the first half of 2004, after the completion of the SERENATE project, an additional report with guidelines for suitable technical and financial standards for campus networks.

In Europe, campus networks are now often the weakest link in the chain of the end-to-end services needed for research and education. Therefore, universities and research institutes and their supervisory and funding authorities need to ensure that their campus networks are appropriately resourced.
In general, expenditure for ongoing technical upgrade in campus networks is best treated as a budget expense on an annual basis.

7.2. MANs and regional networks

As described in section 2.1, in some cases campus LANs are not directly connected to the NREN's national network but via Metropolitan Area Networks and/or regional networks.

If a national research network has to connect only a few dozen institutions, its topology may be designed in such a way that it connects directly to the LAN of each institution. However, when the national network has to connect many hundreds or even thousands of institutions, such fine granularity eventually becomes impracticable. Normally, the NREN will then create points of presence in important cities and each institution will be connected to such a point of presence. If there are many institutions in one area, they may group together to implement a common approach to their local infrastructure needs. Inside a city (or a somewhat larger area) this leads to the creation of a Metropolitan Area Network (MAN) infrastructure. Usually, these networks are based on leased wavelengths or dark fibre.

MANs can represent an important building block in research and education networking. They allow the organisations responsible for research and education networks at a local level to control their transmission infrastructure in the metropolitan area. Usually, that infrastructure can be upgraded in an economic fashion as technology develops.

Regional networks cover larger areas, typically up to 200 km by 200 km. While MANs normally only provide transmission services, regional networks are usually more like small-scale copies of national networks, offering a variety of services. Regional networks usually not only serve research and education but also other public institutions or even the private sector. They are usually, at least partially, funded by regional authorities and are under their control.

There are positive aspects to regional networks, especially in their function to facilitate and promote the use of data networks in all sectors in a region. However, there are risks involved in introducing regional networks, as an intermediate level, between the local and national levels of research and education networks. Regional networks serve a variety of institutions, including local and regional governments, schools, libraries, healthcare institutions and perhaps even small businesses. The choices that are made with respect to investments and technical and managerial solutions, will often be tuned to the lowest common denominator of the requirements of those user groups and may not meet the very different requirements of universities and research institutes. Regional authorities that have no direct responsibility for research and higher education are not likely to give high priority to the network needs of those institutions. Moreover, without very strict co-ordination, different regional networks are bound to opt for different, and often incompatible, technical solutions. During the SERENATE studies, we have heard many complaints about regional networks, from end-users and from persons responsible for research networks at the local and national levels. In countries where the campus LANs are connected to the national research network via regional networks, the regional networks are often perceived as a barrier for the provision of high-capacity transmission and end-to-end service.

If regional networks are used to carry research and education traffic, then it is essential to have extremely close co-ordination between all the regional networks in a country and the NREN. This co-ordination must cover investment planning, policy setting, technology choices and their evolution, and operations.

To a certain extent, similar problems may arise for other user groups. For example, national policies to create a transparent network infrastructure and tailored services for schools or for public libraries, may conflict with the objective of regional authorities to create a single infrastructure for all public-sector institutions in the region. Authorities at the different levels in a country should be aware of the trade-offs between regional and municipal initiatives, which may wish to provide a single infrastructure for multiple local user communities, and the need to co-ordinate content, services, service levels and support for specific user communities at a national level.

8 The Future Structure and Organisation of European Research and Education Networking

8.1. Integrating applications with very high network demands

In chapter 3 we have described the emergence of certain scientific applications that put very heavy demands on networks. Those applications not only require very large network capacities, but also put heavy demands on network availability and end-to-end performance. Existing research network organisations will be able to serve the needs of these most demanding users thanks to the technical developments that we have sketched in chapter 4 – in particular the move to optical transmission and the possibility to deploy hybrid network architectures – and the market developments that we have outlined in chapter 5 – including, where appropriate, the opportunities for direct access to optical-fibre infrastructures.

At least in theory, one could conceive a scenario where a group of these demanding users, based entirely at a small number of locations in countries with competitive pricing, might wish to create their own private high-capacity network to serve the needs of a joint project. This could seem attractive to them in the short term, but there would soon be negative effects for all parties concerned. The economies of scale and the benefits of synergy remain, as well as the need to concentrate scarce resources and expertise. Funding bodies, research network organisations and end-users would all suffer if the coherence of national and pan-European research networking were not maintained.

For research network organisations, it is very important to continue to serve the needs of all end-users, because of economic reasons, and in order to stay at the forefront of technological developments. To achieve this, they will need to take a number of measures, concerning the introduction of optical-fibre infrastructures and network architectures as mentioned above, as well as the establishment of new financial models. At the national level, the existing funding model for the NREN (see section 2.3) may no longer be adequate if a very small number of applications at a very small number of locations need extremely high network capacities. At the European level, the current cost-sharing model (also mentioned in section 2.3) cannot be applied in full if single applications need to be provided with network access capacities of the same size as the access capacity of an entire country, unless the number and locations of those applications would be more or less proportionally distributed over the various European countries; this is not the case.

The NRENs, both acting nationally and acting internationally through DANTE in the development of GÉANT, should support the new, very demanding applications and encourage the researchers concerned to use the common research network infrastructure. The groups generating such demanding applications should collaborate with their NRENs and DANTE in order to obtain under reasonable conditions, including financial conditions, the services that they require. National and European funding bodies should work together to integrate these new, very demanding groups with the rest of the user community of research networks.

8.2. Closer collaboration between NRENs and providers of academic IT services

The discussions in the workshop for network users in the European research community that was organised by SERENATE, led to the conclusion that it will be increasingly important to develop a much closer collaboration between academic IT services and NRENs. Increasingly, important components of educational courses and research materials of all types are delivered to the user via electronic communication that is provided by national research and education networks and campus LANs.

In this context, it will be vital that the procedures for authenticating users in the research and education community, and for verifying their authorisations, are coherent and consistent between the NREN organisation and the IT services in a country. In addition, the planning of content delivery and of network facilities need to be co-ordinated: there is no point in having a server with poor network connectivity to deliver large quantities of content, nor in having high-capacity connections to servers that generate little traffic. The management of access rights is a third area that needs consideration. Most researchers, including those working in the social sciences and the humanities, who may need to pay considerable sums in order to access research materials from commercial databases, want to be able to access those materials from locations other than their regular place of work in the university or research institute.

The NRENs and those responsible for academic IT services at the national and campus levels need to develop much closer co-ordination of their services in several areas, especially the co-ordinated access to content, such as distance-education material and commercial databases.

8.3. A pan-European Authentication and Authorisation Infrastructure

There is a need to move quickly beyond the present primitive use of passwords as the means for authenticating persons in the research and education community (are they who they claim to be?) and checking their authorisations (are they allowed to access the services or data that they are trying to access?). The previous section sketched this need, in the context of access to educational material and databases. But, as mentioned in section 3.1, we expect that over a much broader spectrum there will be a strong demand for authentication and authorisation services. As researchers, teachers and students wish to use network and information services not only from their own desk in their own institution but also from other locations - for example from home or via the local networks of other institutions that they happen to visit -, the authentication and authorisation services will need to serve such roaming users. This makes those services more complex, as well as more useful and important.

It takes a very considerable organisational effort to deploy authentication and authorisation services in a consistent and coherent way, across a country's education and research community, as a national Authentication and Authorisation Infrastructure. Work towards that goal is ongoing in a number of European countries but in rather disparate ways, although the technical experts involved, and their counterparts from the United States, maintain close contacts through a TERENA task force.

What is missing is a strong push to ensure that the Authorisation and Authentication Infrastructures that are being developed are compatible across Europe, and globally. If Europe is to have a single Research Area, it is vital that students and professors can easily access their usual information technology tools and information services with their normal 'electronic identity', when they spend a few hours or a few months at other centres of learning and research in their own or in other countries, or when they are working from home or from other locations.

We recommend to the European Commission and to the multiple other actors involved (universities, academic authorities, governments, funding agencies, hardware and software suppliers) that a major project should be set up with the objective of implementing and validating a coherent pan-European Authentication and Authorisation Infrastructure.

The scale of this project will certainly not be smaller than that of recent major projects supported by the European Commission that are aimed of the deployment of IPv6 across Europe. It is very desirable that the project will have significant industrial participation.

8.4. Greater inclusiveness

One of the SERENATE studies has produced case studies[20] on the provision by NRENs of services to a broader range of user communities than researchers, students and teachers in higher education. Such an extension of the user groups of research and education networks is being promoted by the European Commission, which has asked the project that will support GÉANT during the lifetime of the Sixth Framework Programme, to address the 'inclusiveness' of the research network infrastructure by taking into account the demands of various parties in the field such as schools, educational networks, libraries, e-learning etc.

The case studies describe examples of the 'inclusion' of all levels of the education system[21], students at home, public libraries, museums and government institutions. No large-scale examples have been identified in the field of healthcare; while university hospitals are connected to research networks via their university, this is generally not the case for other healthcare institutions, probably because of their specific, and very strict, requirements in terms of security and confidentiality of data. The case studies show very different approaches towards the diverse user communities in the various countries. One general lesson appears to be that strong long-term political support is necessary when research networks extend their services to users outside research and higher education.

Greater inclusiveness is particularly important for small countries. By extending their user community beyond researchers, teachers and students in higher education, NRENs in such countries can reach a size that will enable them to provide services more efficiently and to have in-house expertise in a large number of fields. In other words, they can achieve a critical mass and economies of scale that are obtained naturally by NRENs in large countries.

Some governments have initiated projects to connect schools, libraries, museums or other public institutions to their national research network, while others have not. Some governments have taken initiatives to connect these kinds of institutions but prefer not to involve the NREN. It will depend very much on national circumstances what the optimal choice will be. In any case, such

20. *SERENATE deliverable D15 "Report on examples of extension of research networks to education and other user communities". See also Appendix C of the current report.*
21. *Providing network connections to all types of schools – not necessarily by the NREN – was already formulated as a specific objective in the eEurope 2002 Action Plan.*

choices are, in view of the subsidiarity principle, within the remit of national authorities. It seems inappropriate to make any specific recommendations for Europe as a whole.

It goes without saying that the level of service provided to users in research and higher education should not be influenced negatively by the attention given to other types of users and the services provided to them. However, in many cases the research community forms a very natural partner for the broader education community, and many governments are keen to see that synergy exploited.

If network connections and services for primary and secondary education are to be provided through the NREN in a given country, then adequate resources must be allocated, additional to those needed to support the research and higher-education communities.
Whatever detailed organisational and funding arrangements are made, it is essential to have excellent co-operation between all organisations providing network connections and services for primary and secondary education, for lifelong learning, for higher education and for the research community.

8.5. The relation to the commercial Internet and Information Society policies

Research and education networks cannot exist without the commercial Internet. As mentioned earlier in this report, as part of their work, researchers, teachers and students need to access the commercial Internet, for example to obtain publicly available information or services in relation to their work. The commercial Internet also allows them to access their usual information technology tools and information services when they happen to be at locations that are not connected to research networks. Conversely, the commercial Internet benefits greatly from the research and education networks, as they are a major source of Internet innovation.

Supporting an advanced information and network infrastructure for research and education, and promoting the broader use of the Internet by the population at large are two equally important political objectives. They are complementary and not conflicting, nor is one a substitute for the other.

It is a matter of concern that there is sometimes insufficient awareness of the importance of research networks, and insufficient knowledge of the difference between the facilities that researchers need and those offered by the commercial Internet. It is particularly disturbing that authorities in some countries believe that the advent of the Information Society, which they interpret as the availability of the commercial Internet to the population at large, will be sufficient to meet the needs of the education and research communities. The matter is further confused by inappropriate terminology; for example, the term 'broadband' seems to be associated increasingly with ADSL, while a user in the research community would probably like to reserve the term for network capacities that are some 10,000 times higher.

This lack of awareness and understanding became apparent in the survey that we have conducted as part of our investigation of the digital divide. That survey covered European countries outside the European Economic Area. However, we are not convinced that even within the European Union all relevant decision-makers at local, national and European level are always sufficiently informed. Research and education network organisations and their user communities need to keep the decision-makers at the relevant levels informed about the developments in research and education networking and about the requirements and opportunities that emerge.

8.6. The collaboration at European level

In this report we have discussed a number of the important challenges facing research and education network organisations, at local and national level. We have also indicated a number of times that intensive collaboration at the European level is crucial. Indeed, in the Final Workshop of the SERENATE project it was emphasised that a strong and active collaboration between all NRENs will remain essential if we are to maintain and evolve a coherent European approach to research and education networking. This coherence requires a single European infrastructure that serves the needs of all users in research and education, and a set of responsible organisations with simple collaboration arrangements.

There are developments that pose challenges to creating and maintaining a strong and coherent European approach. One that was mentioned earlier is the growing diversity of network and service requirements of users in the research community. Another challenge is the inclusion of more countries in (and possibly around) Europe: many choices that need to be made require a broad consensus of all network organisations concerned, and that can obviously become more difficult to achieve as the number of organisations increases. We are pleased to note that the NRENs, DANTE and TERENA have intensified their collaboration and are in the process of developing streamlined procedures for collaborative work and decision making. This will help them to meet those challenges.

To ensure that the forces striving for coherence are at least as strong as any centrifugal tendencies, it is important that the European Commission continues to fulfil the pivotal role that it has played in recent years in assisting the interconnection of Europe's national networks and the development and deployment of new technologies. There can be no substitute for the authority provided by the combination of the European Parliament, the European Council and the European Commission in support of the efforts of Europe's research and education network community.

The European Council and the European Parliament should ensure that the European Commission continues to play a significant role in enabling Europe's research and education network facilities to remain competitive at the global level. 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.

Appendix A
The SERENATE project

Project organisation

The SERENATE project was a series of strategic studies into the future of research and education networking in Europe. It investigated the strategic aspects of the possible developments over the next 5-10 years, looking into the technical, organisational and financial aspects, the market conditions and the regulatory environment. The project started on 1 May 2002 and was completed on 31 December 2003. It was funded by the European Commission as an accompanying measure in the Information Society Technologies programme of the Fifth Framework Programme.

The project partners were TERENA, DANTE, the Center for Tele-Information (CTI) at the Technical University of Denmark, the Academia Europaea and the European Science Foundation. Further information about those organisations is given below. Antelope Consulting, a small independent consultancy firm in the field of telecommunications, contributed to the work as a subcontractor of DANTE. The project also involved active contributions from multiple stakeholders: research and education networking organisations, governments and funding bodies, network operators and equipment vendors, and the users of research and education networks.

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

- Marko Bonač, Director of ARNES, the academic and research network of Slovenia, and member of the TERENA Executive Committee, led the study of geographic issues
- Ian Butterworth, Vice-President of the Academia Europaea, conducted the investigation into the networking requirements of users in the European research community
- Dai Davies, General Manager of DANTE, made large contributions to the work on technical, regulatory and economic developments
- Sabine Jaume-Rajaonia, responsible for commercial and international matters at the French national research and education network RENATER and member of the TERENA Executive Committee, co-ordinated the studies into 'inclusiveness', the extension of the user communities served by research and education networks
- Fernando Liello, who chairs the NREN Policy Committee, was unable to participate in the work of the Steering Committee due to other commitments
- Tony Mayer, Head of the Secretary General's office at the European Science Foundation, contributed to the work on the networking needs of researchers
- Knud Erik Skouby, Director of CTI, led the work of his team on regulatory and economic issues
- Karel Vietsch, Secretary General of TERENA, was the SERENATE Project Manager
- David Williams, CERN and President of TERENA, chaired the Steering Committee.

The individual SERENATE studies were carried out by means of various work packages, which included the organisation of a number of workshops.

In total, five SERENATE workshops were held. The Initial Workshop, which took place in La Hulpe, near Brussels, on 17-18 September 2002, and the Final Workshop, which was held in Bad Nauheim, close to Frankfurt, on 16-17 June 2003, were of a rather general nature and the attendance included representatives of all the groups that are stakeholders in research and education networking. The objective of the Initial Workshop was to provide a broad range of inputs to the project concerning issues to be addressed. The Final Workshop had the aim to consider and discuss the draft findings from the various SERENATE studies and to provide advice on the preparations of the final conclusions.

A workshop in Amsterdam on 7-8 November 2002 focused on the views of service providers, principally telecommunications and network operators. On 17-19 January 2003, a workshop was held in Montpellier to gather and discuss the views of end-users of research and education networks. The workshop that was held in Noordwijkerhout, close to Amsterdam, on 4-5 February 2003, concentrated on discussing the experiences and opinions of national research and education network organisations.

The SERENATE methodology ensured that at least a few hundred persons have been involved in one or more aspects of the studies. In addition, the user questionnaire was completed by approximately 500 people. The presence of participants from equipment vendors and service providers at the workshops also provided an important 'reality check'.

This broad involvement of many different parties over quite a long period had several positive side effects. In particular it has improved understanding of the status and potential developments in European research and education networking, and fostered relations between many of the parties.

Project partners

The Academia Europaea is an international, non-governmental learned society with charitable status under English law. Members of the Academia are all eminent scientists and scholars from countries across the whole of Europe. There are at present almost 2,000 members, including more than 30 Nobel laureates. Disciplines covered include the natural sciences and mathematics, the social and cognitive sciences, the humanities, economics and law.

The Center for Tele-Information has extensive experience in the study of the economics of telecommunications infrastructure and services. It is a multi-disciplinary centre at the Technical University of Denmark, engaged in research and training in tele-information that reflect a synthesis of technical, economic and social knowledge. The research is directed to issues that are important to education, management and policy development.

DANTE was established in 1993 as a not-for-profit company owned by a number of NRENs in Europe. Its mission is to organise, manage and provide advanced pan-European data network services to the European research community. As such, DANTE has played the major operational role in the deployment of a series of subsequent European research network infrastructures. Currently DANTE is the co-ordinating partner of the project that provides the pan-European research network backbone GÉANT.

The European Science Foundation is an association of research councils and grant agencies, national research organisations and academies from more than twenty European countries. Since its establishment in 1974, the ESF has co-ordinated a wide range of scientific initiatives. ESF's core purpose is to promote high-quality science at a European level. The ESF is committed to facilitating co-operation and collaboration in European science on behalf of its principal stakeholders: the member organisations and Europe's scientific community.

TERENA, founded in 1986 as RARE[22], is the association in which research and education networking organisations in and around Europe collaborate. Its current membership encompasses 33 NRENs as well as a number of international research organisations and associate members from the industry sector. TERENA represents the joint interests and opinions of its members, supports the development and testing of new technologies and services, organises conferences, workshops and other forms of knowledge transfer, and provides an environment for new initiatives in research and education networking.

SERENATE publications

In total, SERENATE has published fifteen public reports. All these reports are available from the project website at http://www.serenate.org/ . Moreover, six of the reports have been published in paper form as well.

The full list of public deliverables is as follows:

D1. Report on Initial Workshop results
The report provides a summary of the results of the initial SERENATE workshop, which was held in La Hulpe on 17-18 September 2002. The report contains the presentations given at the workshop as well as an overview of the discussions.
Available from the Web at: http://www.serenate.org/publications/d1-serenate.pdf

D3. Report on the experience of various user communities that have experimented with 'alternative' models of infrastructures
The concept of 'customer-controlled' networks is being implemented in various places around the world. This report describes a number of these initiatives, outlining in particular the success and risk factors.
Available from the Web at: http://www.serenate.org/publications/d3-serenate.pdf

D4. Report on workshop on operators' views on infrastructure and likely evolution
A workshop in Amsterdam on 7-8 November 2002 provided an opportunity for traditional and alternative providers of telecommunications and network services to present their own views on the status of pan-European telecommunications and network infrastructures and their likely evolution. The report contains the presentations given at the workshop and an overview of the discussions.
Available from the Web at: http://www.serenate.org/publications/d4-serenate.pdf

D6. Report on present status of international connectivity in Europe and to other continents
The report presents the current status of international connectivity in Europe and to other continents, covering, in the case of the European market, availability of connectivity, perspectives on the current and evolving market, market structure and a view on the results of market liberalisation.
Available from the Web at: http://www.serenate.org/publications/d6-serenate.pdf

22. *Réseaux Associés pour la Recherche Européenne*

D7. Report on the expected development of the regulatory situation in European countries relevant for the SERENATE project
The report presents the results of the SERENATE fact-finding study on the current regulatory environment in the relevant countries and the expected evolution, especially in relation to alternative models of infrastructure acquisition[23].
Available from the Web at: http://www.serenate.org/publications/d7-serenate.pdf
The report has also been published in book form.

D8. Report on workshop on National Research and Education Network models
In the workshop that was held in Noordwijkerhout on 4-5 February 2003, representatives of research network organisations discussed a number of intermediate results from the SERENATE studies, including in particular the work on alternative models of infrastructure acquisition. The report contains the presentations given at the workshop and an overview of the discussions.
Available from the Web at: http://www.serenate.org/publications/d8-serenate.pdf

D9. Report on the availability and characteristics of equipment for next-generation networks
The report discusses the availability and characteristics of equipment for next-generation networks, dealing with current and potential suppliers, technology in terms of switching and routing elements as well as the emergence of management techniques[24].
Available from the Web at: http://www.serenate.org/publications/d9-serenate.pdf
The report has also been published in book form.

D10. Report on the networking needs of users in the European research community
The report describes the networking requirements of users in the European research community and discusses priorities in introducing novel networking facilities and services[25].
Available from the Web at: http://www.serenate.org/publications/d10-serenate.pdf
The main part of the report has also been published in book form.

D13. Report on the expected evolution of international connectivity in Europe and to other continents over the next five years
The report[26] integrates the results described in reports D6 and D7 as well as the studies of traditional and alternative approaches to network infrastructure. On the basis of these inputs the report gives a forecast of the market development and price dynamics of the transport and infrastructure market.
Available from the Web at: http://www.serenate.org/publications/d13-serenate.pdf

D14. Report discussing future scenarios for the funding of network infrastructure in the European research networking community, and of related costs
Based on a synthesis of the earlier SERENATE results, the report attempts to draw conclusions comparing the different approaches to infrastructure acquisition, using models for cost calculations.
Available from the Web at: http://www.serenate.org/publications/d14-serenate.pdf

D15. Report on examples of extension of research networks to education and other user communities
This report, produced by various authors, describes a number of initiatives in different countries to extend the user community of research and education networks to primary and secondary education, students at home, libraries, museums and government institutions[27].

23. *A summary of those results is presented in Appendix D of the current report.*
24. *An executive summary is presented in Appendix G of the current report.*
25. *A summary of the findings is presented in Appendix B of the current report.*
26. *See the executive summary in Appendix E of the current report.*
27. *Summary conclusions from these case studies can be found in Appendix C of the current report.*

Available from the Web at: http://www.serenate.org/publications/d15-serenate.pdf
The report has also been published in book form.

D16. Report identifying issues related to the geographic coverage of European research and education networking
The report provides a review of the present status of networking opportunities for researchers in various parts of Europe, including the availability and cost of services and infrastructures, and presents possible actions for improving the situation[28].
Available from the Web at: http://www.serenate.org/publications/d16-serenate.pdf
The report has also been published in book form.

D18. Report outlining scenarios for the evolution of the pan-European infrastructure for European research and education networking
Integrating the results described in reports D14, D9 and D10, this report describes a number of scenarios for the future evolution of pan-European research and education networking.
Available from the Web at: http://www.serenate.org/publications/d18-serenate.pdf

D19. Report on Final Workshop results
The report provides a summary of the results of the final SERENATE workshop, which was held in Bad Nauheim on 16-17 June 2003. The report contains the presentations given at the workshop as well as an overview of the discussions.
Available from the Web at: http://www.serenate.org/publications/d19-serenate.pdf

D21. Summary report on the SERENATE studies
This is the current report. It provides a summary of the most important results from the SERENATE studies, including an analysis of relevant aspects as well as recommendations.
This report has been professionally printed and widely distributed.
It is available from the Web at: http://www.serenate.org/publications/d21-serenate.pdf

28. *An executive summary is attached to the current report as Appendix F.*

Appendix B
The needs of network users in the European research community

This appendix describes an assessment of the future networking needs of members of the European research community over the next five years or so, which was published as SERENATE report D10. Its conclusions were derived primarily by analysing the views of active researchers from a large range of subject disciplines and geographical locations. Those views were obtained by a questionnaire and by discussions at two workshops.

The responses to the questionnaire and the experiences of those at the workshops show that there has been great progress during the past five years, such that researchers have a reasonable environment of research and education networking in many parts of Europe. But we cannot be complacent, because the situation in several regions in Europe is far from satisfactory, and arguably getting worse in relative terms.

Satisfactory network performance for the end-user depends on a healthy infrastructure in three areas: on the campus, nationally and internationally. For many European researchers, the major source of limited network performance is primarily at the campus.

The current model, in which one NREN organisation is necessary and sufficient for each European country with international connectivity being provided between the national networks, remains appropriate. But there will be a need for the NRENs to provide enhanced services, and that means that all NRENs will need to engage in a deeper dialogue with campuses and the bodies responsible for their IT infrastructure.

International connectivity is of particular importance in internationally collaborative research. Most researchers collaborate with a small number of distant collaborators: 50% have five or less. Very large collaborations come from experimental particle physics; the earth sciences and nuclear science can involve quite large collaborations in the 30-50 range; collaborations in the 20-30 range cover a wide range of subjects from the physical and life sciences and sociology.

There are a significant number of researchers (14%) who are regularly transmitting rather large files, say of more than 100 Megabyte, over the network, and there are a small number who are moving very large files of up to 1 Terabyte.

We are impressed by the evidence of growing network requirements from all areas of research. The needs will grow dramatically over the next 5-10 years, in all disciplines and in all countries. Examples were given where the research would become much more efficient if network speeds were increased by one or two orders of magnitude. Examples were also given where there is the possibility of starting completely new research activities that were prohibited until now by lack of very high performance network facilities. There is a remarkable interest and involvement in Grid computing. It is clear that Grid computing with all its related resources is something that on a five-year timescale will be demanded by all European researchers if they are to contribute to their subject.

User expectations have evolved beyond the provision of pure bandwidth towards the supply of more complex services. There are concerns about security, privacy and confidentiality, and there is likely to be demand for AAA services (authentication, authorisation and accounting) in the research and education area, which will require new expertise in the NRENs. There will be growing demand for the researcher to be able to access networks wherever he or she happens to be.

NRENs should become more involved in initiatives aimed at reducing 'spam' and protecting against viruses and hacking.

We further recommend that the NRENs, and DANTE, co-operate to put in place a service that, when a user believes there is unusually bad network performance, would determine whether the performance was indeed degraded, and if so, take responsibility for correcting the situation.

The growing development of globally distributed sets of facilities will require flexibility not just in connection with communication hardware but in all NREN services.

We feel that the NRENs should increase the flow of information, including road-maps of likely future service developments, to their end-user communities, and make more educational material available.

In stressing a move to services, it should not be forgotten that there is a demand for more bandwidth from a significant number of research end-users. Two areas given as examples of the broad demand for increased bandwidth are visualisation and the use of videoconferencing.

Networking involves real money, and some feel that some form of charging the end-user might be acceptable, particularly where there is heavy use or special needs. Certainly, end-users should be made aware of the true cost of the service being provided, which may also demonstrate to the user community where investment is needed, especially on the campus. However, we feel that any move in the direction of explicit charging for heavy or special use must be treated with great care. Up-front charging can stifle progress and advanced applications. It should not be considered until both the financial and technical issues are well-understood and stable.

We are far from 'equality of networking opportunities' for researchers in all countries of the European Research Area. Yet, researchers all over the Area wish to do similar work. The reduced network resources in the economically weaker countries of Europe and their consequent reduced contribution to European research imply that an intellectual force is being seriously under-utilised. Provision of good IT infrastructures is also an important factor that can influence the migration of high-quality researchers. The dramatic nature of this internal 'digital divide' in Europe must be drawn to the attention of politicians.

Regulatory liberalisation in the fifteen current members states of the European Union played a major role in reducing prices and improving services. We believe that the elimination of telecommunications monopolies and the rapid introduction of effective competition among several operators will be crucial factors if the digital divide is to be eliminated in the next, say five, years. However, any attempt to implement equal opportunities across the European Research Area within five years will depend on strong political commitment, and spending significant sums of money.

Recommendations

The report lists a number of specific recommendations:

Relevant to universities

A major source of limited network performance is at the campus, and this fact must be drawn to the attention of senior management in the university and similar sectors.

Relevant to NRENs

NRENs should increase the flow of information, including road-maps of likely future service developments, to their end-user communities, and make more educational material available.

NRENs should devote more resources to listening to the needs of users.

NRENs should explicitly explore the problems arising from research collaboration between universities and for-profit organisations such as SMEs[29] and give advice to the relevant stakeholders.

NRENs must take account of the growth in user expectations in the form of more complex services.

The NRENs should plan for good broadband remote access for researchers at the office, laboratory, home or away on a mission.

NRENs should recognise that a greater demand for AAA services will in most cases require new expertise.

It is important for academic and education users that the deployment of AAA (or similar) services is handled in a compatible manner across Europe.

NRENs and universities together should establish appropriate licensing arrangements for the research community.

NRENs should become more involved in initiatives aimed at reducing 'spam' and protecting against viruses and hacking.

NRENs, and DANTE, should co-operate to put in place a service that when triggered by the user, would determine whether the performance obtained was indeed degraded, and if so, take responsibility for correcting the situation.

Particularly relevant to the European Commission and national funding bodies

Basic research networking should be regarded as a public good.

Any move in the direction of explicit charging for heavy or special use must be treated with great care. It must not be considered until both the financial and technical issues are well-understood and stable.

29. *Small and Medium Enterprises*

We are far away from 'equality of networking opportunities' for researchers in all countries of the European Research Area. There is a European internal 'digital divide'. To implement equal opportunities requires strong political commitment, and spending significant sums of money.

Elimination of telecommunications monopolies and the rapid introduction of effective competition among several operators are crucial.

The Regular Reports on each accession state's progress towards accession should be required to specifically address the extent to which their national research and education network has been brought up to EU levels.

Appendix C
Greater inclusiveness - extending the user community

Summary of recommendations

Strong long-term political support is necessary when research networks extend their services to users outside research and higher education.

Research networks need adequate resources to cater for the needs of users outside research and higher education; these users are looking for more services than simple network access.

The level of service provided to users in research and higher education should not be influenced negatively by the attention given to other types of users and the services provided to them.

Countries should be aware of the trade-offs between regional and municipal initiatives, which may wish to provide a single infrastructure for multiple local user communities, and the need to co-ordinate content, services, service levels and support for specific user communities at a national level.

Connecting users outside research and higher education to national research and education networks remains an issue to be decided at a national level, but countries that wish to choose that option might be encouraged by decisions made and policies set at the European level.

Introduction

Currently, many countries emphasise the need to link their entire education system strongly with their national research network. The *e*Europe 2002 Action Plan, which was adopted by the European Council in June 2000, already stated that a very high speed trans-European network for electronic scientific communications should link research institutions and universities, as well as scientific libraries, scientific centres and, progressively, schools. Furthermore, any institution's networked teaching resources should be available 24 hours a day and 7 days a week, and students need access both on-campus and from their weekday and weekend lodgings.

As a result, it is becoming essential to have really excellent connections between the national research and education network and the local (normally fully commercial) Internet. In some countries a potentially even wider scope for the NREN is investigated, for example through linking up with municipal networks through municipal points-of-presence.

Besides the full range of educational institutes, there are in a number of countries other types of users outside research and higher education that have been connected via the national research and education network. In SERENATE report D15, descriptions of some of these initiatives are provided, with an analysis of organisational and financial issues, and a discussion of the success and risk factors.

That study also addresses the needs of these users and how they can be fulfilled within the national research and education network. Addressing new user communities may lead to the development of new services to meet their requirements. Different countries may take different approaches in this area, and the case studies present different perspectives on this issue.

In total, ten case studies were carried out. The corresponding reports are contained in SERENATE report D15.

Background for connecting these user communities

Initiatives to connect users outside research and higher education seem to require a strong political push and such political support is probably essential. Funding models often involve public investment, at least in an initial phase. Support also needs to be sustained over the long term, as in many cases the solutions provided to the user communities evolve over time, taking on board technological developments and changing user needs.

The issue of competition with commercial Internet Service Providers does not seem to be a major problem. Perhaps essentially because there is a real added value in being connected to a national research and education network. However, there are several cases where competition with local initiatives seemed to arise. In some cases there is a preference not to connect to the national research and education network but to a service provider that is able to connect all types of users in a municipality.

An officially established and published Acceptable Use Policy and strict adherence to that policy are important instruments for NRENs to avoid complaints about competition. If an Acceptable Use Policy clearly limits the type of users that will be connected and the kind of traffic that will be carried, and if new user communities that are being connected are evidently within that limited group, then fears of commercial companies about unfair competition can be prevented.

Main conclusions

All case studies are very positive about the experiences in the initiatives described, even if one of them emphasises the difficulties of launching the initiative and of creating a nation-wide approach. The case stories show that a strong policy and continued political and financial support are necessary. Without strong government backing for an initiative, nothing is likely to happen.

There are a few underlying reasons for this. One is that institutions outside the community of research and higher education are less familiar with the Internet and the opportunities that it offers for innovative applications. Of course, there are also people in those institutions who realise the potential and try to take small-scale initiatives, but the efforts of those pioneers usually do not lead to large-scale implementations of new infrastructures and services unless there is support from the very top. Moreover, the institutions concerned are usually smaller than universities or research institutes and have a smaller budget. Therefore they find it very hard to make significant start-up resources available from their existing budgets.

Political support in the beginning is one thing, but continued political and financial support is another. While most governments now realise that advanced networking facilities for research and higher education are a permanent, essential and expanding requirement, such facilities for other user groups are often supported only on a project (and therefore: temporary) basis. Moreover, compared to the world of research and higher education there may be more (independent) policy makers involved in other user communities, which makes continuity and consistency of policy-making less self-evident.

A particular example is the relation between the policies of national authorities and those of regional or local authorities. This is not normally a major issue for research and higher education, since in most countries the policies in those fields are determined at a national level. But in many countries regional and local authorities have important responsibilities, and they are often the funding authority for schools, public libraries, museums etc. This means that providing network services to those kinds of institutions is more complicated, as it needs co-ordination of policies (and funding) by authorities at different levels. As Internet use becomes more widespread, conflicts of interest between these different authorities may appear: several of the case studies show that while from a national perspective connecting schools and libraries via a national infrastructure with services that are tuned to the needs of that particular user community may seem optimal, from the perspective of a local authority that finances those schools and libraries it may appear more cost-effective to make them share the Internet facilities with other municipal or regional organisations.

To address the needs of the user communities outside research and higher education, NRENs need to face challenges and changes. They can cope with these if they have adequate resources to provide the assistance and related services that are requested by these users; those services can then be provided in-house or they can be outsourced.

Being connected to a national research and education network seems a logical solution for users who work together: being on the same infrastructure avoids many bottlenecks and brings all the added value of end-to-end services between users spread all over Europe, thanks to the connectivity and services provided by the national networks and GÉANT.

Connecting various user communities to the national research and education network also brings important economies of scale, especially in small countries.

Connecting users outside research and higher education to national research and education networks remains an issue to be decided at a national level, but countries that wish to choose that option might be encouraged by decisions made and policies set at the European level. The European Commission has asked the project proposal on GÉANT in the Sixth Framework Programme to address the objective of enhancing the ‘inclusiveness’ of the research network infrastructure by taking into account the demands from various actors in the field, such as schools, educational networks, libraries and e-learning.

Appendix D
The development of the regulatory situation

One of the SERENATE studies concerned the implications of regulatory issues for the development of research and education networks. The topic is heavily influenced by a major revision in mid-2003 of the EU communications regulation, which is the latest since the liberalisation was first mapped out in a Green Paper in 1987. Regulatory issues may not be highest on the priority list of important questions in NREN communities, since they are not often encountered in daily work. However, communications regulation matters a great deal to the conditions under which national research and education networks and GÉANT develop.

What is regulation?

The term regulation means the politically instituted rules and provisions that market parties have to follow and the enforcement of regulations by regulatory agencies. In the SERENATE studies, the regulations dealt with are communications regulation governing communications infrastructures and the services associated with the conveyance of communications on networks, however excluding content regulation.

Whereas formerly telecommunications operators had national or regional monopolies and whereas political decision-making, operation and regulation were often closely tied together in telecommunications administrations, the reform process in the telecommunications area has not only entailed a liberalisation of markets and a process of privatisation, but has also meant a separation of the political, operational and regulatory fields, with regulation as an external activity to the operation of communications networks.

In this context, communications regulation most often encompasses three areas: competition regulation, including, for instance, interconnection regulation; regulation of scarce resources such as frequencies, rights of way, and names and numbers; and finally, universal service regulation and consumer protection. Among these areas of regulation, competition regulation and regulation of scarce resources are the most relevant for research and education networks to consider, as they have implications for their activities. However, the basic liberalisation of communication markets should not be forgotten, as this constitutes the basis for allowing research and education networks to deploy their self-owned physical network infrastructure where this is the best solution.

Own fibre infrastructure

Because of technical advances and the decreasing prices of fibre network technologies, the possibility of deploying a proprietary fibre network will appear more and more on the agenda of NRENs. It is important to emphasise that in a liberal regime without special rights of any operators to build and operate communications infrastructures, there should be no overall impediments, of a communications regulatory character, for NRENs to establish self-owned infrastructures. NRENs can choose this option if they find it advantageous. Furthermore, no matter which kind of infrastructure NRENs choose to apply, there will be technology-neutrality under the new EU regulation, meaning that different kinds of infrastructures will be regulated in the same, neutral manner.

Under the previous EU regulations, obligations to obtain licenses and the conditions under which such licenses were awarded may effectively have constituted limitations on the establishment and operation of networks in various countries. However, with the new 'light-handed' type of authorisation in the new 2003 EU regulatory package, NRENs and other entities operating communications networks are not required to obtain permission but only to notify national regulatory authorities. This makes it even easier for NRENs to choose the network solutions best fitted to their needs.

The question of rights of way (RoW), however, still has to be taken into consideration. A downside of installing own infrastructure may be the need to obtain RoW and accompanying permissions, for example, to dig up streets or put down cables on private properties. Rights in these areas were normally only available to public network operators. However, in a liberalised regime everyone can apply for RoW and should receive fair treatment based on objectively justifiable grounds.

The authorities responsible for granting RoW in the different countries vary. In some countries, local authorities are in charge, and in others, RoW are granted in a more co-ordinated fashion at the national level. Or a combination of local and central authorities is involved. RoW may, consequently, be a real hurdle and this is an important issue for NRENs to be aware of. For this reason, NRENs may consider to sidestep the issue of RoW by acquiring infrastructure already installed by operators with RoW instead of building the infrastructure from scratch. These are, however, issues that must be specifically addressed in the different national contexts.

In addition to the RoW question, there may be other hindrances for NRENs to take advantage of the option to choose the technology solutions best fitted to the specific circumstances. NRENs may be subject to certain political priorities and decisions, being publicly owned entities, or there may be provisions in the statutes of NRENs hindering them from owning proprietary infrastructure. But these kinds of limitations on the freedom of action of NRENs are not determined by communications regulation, and it is crucial to underline that liberalisation allows NRENs to apply all possible networking solutions.

Direct and indirect implications of regulation

There are both direct and indirect implications of regulations, where the indirect implications are the most important; they may however not always be conceived as regulatory issues but tend to be looked upon as market conditions, e.g. prices of connectivity. However, market conditions are strongly affected by regulation, and regulatory changes will certainly have an impact on the development possibilities for research and education networks. This implies that besides the entry of more competitors on a given market, which every thing else being equal would support a greater competition level, also price regulation is an important regulatory tool for lowering the price levels and thereby creating better conditions for NRENs.

The fifteen current member states of the European Union are moving from the 1998 liberalisation package to the new 2003 regulatory regime and the accession countries are adapting as fast as they can to the 'acquis communautaire'. These different paths and liberalisation stages create a number of direct and indirect implications for the research and education networks throughout Europe.

The direct implications can be subdivided into three main categories:

- The basic right to establish self-owned networks. Under an infrastructure monopoly regime, only the monopoly provider has the right to build infrastructure. When infrastructure provision is liberalised, NRENs have the possibility to choose between leasing capacity and building their own infrastructure. However, when considering a proprietary infrastructure NRENs must evaluate the problems involved in acquiring rights of way.

- The distinction between private and public networks can be important – based on the new EU telecommunications regulatory package the rights and obligations of private and public networks are different: public networks have the right to negotiate interconnection agreements and obtain interconnection prices. Public networks, however, also have to meet interconnection obligations and can be made subject to other regulations, e.g. regarding communications standards and quality of service. The classification of a national research and education network as a private or public network may, therefore, affect its development, and it may be important for NRENs to clarify their status.

- A third issue deals with competition between privately owned public network providers and NRENs. To the extent that NRENs provide services to groups of users and customers outside a closed user group of research and education institutions, privately owned public network providers may claim that they are subject to unfair competition as NRENs are supported by government funding.

With respect to the two last issues, NRENs have, at times, operated in grey zones. National research and education networks operate as private networks, but could with good reason be designated as public networks if they provide services to a broader range of user groups. And this would also open the question of unfair competition between publicly financed NRENs and privately owned operators wanting to serve the user groups of NRENs.

It is possible that NRENs have not often had to confront these issues directly yet. However, this may not always be so. In the communications field there has, with the liberalisation of telecommunications markets, been a call for increasing clarity with respect to rights and obligations. There are thus issues that may need to be clarified concerning the private and public status of NRENs and the relation to privately owned operators.

Regulations also have indirect implications for the development of research and education networks. The creation of competition in the telecommunications markets has clearly led to greater variety of services, higher quality and lower prices. All these factors are important for NRENs leasing capacity from infrastructure and network providers. It is documented that the costs of international connectivity are far cheaper in competitive markets than in markets with little or no competition. With respect to list prices for national leased lines, however, the differences between the different kinds of market situations are not that clear. But the negotiated prices clearly reflect the competitive situation and there seems to be ample room for further price decreases in the high-speed connectivity markets. The whole communications market environment is very important for the development of research and education networks.

SERENATE findings

We have focused our study mainly on the EU candidate countries, as the regulatory and market conditions and the developments of national research and education networks are less documented there than in the existing EU member states. The analysis shows however that the candidate countries cannot be considered as one homogeneous group of countries, and it also shows that there is no clear line of division between existing EU countries and the candidate countries. Some of the candidate countries are relatively far from the market and regulatory situation in the most advanced EU countries, and others are on the same level as most EU countries.

All candidate countries have been dealt with separately, and Greece and Portugal have also been analysed separately, as the liberalisation process started somewhat later in these two countries compared with most other EU countries.

The prospect is that the implementation of the EU regulatory package will help improve the conditions and possibilities for NRENs in both existing and new EU member states. But as shown in the analysis of direct regulatory implications, there are also challenges to be met with regard to clarity of the status of NRENs.

Appendix E
Market developments

We have analysed the development of the transport infrastructure for research and education networks within a five-years' perspective. This evolution depends on a wide range of regulatory, organisational, technical and economic parameters. The regulation defines the rules related to various options for ownership and specifies possible special obligations. The organisation or structure of infrastructure providers sets the framework for how the network is managed and affects the overall design. The technology defines the technical options and specifies characteristics, availability and prices of equipment. Finally, the market for connectivity shapes the availability and the prices for various types of connections.

The new EU framework for telecommunications regulation aims to create a competitive market for telecommunications services and it was foreseen to be implemented by mid-2003. The implementation is, however, delayed in several countries and inadequate procedures for licensing and interconnection will thus continue to hamper the development of real competition in the telecommunications markets. With respect to this, there is no sharp borderline between the EU members and the accession countries, rather there is a graduation basically following the ranking from low-income to high-income countries.

The European countries are categorised in four groups of markets:

- Liberal markets with transparent pricing: Belgium, France, Germany, Italy, the Netherlands, the Nordic region, Switzerland and the United Kingdom

- Liberal markets with less transparent pricing structure: Austria, the Czech Republic, Hungary, Ireland, Luxembourg, Slovakia and Spain

- Emerging markets without transparent pricing: Croatia, Poland and Slovenia

- Traditional monopolist markets: Bulgaria, Cyprus, Estonia, Greece, Latvia, Lithuania, Malta, Portugal and Romania.

Today, there are huge differences between the four groups of countries in the price for high-capacity international connectivity. If the minimum price is set to 1, the prices vary from 1-1.4 on transparent liberal markets, 1.8-3.3 on less transparent liberal markets, 7.5-7.7 on emerging markets and 18-39 on de-facto monopolistic markets.

Three scenarios are constructed to show how the markets in the four groups will develop:

1. An optimistic scenario with annual price reductions of 10% in the liberal markets and convergence towards this level in the other country groups resulting in a uniform market price

2. A neutral scenario with annual price reductions of 10% within each country group

3. A pessimistic scenario with slight price increases in liberal markets, while emerging and de-facto monopolistic markets remain stable.

The first scenario is considered to be unlikely without significant new policy initiatives. The probability of the two other scenarios depends among others on how the demand will develop. Up to now, the telecommunications markets have seen dramatic decreases in prices for high-capacity lines, and for some routes the prices are now extremely low in relation to the underlying costs, in particular for long distances. It is therefore possible that in certain markets prices will increase. On the other hand, technological developments and increasing demand will lead to cost reductions in the long term.

The new EU framework allows in principle NRENs to establish their own networks, but in reality obtaining rights of way may be a bottleneck. Although these issues in some countries may complicate the construction of NRENs' own network facilities, 'do it yourself' will become an option especially in the present monopolistic markets.

In relation to the above, the following alternatives have been studied:

- Full ownership
- Dark fibre
- Direct access

Based on EU average prices for dark fibres and best-practice prices for wavelength connections, the general conclusion is that the cheapest option is to use a 40 Gb/s wavelength connection for long distances (>1,000 km) and to lease a dark fibre with amplification for shorter distances. For long distances, if no 40 Gb/s wavelength connections are available, the next-best solution is to lease a dark fibre with amplification and regeneration. In emerging or monopolistic markets the situation may be very different. Even in liberal markets there may be routes where the terms for acquiring a dark fibre are less attractive.

Construction and deployment of fibre-build solutions is the most expensive solution in all the examples discussed. It costs about 20 times as much to construct your own link as to lease a dark fibre without amplification. This result relates, however, to the basic assumption in the build-example excluding the possibility of cost sharing with other users. On routes where dark fibres and wavelengths either are ten times as expensive as best-practice prices or simply not available, a build-solution is worth considering. It should however be noted that such routes may not be confined to monopolistic markets, but may be found outside the capital or major cities in countries with developed telecommunications markets.

The option of using fibre-build solutions is particularly expensive for long distances, where regeneration facilities are required, and the 'do it yourself' options are most attractive for short routes and for routes where a high capacity is needed.

In liberal markets it does not seem to be economically attractive for research and education networks to install their own fibre or to assume the responsibility for amplification and regeneration on the route. In markets where dark fibres and wavelength connections are either very expensive or not available, the research and education networks should consider acquiring their own fibres – in particular if construction costs can be reduced through co-operation with other users or infrastructure providers. The viability of the various options for ownership depends on how market conditions develop.

Looking at the three scenarios for market development, the ‘do it yourself’ option will generally not be viable in the first scenario, where prices in all parts of Europe are expected to converge towards cost-based prices. This is due to the substantial economies of scale that are more exploitable by network carriers with a high volume of traffic. In scenario 2, where the markets largely remain as today, ‘do it yourself’ should be considered in countries with monopolistic markets, and for routes outside the major cities also in countries with emerging markets. The same conclusion is valid for scenario 3, as the prices in liberal market generally still will be on a level too low to consider laying your own fibre. Generally, however, knowledge of and the possibility to implement the ‘do it yourself’ model is useful in negotiations and market shaping.

This finally also implies that the countries belonging to each of the four groups are likely to change in all three scenarios. Scenario 1 implies that there will be one competitive market in Europe. In scenarios 2 and 3, the market development and the use or just the potential use of the ‘do it yourself’ model might push some countries into a more liberal environment. Which of the countries this will affect depends, inter alia, on the development of demand and on network strategies adopted by the NRENs.

Appendix F
Issues related to the geographic coverage of European research and education networking

The topic of this SERENATE study was the current state of research and education networking in the wider Europe. It focuses on geographic variations and in particular on the digital divide between the most developed and least developed national research and education networks. A major part of the report is based on a comprehensive survey of NRENs in 'Neighbouring Countries' carried out in spring 2003.

The geographic coverage of the study is the 'Neighbouring Countries' of the European Economic Area, which for the purposes of the report are defined as the ten countries (Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia) that plan to join the European Union on 1 May 2004 and eight other European countries (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, FYR Macedonia, Romania, Serbia and Montenegro, and Turkey).

The concepts of equal opportunities for researchers and of the digital divide are central to the study. Equal opportunity is the goal, but we have found that in Europe today there is a significant digital divide and that there is a real risk of 'research exclusion'.

Research network provision

The survey reviewed the current standard of research network provision in the Neighbouring Countries. There is a great variation between countries. Several accession states have research networks of a high standard. Elsewhere there are some countries with no effective research network at all. Most lie somewhere in between. It should be emphasised that no country is entirely free of problems and, equally, there are none without some positive aspects.

Overall, fourteen of the eighteen countries reported major problems either at the international, national or LAN level. From the detailed responses it is clear that the lack of low-cost high-speed lines is seen as the major obstacle to improving research network provision. This is due to a lack of competition and the continuing dominance of the (former) monopoly telecommunications operators. The situation is similar to that in EU countries ten years ago. However, some of the fourteen countries have succeeded in taking the opportunity to acquire dark fibre and this has enabled them to leapfrog and rapidly develop quite an advanced network. Those who have not succeeded yet in doing this, lag behind, especially in the development of their backbone capacity.

Some conclusions derived from the study

Firstly, the digital divide exists in research in Europe and to such a level that, if uncorrected, will prevent the goal of equal opportunities for researchers being attained.

Secondly, in the countries most affected by the digital divide the case for effective government support for research networking still needs to be made. This is an area where the European

Commission, national governments, TERENA and the NREN community all need to play their part.

Thirdly, looking to the future, we conclude that research exclusion is a real risk in most of the Neighbouring Countries and that this will obstruct attempts to build the European Research Area. Many national governments are aware of the risks of information exclusion and recognise the need to follow the lead of *e*Europe in building an Information Society. Far fewer perceive the dangers posed by the digital divide in research networking and the need to close this gap.

Proposed steps to achieve equal opportunities for research and education

First, we do see an opportunity to make major strides towards diminishing the digital divide. If an NREN can get access to dark fibre, then it can, within the same budget, immediately upgrade the network capacity by as much as a factor of 100. In a monopoly situation it is not easy to get access to dark fibre; however, we have found cases where this has been done successfully (Serbia and Montenegro provides an example).

Secondly, there is a wealth of testimony to the fact that participation in joint projects has been helpful to the NRENs in Neighbouring Countries. These are joint projects with other NRENs from all parts of Europe that often, but not always, have been supported by EU funding. This should be continued and extended to cover the new countries. For these countries, a small amount of funding could make a large difference.

Finally, the survey shows that the European Union has already proved to be very influential in persuading governments in Neighbouring Countries that are accession states or aspire to EU membership, to commit to the Information Society. Therefore the EU could be equally persuasive in showing the importance of research networking. Specifically, the EU should help drive the further liberalisation of telecommunications and in particular help to persuade national governments that NRENs should get access to dark fibre. The EU could also support the investments in research and education infrastructure inside accession countries through other measures (e.g. Structural Funds).

Appendix G
Availability and characteristics of equipment for next-generation networks

The basic service provided by NRENs nationally to their users is a best-efforts IP service. The equivalent service is extended across Europe, and to research networks in other world regions, by the GÉANT network. The characteristic of a best-efforts IP service is that it offers ubiquitous connectivity, but that is all. There are no guarantees of performance. In parallel with best-efforts IP, there have been a number of national and pan-European initiatives to offer guaranteed performance between end-locations in the form of Virtual Private Networks as well as a multicast service which provides network-based broadcasting capabilities. There is a generally increasing demand from users for higher performance and/or more predictable services.

A SERENATE study has examined the way telecommunications technology is likely to develop in the next five years, its ability to meet user demands, and the effects this can have on the implementation of research networking in Europe.

Current networking environment

The best-efforts IP service is normally provided by routers interconnected by leased circuits. Historically, both nationally and internationally within Europe, leased circuits were provided by monopoly telecommunications operators. As a consequence, there was considerable reluctance, on the part of these operators, to provide access to leading-edge technology. Service provision, as defined by speed of operation of connectivity provided and availability, was generally rationed and expensive. The liberalisation of the European telecommunications marketplace has changed this picture quite dramatically in the last four years. For many locations in Europe, it is now possible to gain access to leased connectivity, which offers the maximum performance technically available today (currently 10 Gb/s). In addition, liberalisation has, in some locations, allowed direct access to physical connections, typically fibre-optic cables. This has enabled some NRENs to implement their own transmission technology rather than relying on services provided by telecommunications operators. These factors are changing the technical options available for constructing research networks in Europe.

A further factor of importance is the emergence of groups of users with potentially very large demands for connectivity between a limited number of locations. There have been several reasons for this, notably:

1. The enormous reductions in cost, particularly for international connectivity, have enabled a number of research activities to consider network-based solutions for their connectivity needs where previously these were too expensive. This meant that, in the past, either research co-operation was geographically constrained or that alternative 'non-network' based communications such as the physical transport of magnetic tapes were employed.

2. The very large, and increasing, costs of research infrastructure have led to a much more European approach to research and, as a consequence, a significant increase in the demand for

pan-European research connectivity. The European Research Area is the political manifestation of this trend.

3. The development of distributed computing power, capable of exploiting high-capacity wide-area connections, and the standardisation of these capabilities in the Grid computing initiatives.

All the above factors mean that the simple model of a basic, best–efforts IP service provided by routers, is no longer sufficient to meet the service requirements of an environment where there may be very large flows of data between a limited set of locations, and which requires predictable and defined performance. In addition, the option of a direct implementation of transmission technology, as an alternative to leasing capacity from telecommunications operators, opens new technical opportunities for the provision of service.

Basis for the study

The study has focused on four areas of technology:

1. Routers. These are currently the basic building blocks of an IP network. They are packet switches that operate and process on a per-packet basis.

2. Optical switching devices. These are relatively new products designed to switch streams of data on a per-stream basis.

3. Transmission equipment. This equipment is responsible for transmitting data, in the form of a bit stream, between switches or routers.

4. Network control techniques. These enable network operators such as NRENs or DANTE to manage the various elements that are used to construct networks. When only providing best-efforts IP services, based on interconnected routers, there is limited network intelligence, and network control techniques are not very important. As equipment becomes more complicated and varied, the ability to manage and control network elements becomes a significant issue. A particular question here is the extent to which such control techniques can operate across networks managed by different network operators.

Routers

IP routers are mature products and offer a wide range of functionality. These features are becoming common on most routers targeted at research backbone networks. In most cases they are, or will become conformant to standards and will be able to operate so that they fully utilise the transmission rate of the circuits to which they are connected. In many cases this is already possible. In terms of developments, for interfaces operating at 40 Gb/s and higher speeds, a number of manufacturers already offer the switching capacity, i.e. the ability within the router itself to support interfaces operating at 40Gb/s, although interface cards offering single-channel 40 Gb/s are not yet available. This is due to

1. low demand for interfaces operating at this speed,

2. high prices (several vendors stated that a single 40 Gb/s interface was likely to be more expensive than the aggregate cost of four 10 Gb/s interfaces)

3. the lack of commercial transmission services operating at 40 Gb/s.

For the next two years it is expected that a 40 Gb/s connection to an IP router will be delivered by four 10 Gb/s channels. A common view is that demand for routers in the research community will be the main driver for availability of commercial, single-channel 40 Gb/s systems

Optical switching devices

In the last few years a lot of attention has been given to all-optical switching. Sometimes the term 'all-optical' has been confused with devices that offer optical interfaces but operate partially using electrical technology. For example, devices that are able to switch and multiplex Gigabit Ethernet (GE) and SONET frames are optical switches, insofar as they offer optical interfaces, but they use electrical technology to carry out the switching. These devices are also called O-E-O devices (optical-electrical-optical) and have been available for some time, although they are undergoing significant developments in terms of scalability and granularity of the services they can offer. The main issues that need to be resolved for these switches over the next few years relate to standardisation of functionality and interoperability.

The term 'all-optical' relates to switching equipment that operates entirely using optical signals, and therefore is also referred to as O-O-O devices. They are independent from (or transparent to) the signal that is being carried over an optical channel (GE, 10 Gb/s, 40 Gb/s,…). These switches use a variety of complex light-switching techniques, such as MEMs (Micro Electromechanical Mirrors), liquid crystals and other 'proprietary' methods. While the technology for all-optical switching is improving rapidly, and all-optical switches are available at reasonable prices, there remain some fundamental issues with this technology. These include re-routing of light paths with or without electrical regeneration. The distances between amplifier sites may be different between a main path and a re-routed path. As a result, optimal engineering rules, required by this analogue technology, may not be met in case of re-routing, and the switches themselves also introduce relatively high attenuation of optical signals.

In addition, devices that operate using electrical technology remain needed for multiplexing and bandwidth grooming, allowing bits streams with various combinations of speed of connectivity to be multiplexed and switched efficiently, although these functions may be confined more towards the edges of the network. The main advantages of all-optical technology relate to protocol independence, lower unit cost and lower operational costs, particularly in support of 40 Gb/s and higher speeds.

Transmission technology

Transmission technology developments have demonstrated that speeds of 40 Gb/s, and higher, are technically possible. In fact, speeds up to 600 Gb/s transmission have been demonstrated in a laboratory environment. Offering 40 Gb/s, commercially, at attractive prices is a different matter, influenced by numerous factors. These include general market conditions, and mass production, which will drive prices up or down, as well as many technical details. From a technical perspective, 40 Gb/s is much more complex to implement than 10 Gb/s. Transmission degradations, such as dispersion, cross talk and attenuation, are significantly more pronounced than is the case for lower speeds. Consequently, techniques to compensate for these effects must be developed, and better amplification methods, compensation for Polarisation Mode Dispersion (PMD) and complex Forward Error Correction (FEC) methods need to be deployed. This will all increase the price for integrated systems operating at 40 Gb/s in a full operational environment. It is thought that, over the next few years, the improvement of Forward Error Correction techniques will be the main enabler for commercial availability of 40 Gb/s transmission systems.

Commercial 40 Gb/s systems will certainly be available soon. It is unclear where we will see their first appearance. Transmission equipment vendors interviewed felt this would be in the market of Ultra Long Haul (up to 4,000 km) transmission systems, while router vendors foresee that this would be in the metropolitan area.

Many NRENs are currently deploying, or planning to deploy, their own fibre. This is enabled by the increasing developments of transmission technologies, which, even if components are not yet off-the-shelf, allow NRENs to adopt a 'do-it-yourself' approach towards the network infrastructure, in contrast with the traditional approach of buying connectivity from carriers. The reach of transmission equipment is of crucial importance for understanding and planning appropriate network architectures that satisfy the needs of NRENs without involving excessive costs. Unfortunately, NRENs still have limited experience with transmission equipment. Reach depends on many factors including fibre type, fibre quality, bit-rate of each wavelength, the number of wavelengths transmitted in parallel, amplification and transmission technology used, FEC and other components.

An issue with transmission is the need to regularly boost the signal between circuit endpoints. Transmission technology is improving significantly in relation to the spans between amplification (boosting the size of the signal to offset attenuation) and regeneration (reconstituting the signal to eliminate signal distortion). Current transmission systems for 2.5 Gb/s or 10 Gb/s require regeneration of the signal after four or five amplification stages. This means: after approximately 400 km. Newer transmission technology will enable 10 Gb/s to be transmitted up to 4,000 km without regeneration. For 40 Gb/s this range is expected to be up to 1,000 km. There is no current knowledge of the relative costs of such equipment. The provision of amplification and regeneration equipment in the network is operationally complicated and expensive, since it can impose the requirement to install and operate equipment in remote locations where NRENs have no reason to be present. Increasing span lengths will enable new network architectures for future research networks, where the ownership and management of long-distance fibre spans, without the need for amplification and regeneration, becomes a possibility worth serious consideration. This is known as 'Nothing-in-Line' operation, reflecting the absence of any amplification and regeneration equipment between the terminating points of the fibre. Successful experiences in this direction are taking place in Europe already, as demonstrated by CESNET, the Czech NREN, in reaching 230 km with Nothing-In-Line (NIL).

Network control capabilities

The next-generation research networks are very likely to include a mixture of networking elements (routers, O-E-O and/or O-O-O switches, multiplexing devices and possibly transmission equipment). In addition, the service portfolio that will be offered to users is intended to allow greater user control over network resources and performance. All of these trends imply much greater real-time operational-control network resources. To achieve this, NRENs will have to introduce new element managers in their network management systems. They will have to become accustomed to different protocols, traditionally used by telecommunications operators, which differ considerably from the techniques used in IP. Advances in TMN/Corba (telecommunications operators' world) and SNP/Corba (IP world) will assist in the integration of different network management systems, although, at present, these standards are immature and require much development.

The organisational structure of research networking is expected to remain unchanged. This will require a much more co-operative approach, among network operators, to resource allocation and control if end-to-end services, crossing the management domains of individual NRENs, are provided to end-users.

Conclusions

A simple extension of the current service model of offering best-efforts IP, at higher speeds of operation, will not meet emerging user requirements.

In the area of transmission technology, it is likely that 40 Gb/s systems will emerge in the next two years. It is perceived that these will not necessarily be cost-effective and the use of parallel slower-speeds wavelengths is more appropriate at present. The potential exploitation of dark fibre is heavily dependent on the reach and economics of 'Nothing-In-Line' systems. This is currently limited to spans of less than 250 km.

There are developments in both routers and optical switches that suggest that a combination of these elements can effectively be used to provide a more flexible and manageable network structure. In the case of switching, these will be based on O-E-O devices. Developments of O-O-O technology will require considerable additional effort before they result in widely deployed products.

Developments in network control suggest that it will be possible, in the future, to provide management functions that cross domain boundaries. However, this will require the emergence of standardised implementation of network management and control functions.

Acknowledgements

We would like to thank the two people who acted as the European Commission's project officers during the lifetime of the SERENATE project, Dr. Antonella Karlson and Mr. Wim Jansen, for their collaboration and guidance. We are grateful to the head of their unit, Mr. Mario Campolargo, for his encouragement and assistance since the inception of the project. We would also like to thank Dr. Spyros Konidaris, Mr. Frans de Bruïne and Mr. Luis Rodríguez-Roselló for their support.

Many people from research network organisations helped us by replying to specific enquiries or by participating in SERENATE workshops. Some of these organisations provided staff to work on specific analyses and reports.

People from many different organisations and backgrounds participated in various SERENATE workshops or provided information in other ways, and we thank them for their collaboration.

Malcolm Harbour MEP took time from his very busy schedule to address SERENATE's Initial Workshop. The attention that he and some of his 'technology-wise' fellow politicians devote to issues of the Internet and research and education networking is much appreciated.