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The History of NORDUnet

Twenty-Five Years of Networking Cooperation in the Nordic Countries

SKALAT MAÐR RÚNAR RÍSTA
NEMA RÁÐA VEL KUNNI.

None should write runes,
who can't read what he carves.

(The NORDUnet motto from an Icelandic saga by Egill Skalla-Grimsson)

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NORDUnet and Its Mission

NORDUnet is a data communications network interconnecting the national research and education networks of the five Nordic countries: Denmark, Finland, Iceland, Norway and Sweden. It connects about one million users and 600 research institutions in the Nordic area. It is via NORDUnet that the Nordic national research networks (NRENs) have access to other research networks around the world and to the general Internet.

NORDUnet is not only a data network, but also a non-profit organization acting as a framework for Nordic collaboration in networking. As such, it represents the Nordic NRENs in international collaborations and organizations. By speaking with one voice, the Nordic countries have much more weight in international networking collaborations.

NORDUnet is organized as a limited company, NORDUnet A/S. It is owned by the Nordic ministries of education and research or institutions under their control. The company administration is located in Hørsholm, Denmark, but otherwise the company has a distributed organization and personnel in Denmark, Finland, Norway and Sweden. The network operations are carried out by the Network Operations Center (NOC) in Stockholm, Sweden, and by the national networks.

The member networks of NORDUnet are Forskningsnet in Denmark, FUNET in Finland, RHnet in Iceland, UNINETT in Norway and SUNET in Sweden. The representatives of these national research networks form the NORDUnet board, the managing body of NORDUnet A/S. The board meets at least four times a year to decide on strategic issues.

One of the most important ways in which Nordic cooperation in networking is maintained is through the NORDUnet networking conferences. At these conferences networking specialists have the opportunity to discuss plans for the future and learn about new networking developments. Indeed, the NORDUnet network itself is a result of these meetings.

The Nordic cooperation in networking has now been going on for a quarter of a century. The first meeting for Nordic networking experts was arranged in 1980. From that year on, conferences

have been held with each Nordic country serving as a host. The mid 1980s saw the launch of the NORDUNET program, which had as its objective the building of a joint data communications network for research and education. Financed by the Nordic Council of Ministers during the years 1985–91, this program proved a success: the NORDUnet network was built in 1988 and fully implemented in 1989.

From the very beginning, the aim was for the NORDUnet network to offer the best service in the world. It interconnected the Nordic countries and connected them to Europe and the United States using an innovative multi-protocol technique. By choosing to use the Internet protocol developed in the United States but not yet approved by the other Europeans, NORDUnet took a courageous step which later proved to be the right decision.

Over the years, NORDUnet has continued to provide best possible service for research networks in the Nordic countries. It has not always been easy, as the demands have grown enormously since the early 1990s. The popularity of the Internet and the World Wide Web have made computer communication a must for an increasing number of people throughout the world, and that has created pressures for networks to keep up with new needs.

Today, one of the main objectives of NORDUnet is the development of the next generation of networks. To achieve this goal, NORDUnet and the Nordic national networks are actively participating in international networking development and providing support for advanced international collaborations. About 10–15 % of NORDUnet's budget is reserved for network development purposes.

In the future, NORDUnet will continue to maintain a strong Nordic presence in international networking organizations and collaborations. Without, of course, forgetting its original purpose: to provide a world-class networking service for Nordic research and education.

Beginnings:

Early Networking in the Nordic Countries

The birth of the NORDUnet community can be traced back to the year 1980, when the first of many conferences was held in Tällberg, Sweden. This meeting of Nordic networking experts was organized by Nordforsk, an organization promoting Nordic cooperation on technical and scientific research.

Before the Tällberg meeting, in the 1970s, there had already been several individual projects in the Nordic countries aiming to set up computer networks for research purposes – most notably the UNINETT project in Norway and the Centernet project in Denmark. Norway also played a role in the history of networking in the 1970s, being the first country outside the United States to be connected to the ARPANET network, the predecessor of the Internet.

The interest in networking grew strongly during the 1970s and several actors were developing networking technology in the western industrialized countries. This did not happen without conflicts: telecommunication carriers, computer users and manufacturers all had their own views on developing the new technology. Inevitably, the different interests led to the so called "Protocol War", a prolonged debate over the standardization of networking protocols. The question of protocols also affected networkers in the Nordic countries and turned out to be a big challenge in planning the inter-Nordic research network.

The Competing Protocols

The leading country in the networking technology in the 1970s was clearly the United States with its ARPANET network, the first large-scale data network in the world. The ARPANET was

established by ARPA (the Advanced Research Projects Agency) in 1969 to connect universities and institutions with ARPA-funded research.

Throughout the 1970s, ARPA (renamed DARPA, Defense Advanced Research Projects Agency, in 1972) was also building other networks alongside ARPANET. These networks used different technologies and were therefore incompatible with each other. To make the interconnection of separate networks possible, DARPA established the "Internetting Project" in 1973. The goal of the project was to develop a communication protocol that would guide the transmission of data across different networks.

The Transmission Control Protocol, TCP, was outlined in 1974 by DARPA researchers, and in a few years, it was developed as the TCP/IP Protocol Suite. Later, TCP/IP would become the standard networking protocol, but in the 1970s it did not yet seem a useful option for other networks. The DARPA networks were built for defense research, and access to them was restricted.

In the meantime, networking technology was also being developed for public use. In several countries, the public telephone carriers, the PTTs, were planning their own data networks. Some of the biggest computer manufacturers were offering networking solutions – IBM had developed SNA (Systems Network Architecture) and Digital Equipment Corporation had the DECnet system – but choosing the proprietary system of a particular computer company would have meant a great dependence on that manufacturer's products. The PTTs wanted to avoid that kind of situation, and were therefore eager to create public networking standards.

In 1975, a standardization organization dominated by telephone carriers, the Consultative Committee on International Telegraphy and Telephony (CCITT) began the development of a networking standard. The new standard, X.25, was promptly accepted by CCITT members the following year, and it was soon adopted by many public data networks.

Within a few years, another standardization body, the International Organization for Standardization (ISO), also began to plan a formal networking standard, called Open Systems Interconnection (OSI). The notion of "open systems", as opposed to the proprietary "closed systems" of the computer manufacturers, was an ideal for the computer scientists.

The idea of OSI was introduced in 1978, together with the general framework for the future model. The model included seven layers of protocols, and thus it was possible to accept the CCITT standard, X.25, as a part of the OSI model. The American TCP/IP, however, was rejected. The main reason for this rejection was that Europeans saw the OSI model as a means to elevating European computer and networking technology to compete with the American industry.

The idea of OSI had a huge impact on networking communities on both continents. Especially in Europe, the development of this complex model dominated the planning of all future networks for over a decade.

Networks for Nordic Universities

In the 1970s, prior to the NORDUNET collaboration, Nordic universities were beginning to establish computer networks, usually in cooperation with domestic institutions. The computers

involved were big and expensive, and joint use was economically necessary. To make it possible to operate the mainframe computers from a distance, connections with remote stations were established.

At the beginning of the 1970s the University of Oslo took part in the joint purchase of a CDC computer, which was meant to be used by several Norwegian research institutions. To the university's disappointment, the computer center was located 20 kilometers outside Oslo, at Kjeller. Rolf Nordhagen, the former director of the computer center at the University of Oslo, recalls that the original plan was to have trucks taking card input from the university to Kjeller, and then listings back. Luckily, a better idea won: "Instead of having a truck scuttling back and forth with punched cards and listings every day, we persuaded the purse holders to finance a remote station run over a 'fast' (fixed) line. The line turned out to be 48 kilobits, which was real fast in 1972."

The computer scientists at the University of Oslo decided not to buy a CDC remote station, but to set up their own system, programmed on a minicomputer. According to Nordhagen, this programming became an important learning experience for Norwegian scientists as they gained knowledge about open systems: "At that time we were heavily involved in studying the emerging principles of computer communication, the open systems model, with its clear delineation into seven levels. This model later became developed into the OSI model."

The experience was to prove useful in 1976, when the university bought a DEC-10 computer. Nordhagen and the computer scientists supported this purchase because they believed that it was time to move from batch processing to interactive processing. Nordhagen considers the arrival of the DEC-10 as an important turning-point: "Without this interactive experience we would not have known what network computing was about." In the late 1970s, the networkers in the University of Oslo built a packet switching computer network based on OSI principles.

Norwegian networkers had also another chance to learn new things through a special collaboration with the Americans. In the early 1970s DARPA was planning a packet switching satellite network in cooperation with the Norwegian Defense Research Establishment (Forsvarets forskningsinstitutt, FFI). As a part of this project, a TIP (Terminal Interface Processor) was installed at Kjeller, Norway, in June 1973. It was connected to the computers of NORSAR, the Norwegian Seismic Array project, which gathered seismic data and monitored the Soviet Union's nuclear arms testing. A 9.6 kbit/s fixed line was established via the Nordic satellite center at Tanum, Sweden, to SDAC (Seismic Data Analysis Center) in Virginia, United States, and a similar line to London, England.

Norway and England were thus the first countries outside the United States to be connected to the ARPANET network, as early as 1973. Three years later, in 1976, NORSAR was connected to the Atlantic Packet Satellite Network (SATNET).

In July 1977, Norway took part in the "internetting" demonstration in which three networks, the ARPANET, the SATNET and the Packet Radio Net (PRNET), were interconnected and the TCP protocol tested. In the demonstration the messages travelled from the United States to Norway, then to England and back to the United States across three different networks. In many Internet histories, this demonstration is considered ground-breaking, because the test proved that the idea of the Internet, the network of networks, really could work.

Thus the Norwegians had an early ARPANET connection and they were even "internetting" before the Internet was actually born, but this was not something the general public could enjoy. Although the computer center of the University of Oslo had an ARPANET connection, the ARPANET rules did not allow the network to be used for general university purposes. For Rolf Nordhagen and other Norwegian computer experts, this led to "heavy pressure to create connectivity for the whole

academic community, both in Norway and elsewhere in the Nordic countries."

The pressure led to concrete action. In 1975, the Computing Center at the University of Trondheim applied for funding for the Datanett project from the Royal Norwegian Council for Scientific and Industrial Research (NTNF, Norges Teknisk Naturvitenskaplige Forskningsråd). The application was a joint venture of four universities, Trondheim, Oslo, Bergen and Tromsø, and two computer centers: the Computing Center at Blindern-Kjeller and the Norwegian Computing Center (NR, Norsk regnesentral). Funding was granted, and the project to establish a university network began in 1976 under the name UNINETT.

By 1978, UNINETT had set up a packet switching network based on the X.25 protocol, which was the international standard at the time. All Norwegian universities were connected to the network by the end of 1979.

In Denmark, the big networking project of the 1970s was the connecting of the three regional computing centers. The project was called "Centernet" and it continued during the years 1977–83.

In the early 1970s, the regional computing centers with telecommunication-based access were established in Aarhus, Copenhagen and Lyngby. Especially active was RECAU, the computing center at the University of Aarhus, where early plans for a national network were designed already at the end of the 1960s. RECAU established a campus-wide packet switching network in 1972 with more than 200 terminals.

The need to connect the computing centers grew in the mid 1970s. In 1976, a committee for the project was established, and the following year the Centernet project was launched. The objective of the project was to create a Danish research network by connecting NEUCC at the Danish Technical University in Lyngby, RECAU at the University of Aarhus and RECKU at the University of Copenhagen, and thus give researchers remote access to the facilities of these computer centers.

The building of the network began in collaboration with Danish telephone companies. Like the Norwegians, the Danish networkers were committed to international standards, and the network was based on OSI principles. Later, the network became the backbone for PAXNET, public national X.25 network, established by the telephone companies.

Ole Brun Madsen was the Centernet project leader in 1977–81. In his view, the project made a substantial contribution to research in the field of data networking in Denmark: "It provided very significant insight for the large group of R&D people involved. The cooperation between the universities, the Danish telecoms and Regnecentralen – a Danish manufacturer – was unique. All hardware and software was developed as part of this cooperation and exchanged between the partners. It attracted a large proportion of the nation's expertise on networking at that time."

In other Nordic countries such large-scale research network projects were not yet accomplished during the 1970s, but telecommunication access to mainframe computers were organized. In Finland, a university computer network was established in the years 1970–71 to allow joint use of a supercomputer. The UNIVAC 1108 main computer was at the State Computer Center in Helsinki, and computers and terminals were connected to it through phone lines. The network was used by Finnish universities, the Bank of Finland and SITRA, the Finnish National Fund for Research and

Development.

In Sweden, most of the networking activities went on at QZ, the Stockholm University Computer Center. The center was established in 1968 and the main computer was used jointly by several research institutions: the Royal Institute of Technology (KTH, Kungliga Tekniska högskolan), the medical university Karolinska Institutet, Stockholm University and Defense Research Institute (FOA, Försvarets Forskningsanstalt).

An interesting turning-point in Swedish computing history happened in the mid 1970s, when the KOM computer conferencing system was developed and installed at QZ. At that time, KOM was a unique system of computer communication, and it soon became a popular forum for Swedish computer experts. Later it also attracted attention in other countries.

Collaboration on networking in the Nordic countries was mainly informal in the 1970s. The directors of Nordic university computer centers met at NORDATA conferences, which were organized by the national data processing associations. Collaboration between the centers, however, was at that time very limited. As Lars Backström of the University of Helsinki says: "The collaboration between the computer centers was not so concrete or unifying. In the 1970s and in the early 1980s the collaboration was mainly between those centers which had the same brand of computers."

The closest contact was perhaps between the Swedish computer center in Stockholm, QZ, and the University of Oslo computer center. Rolf Nordhagen explains: "We had the same type of computers – made by Digital – and had similar challenges. We cooperated closely in the Digital Equipment Computer Users Society, DECUS, and met frequently. And our chemistries worked excellently, we became great friends."

The KOM system was installed at the University of Oslo in 1978 and it gave a chance for Swedish and Norwegian computer scientist to practice international networking with each other. This inter-Nordic experience was also to further motivate efforts to create national and international networks.

Some networking collaboration did, however, exist even in the 1970s. In 1974 the Scannet project was established to allow remote-terminal access to library databases. Scannet, a packet switching network, became operational in 1976. The project was originated by Nordforsk, the same organization which would also be the initiator of the NORDUNET cooperation.

The First NORDUNET Conferences

By the year 1980, it had become clear that cooperation on networking development would be beneficial for the Nordic neighbors. The idea for collaboration did not suddenly spring out of thin air, since research cooperation has a long history in the Nordic countries.

"Nordic cooperation" is an established and well-known concept, and is manifested in official institutions. The most important of these are the Nordic Council, established in 1952 for parliamentary cooperation, and the Nordic Council of Ministers, which was formed in 1972 to serve cooperation on governmental level.

Nordforsk, the Nordic cooperative organization for applied research, was founded already in 1947 to promote Nordic cooperation on technical and scientific research. The organization arranged seminars and conferences and established contacts between researchers and scholars.

Björn Grönlund, a senior adviser at Nordforsk, decided to gather the Nordic networking experts together and organized a conference for them in Tällberg, Sweden in 1980. The meeting was the very first NORDUNET conference, an abbreviation for Nordic University Network.

The role of Björn Grönlund and Nordforsk was instrumental in instigating the Nordic networking collaboration and bringing the NORDUNET community together in the first place. Lars Bäckström sees Grönlund's initiative as decisive for the whole NORDUNET enterprise: "Thanks to him, it happened at such an early stage. It is really hard to see how the collaboration would have begun without the Nordforsk initiative."

At the Tällberg conference, the enthusiasm of the Nordic networkers was obvious. One of the participants was Rolf Nordhagen from the University of Oslo. For him, the Tällberg meeting was an exhilarating experience – finally there was a group large enough to achieve something more than local research networks. The long discussions continued into the night. Nordhagen recalls: "We split into groups, trying to work out if we could create inter-Nordic networks for our various brands of computers. And we agreed to work together – which of course turned out not to be easy in the cold light of coming home."

But it was a start. The next NORDUNET conference was arranged already in the following year, in Copenhagen, Denmark. It was organized by RECKU, the Computing Center of the University of Copenhagen. This time, the conference expanded to become even more international: the main guest was a networking expert from the United States, Carl Sunshine, and the conference language was English. That was somewhat exceptional within the Nordic cooperation framework at that time, because in the early 1980s there was still a strong belief that one should use Scandinavian languages in Nordic cooperation.

Ever since that second conference in Copenhagen, English has been the language used at NORDUNET conferences. The need to use English was based on the fact that networking experts outside the Nordic countries were invited to the conferences. But it was also a relief for some Finnish participants, who preferred communicating in English to using Swedish or any other Scandinavian language.

The main emphasis in the first conferences was on the sharing of new knowledge about networking development. Another important function was to gain information about the networking projects of the other Nordic countries, and to consider the ways of working together.

In the early 1980s three of the Nordic countries had their university network projects: Norway

had established the UNINETT project and Denmark its Centernet in the 1970s. SUNET, Swedish University Network, began in the year of the first NORDUNET conference, in 1980. In Finland some networking experiments had been carried out under the working title "FINNET" in the early 1980s, but it took a few more years to establish a research network. The fifth Nordic country, Iceland, was not yet a participant in the NORDUNET cooperation.

In the conferences of the early 1980s the number of participants was less than a hundred, usually something between 50 and 70 people. Lars Backström valued the relatively small size of these gatherings: "They were not that big at that time. They were just about the right size for discussions and getting to know the other participants."

Peter Villemoes, the General Manager of NORDUnet, participated in his first NORDUNET conference in Copenhagen in 1981 and later in Gothenburg, Sweden, in 1984. Also for him, the conference atmosphere seemed very cozy: "People were enthusiastic and friendly. And in Gothenburg I was very impressed about the seriousness of talks given there. Many of the presentations were much more thorough and scientific than we see today."

The NORDUNET Program Proposal

The will for collaboration grew stronger at the conference in Oslo, Norway, in 1982. According to Lars Backström this was the beginning of serious collaboration: "At the Oslo conference we agreed that the directors of the university computer centers in the Nordic capitals and Björn Grönlund should prepare the collaboration."

After that decision a small group – Grönlund, Backström, Birgitta Carlson from Stockholm's QZ, Erik Kofod from Copenhagen's RECKU and Rolf Nordhagen from the University of Oslo – had several meetings. "Soon we realized that nothing would come out of it unless we write a program proposal", says Backström.

Nordforsk had already planned a Nordic networking program back in 1980, the year of the Tällberg conference, and had even asked for funding from the Nordic Council of Ministers. But the time was then not yet ripe for such a program. By 1983 the NORDUNET community was ready to try again. At the Helsinki conference in Finland, it was decided that a working group would write an application to ask for funding for the NORDUNET network project. The goal of the project was to establish an operating computer network connecting the Nordic educational and research institutions.

An application proposal was drafted by the working group, which consisted of Lars Backström (University of Helsinki), Birgitta Carlson (QZ), Björn Grönlund (Nordforsk), Arild Jansen (University of Oslo) and Jörgen Richter (NEUCC), with Jansen and Richter writing the final text. The proposal was approved by the next conference in Gothenburg in 1984, where it was decided that the application should be presented to the Nordic Council of Ministers.

This time, the Nordic networking community had better timing in its search for funding. The Nordic Council of Ministers was at the time especially looking for new initiatives for cooperation. The NORDUNET program application seemed to fit the requirements perfectly: the project itself was

cooperative as the networking experts would work together to build a university network. Also, the goal of the project was to increase cooperation since a joint network would give Nordic researchers better opportunities to communicate with each other in spite of the geographical distances separating them.

In May 1985 the Nordic Council of Ministers granted 9.2 million Norwegian crowns to the NORDUNET program for the years 1986 – 1989. For project planning in 1985, it was given 800,000 Norwegian Crowns. Nordforsk was to act as the secretariat of the program.

The funding decision also contained a clause stating that Iceland should be given the opportunity to participate in the program. That had been the wish of the Icelandic research community, hoping to set up a data network in Iceland.

Thus, in 1985, all five Nordic countries were ready to start the NORDUNET program.

The Advent of NORDUnet

The NORDUNET conferences of the early 1980s were the basis for the collaboration that would create the NORDUnet network by the end of the decade. The close contacts and the friendly relations between networkers in the Nordic countries were already established and the participation of all five Nordic countries was guaranteed.

The NORDUNET program administration began the planning of a common Nordic research network in 1985. This task, however, proved to be a bigger and more difficult job than anyone had expected. The networking field was developing at a rapid pace, and the original plans of the NORDUNET program proposal were soon outdated. Meanwhile, the issue of protocol standards remained unresolved: in the mid 1980s, there were several competing communication protocols.

The first assumption was that the Nordic research network would be based on the OSI model (Open Systems Interconnection), which was backed by the European Commission and was expected to be the future networking standard. But the designing of the complex OSI protocols seemed to be going on indefinitely. The NORDUNET community had to look for a more practical solution.

Networking Development in the 1980s

The birth of the Internet is usually set in the year 1983, when the ARPANET network in the United States adopted the TCP/IP protocol. However, the use of the network was still limited to those universities which had a contract with DARPA (the Defense Advanced Research Projects Agency), and it would take years before the Internet would develop into the popular means of communication it is today.

By the early 1980s DARPA was not the only organization in the United States building networks.

In fact, interest in networking was growing strongly even in "unofficial" groups. One of the early networks was USENET, created by the users of the Unix operating system in 1979. This simple network used the UUCP (Unix-to-Unix Copy) program to distribute email and electronic newsletters, on-line forums called "newsgroups".

The universities with no DARPA funding and no ARPANET connection wanted networking services as well. In 1981 the National Science Foundation (NSF) began to fund the CSNET (Computer Science Research Network) in order to unify the computer science research community. In the meantime, the computer manufacturer IBM financed the building of BITNET for educational purposes. BITNET became operational in 1981 and was joined later by its European counterpart, EARN.

In Europe, the first international network was EUnet, European Unix Network. EUnet was announced in 1982 at the European Unix Users Group conference. The hub of the EUnet backbone was MCVAX at the Center for Mathematics and Computer Science in Amsterdam, Netherlands, and the first countries to join were Denmark, France and Switzerland. In 1983, Sweden was connected to MCVAX and in the same year Finland also got a EUnet connection, initially via Sweden. In Norway, the company Kongsberg Våpenfabrikk was connected to the American USENET already in the early 1980s, and the University of Oslo also had a USENET connection via ARPANET. For other Norwegian Unix users, the EUnet connection became available in 1985. In 1986, the Marine Research Institute in Iceland (HAFRO) established a dial-up UUCP link to EUnet, first via Sweden, later to Amsterdam.

The other early international network in Europe was EARN, sponsored by the computer manufacturer IBM. The company contacted European universities during the year 1984 and began to donate hardware and equipment for the construction of a research network. The first meetings of networkers from the universities were organized, and in November 1984 at the meeting in Rome, Italy, the name EARN (European Academic and Research Network) was suggested. The EARN association was formally established in February 1985. The Nordic countries were among the first to participate in the EARN collaboration: Denmark, Finland, Norway and Sweden were all connected to EARN in 1985, Iceland in 1986.

These first international European networks used different techniques for data distribution, thus adding to the variety of networking protocols: EUnet was a UUCP network, and the EARN network used IBM's technology, the Remote Spooling Communications Subsystem (RSCS) and the Network Job Entry (NJE) protocol.

The need for standardization became more and more important for European networkers. However, standardization was not only a technical issue, but a political one as well: standards were vital for the companies involved with networking technology and European politicians wanted to favor their own industry.

In 1986 the European national research networks founded RARE (Réseaux Associés pour la Recherche Européenne / European Association of Research Networks) to harmonize network development in Europe. All the Nordic countries except Iceland were among the founding members. RARE became deeply involved in the COSINE project, which was aiming to establish a common pan-European research network. The name COSINE, Cooperation for Open Systems Interconnection Networking in Europe, was derived from the decision to base the network on OSI communication infrastructure. RARE became the contractor for the work, and by 1987 there were 19 European countries participating in the COSINE project, among them all five Nordic nations.

Although networkers in the Nordic countries had their common NORDUNET project, each

nation was continuing to develop their own networks independently. SUNET, the Swedish University Network, was established in 1980. At first, it was a project sponsored by the Swedish Board of Technical Development (STU, Styrelsen för Teknisk Utveckling) and the Swedish Council for Planning and Coordination of Research (FRN, Forskningsrådsnämnden). The goal of the project was to connect researchers and university computer centers, and to build a network to connect the six university regions. Communication was based on the X.25 service of Televerket, the Swedish national telecommunication carrier.

SUNET's X.25 services were modernized during the years 1985–1988. New equipment was bought to make the DEC computers communicate with each other. The modernization was considered necessary because there were 65 DEC computers in the Swedish universities that would benefit from data communication. SUNET networkers were also experimenting with multi-protocols, and in 1987 SUNET decided to use the TCP/IP protocol.

In Finland, the mainframe computer of the University of Helsinki was connected to the Swedish packet switching Telepak network in 1981. Telepak was connected to UNINETT in Norway and Tymnet and Telenet in the United States, and the computers on those networks could therefore be reached. FUNET, the Finnish University and Research Network, was finally launched in 1984. Initially it was built over DATAPAK, a public X.25 service, which replaced the connections most universities had to the central Univac mainframe since the early 1970s. In 1986 FUNET began to replace X.25 connections with Ethernet bridges over leased lines to support TCP/IP and DECnet.

In Denmark the Centernet project implemented an X.25 network for terminal access to the regional computing centers during the years 1978–83. The network was developed in collaboration with the Centernet project and the Danish telephone companies. Later, Centernet was integrated into the public PAXNET X.25 service.

In 1986, the three regional computing centers, NEUCC at the Danish Technical University in Lyngby, RECAU at the University of Aarhus and RECKU at the University of Copenhagen, were consolidated as one whole, UNI-C, the Danish Computing Center for Research and Education. In 1987, UNI-C began to build a nationwide network, DENet, the Danish Educational Network.

In the 1980s Norway was one of the few countries to have an Internet connection, organized via the satellite network SATNET. However, access was limited to only a few institutions and it was used by only a small number of enthusiasts. The service used by researchers and the universities was UNINETT, the X.25 network that had been built back in the late 1970s. UNINETT as an operational organization was established later, in 1987.

The University of Oslo had been one of the initiators of UNINETT project and built a packet switching network in the late 1970s based on OSI principles. This network ran until 1985, when an Ethernet-based network was installed at the university.

The fifth Nordic country, Iceland, was not represented in the early NORDUNET conferences, but that situation changed in 1984, when RHÍ, the University of Iceland Computing Center, was invited to the NORDUNET conference in Gothenburg, Sweden. The University of Iceland had already planned to set up a data network and these plans seemed to accord well with participating in the NORDUNET program. The Icelandic representative of the Nordic Council of Ministers was informed about the interests of the research community and, as a result, in the funding letter of the Nordic Council of Ministers, it was stipulated that Iceland should be represented on the steering committee of the NORDUNET program.

Joining in the NORDUNET program provided the needed push for Icelandic networking. Of special importance was the seminar organized by the NORDUNET program in Iceland in November

1985. According to Jóhann Gunnarsson, the Icelandic member of the steering committee, the seminar "did much to spread the idea of a research network". Before this seminar, the idea of a research network had been fostered only by the University of Iceland and a few research institutions.

In 1987 SURÍS was founded to represent Iceland in international networking collaborations and organizations. The members of the organization were mainly research and educational institutions and network operators, but private companies were also accepted as supporting members with limited rights. The task of SURÍS was to set up and operate gateways to enable interaction between local networks and to harmonize the networking activities of its members.

Planning the Network

Nordforsk appointed a steering committee in June 1985 for the NORDUNET program. On the committee there were two members each from Denmark, Finland, Norway and Sweden, and one member from Iceland. The members of the committee were in most cases representing university computing centers or computer science departments. In addition, the steering committee also named associate members to participate in the committee work.

From Denmark, the members of the steering committee were Christian Gram from the Technical University of Denmark and Peter Villemoes from UNI-C. Finland was represented by Lars Backström and Martti Tienari, both from the University of Helsinki. Jóhann Gunnarsson of the University of Iceland Computing Center was the Icelandic member. From Norway came Arild Jansen from the Ministry of government administration and Alf Engdahl from the University of Trondheim, but later Roald Torbergsen from the research organization SINTEF DELAB was appointed in Engdahl's place. Sweden was represented by Birgitta Carlson of QZ and Sven Tafvelin from the Chalmers University of Technology. The first associate members to be named were Björn Grönlund of Nordforsk and Rolf Nordhagen of the University of Oslo.

The planning of the Nordic research network began, but it turned out to be much more difficult than expected. The work was at times very frustrating for the members of the steering committee. Peter Villemoes remembers feeling impatient during the first years: "My fear in the first two years was that nothing seemed to be coming out of this NORDUNET program." Lars Backström also recalls the uneasy time: "The planning period took much longer than we first thought. In fact, we were sometimes worried whether we were going to find the right way to proceed. Of course, we could have based the work on the original program proposal, but that was not sensible any more."

In the original NORDUNET program proposal there were many plans that were never carried out because they were based on assumptions that were outdated within a year. Backström explains: "When we were writing the proposal, we thought that every university mainframe computer should be connected to the network and we would need to write software for each of them. That of course never happened. We did something else."

The main reason for the long planning period was the question of networking protocols. The Nordic countries were, like other European countries, committed to using OSI, the Open Systems Interconnection protocols. The International Organization for Standardization (ISO) was trying

to create this ambitious OSI model and it was expected to be the standard protocol in the future. X.25, which was used by the Nordic research networks, was accepted as a part of the OSI model and supported also by another standardization authority, the Consultative Committee on International Telegraphy and Telephony (CCITT).

Important European networks, such as EARN, the European Academic and Research Network, HEPnet, the network for high energy physicists, and EUnet, a network of Unix computers, were each running different protocols: EARN was based on NJE, HEPnet on DECnet and EUnet on UUCP. In the United States, the TCP/IP protocol used by the ARAPANET and the Internet was already becoming a de facto standard. However, the European governments and the European Commission were supporting OSI standardization in order to give European industry a chance to compete with American technology.

The people planning the Nordic national networks followed networking developments on both continents very closely. At one stage, a possible solution seemed to be the Coloured Book protocols used by JANET (Joint Academic Network) in England. Within the NORDUNET community of the early 1980s, JANET was respected as an ideal example of networking. Peter Villemoes remembers studying JANET Coloured Book protocols together with Einar Løvdal of the University of Oslo: "We were looking for working examples of OSI-like protocols, Einar Løvdal and I. The only place in Europe where such a thing was functioning was England. So naturally we looked there and we also visited England to study JANET to find out what it was all about."

The ARPANET network was very much admired by Nordic networkers, but TCP/IP was an unacceptable choice. The European Commission was promoting the OSI model and funding an expensive COSINE project to build an OSI network. For this reason, every European networker was obliged to be an OSI supporter, and other options seemed almost impossible.

Peter Villemoes recalls that even mentioning TCP/IP was considered improper. "I remember Birgitta Carlson once saying at a program meeting: 'We are looking at different protocols, maybe we should also look at TCP/IP.' And that was perceived as a very naughty remark at that time. We were not allowed to do that."

The commitment to OSI was strongest in Middle Europe, but OSI also had its supporters in the Nordic countries, especially in Norway, where networkers were interested in OSI standardization because they had studied the protocols and even developed them for years.

Although the NORDUNET community was officially committed to OSI development, everyone could see that the complex model was far from ready. It meant that waiting for OSI could have delayed their project for years. Those involved in the NORDUNET program wanted to provide networking services for Nordic researchers as soon as possible. To be able to do that, they had to base the services on existing technology.

The Multi-protocol Solution

The NORDUNET project was at first administrated by Nordforsk, but in 1986 Mats Brunell of QZ became the project manager. Einar Løvdal from the University of Oslo was named as technical

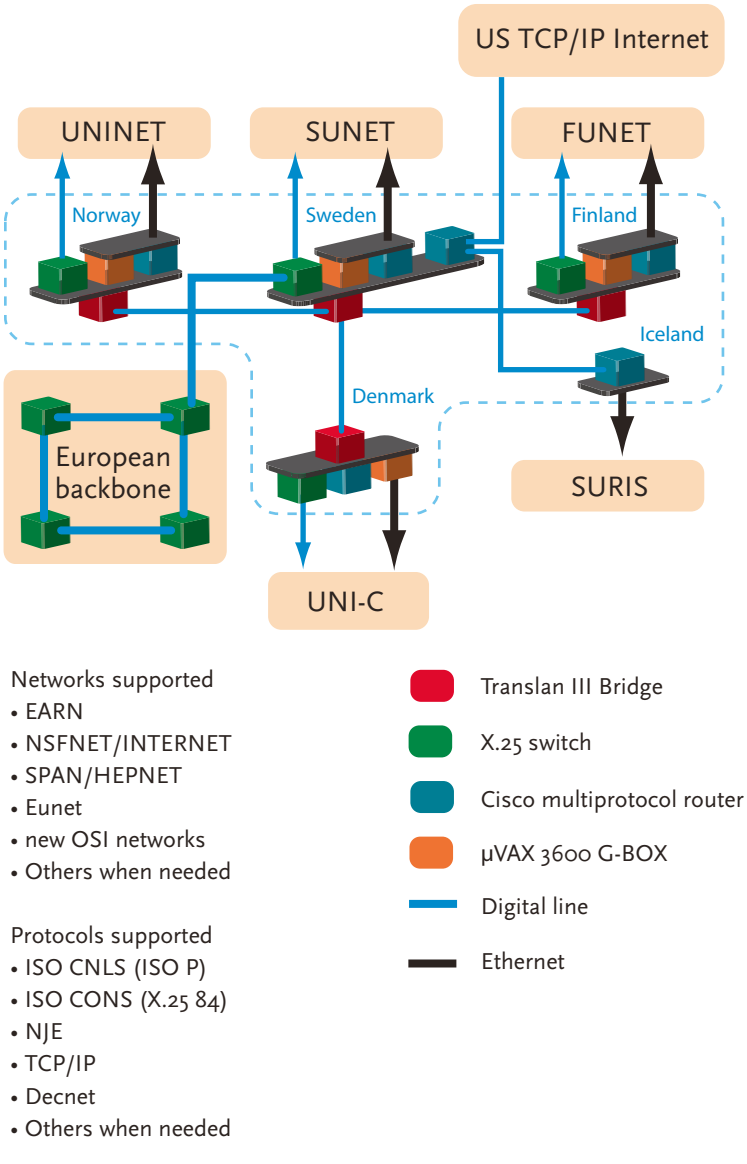
coordinator.

Things started to move forward when Brunell and Løvdal began to lead the project. Peter Villemoes remembers that these two men made the work of the steering committee much easier: "Very soon when we got Mats Brunell and Einar Løvdal in, life became pleasant. So what we did in the steering committee was that we agreed on: 'so much money for that, so much money for that', supporting these two men. Their work was going the right way."

According to Einar Løvdal, the NORDUnet idea was conceived and developed during several stages in 1987: "In 1986 and particularly in 1987 it became increasingly clear that the original NORDUNET goal to 'establish a stable, operational Nordic network based on public data communication services and OSI standards' needed a revision."

The planning of the Nordic research network coincided with changes in European research networking. The future of the EARN network was compromised, because IBM was to stop its financing by 1988. All the Nordic national research networks were connected to the EARN network, and there was great pressure for the NORDUNET program to continue the service.

The use of the EARN lines and even the possibility of a multi-protocol solution was discussed by



The NORDUnet network architecture. ▶

The NORDUnet network was designed to support several network protocols and thus to provide connectivity to the most important European and US research networks. The multi-protocol solution presented by Harri Salminen.

the project leaders Mats Brunell and Einar Løvdal at an early stage. Løvdal remembers: "I especially recall discussions with Mads (Mats Brunell) on a flight from Iceland in June 1987, returning from a NORDUNET steering committee meeting at Thingvellir. I recall that we discussed the possibility of upgrading the EARN lines, making them a backbone not only for EARN traffic, but also for other users in the Nordic countries. I think that we also agreed on the possibility and the advantages of a true multi-protocol approach. I remember this discussion vividly because I think we both realized the potential of the solution, both for inter-Nordic connectivity and shared connections to all important international networks."

The NORDUNET program organized a meeting in August 1987 for Nordic EARN directors and national research networks to work out the EARN problem. Representatives from all the Nordic countries except from Iceland took part in the meeting. EARN had never been in extensive use in Iceland, and the Icelandic networking authorities had decided not to continue the EARN service.

At this meeting it was decided to set up the X.EARN project to study how to use the existing EARN lines for the Nordic research network. From the very beginning it was realized that the fixed lines should be used for other traffic also, not just to continue the EARN service.

After two years of studying different alternatives it was time to change the strategy of the NORDUNET program. It was understood that waiting for OSI was no longer a possibility; rather, the network should be based on interim solutions, like EARN and UUCP networks, DECnet by Digital, and the Internet IP. The multi-protocol solution became the starting-point for the work of the X.EARN project group.

Also OSI and X.25 were included in plans, even though the using of public X.25 networks had turned out to be quite problematic. Hans Wallberg, the Managing Director of SUNET, explains that in the fall of 1987 it became impossible to base communication on the X.25 service any more: "X.25 became terribly expensive when usage grew, since the cost was based on the amount of data transferred. The performance was also too poor. Even if you had a 64 kbit/s connection you never got more than 2400 bit/s due to all overhead."

The X.EARN project group received help from other networking experts, not part of the official technical team. In particular, Juha Heinänen from Finland and Peter Löthberg from Sweden were strong supporters of using IP. According to Heinänen many networkers within the NORDUNET community never really regarded OSI as an option, but were from the start determined to build a TCP/IP network. OSI remained in the NORDUNET plans only because it was pushed so strongly by the European Commission. Harri Salminen, a member of the project group, also says: "At that time OSI was a real threat, so we had to prepare for it".

Norway was the Nordic country most interested in OSI and X.25. Networkers in the computing centers of Norwegian universities had participated actively in ISO standardization work and they had a very good knowledge of the X.25 protocol. Also, the X.25 UNINETT backbone was stable and efficient, and for that reason many Norwegian networkers were interested continuing the service.

However, X.25 was never the only choice for the Norwegians. Einar Løvdal points out, that networkers in Norway had also gained early experience of TCP/IP: "The experiences we had with the early SATNET connection to ARPA became very useful in setting up the NORDUnet IP service." Thus the using of TCP/IP was never questioned by the planners of the inter-Nordic network. "The need for TCP/IP was understood in every Nordic country and all national research networks wanted to carry TCP/IP traffic," says Harri Salminen.

The Swedish networkers in SUNET had experimented with multi-protocol systems and were very enthusiastic about TCP/IP. Their work became useful in planning the inter-Nordic solution.

According to Mats Brunell, the project manager: "The overall design and technical solutions of the NORDUnet network were based on a similar Swedish solution used in SUNET."

The planners of the network had thus moved away from the old NORDUNET program plans, and changed the strategy completely. The solution for the inter-Nordic network would carry multiple protocols: X.25, NJE of EARN, DECnet and TCP/IP. They would be arranged as a system later known as the "NORDUnet plug".

The Wide-area Ethernet

The decision to use EARN lines for multi-protocol traffic was not the only big innovation in planning the network; Nordic networkers also had their eyes open for new technology. The technical details of the future network were discussed at the NORDUNET conference in Espoo, Finland, in October 1987. Mats Brunell and Einar Løvdal gathered a small group for discussions and it was at these meetings that the Ethernet solution came up.

Ethernet was a technology originally created to build local area networks (LANs) and some universities in Denmark, Finland, Norway and Sweden had already built them. The experiences of Ethernet had been positive, and the Swedish SUNET and the Finnish FUNET had even begun to plan connecting their national Ethernets by remote bridges. At the Espoo conference it was realized that maybe it was even possible to create a Nordic-wide Ethernet.

The Nordic Ethernet, which would have its center in Stockholm, Sweden, was accepted as a framework for future planning. There were still other options besides the Ethernet, and the project group discussed them in their meetings and emails. Many Norwegians were still supporting X.25, but according to Harri Salminen, the Ethernet idea finally won because it was considered to be a better solution for IP than X.25: "The Norwegians were also able to accept it when it was discovered that there was an X.25 switch that supported X.25 over the Ethernet."

The US Connection

The original idea of the NORDUNET program was to interconnect the Nordic research networks, but choosing TCP/IP as one of the protocols to be supported opened up a new possibility: connection to the United States.

In the 1980s, more and more networks were attached to the ARPANET, thus making the Internet larger. At the same time, the system attracted an increasing number of people outside defense research, and finally, the Internet was transferred from military to civilian control. In 1986, the National Science Foundation (NSF) had initiated a network for research and education, NSFNET, and in the late 1980s, the NSFNET replaced the ARPANET as the main government network in the United States and became the backbone of the Internet.

Lawrence Landweber, the American networking pioneer, the founder of CSNET and the developer of NSFNET, participated in the NORDUNET-87 conference in Espoo and the possibility of connecting the Nordic networks to the NSFNET was discussed with him.

By that time the only Internet connections to the United States were tied to a certain projects – like the SATNET connection of Norway and England. In those projects Internet access was restricted to a small community. No European country had an Internet connection that could be used freely by university students. That, however, was precisely what the Nordic countries wanted.

Juha Heinänen recalls that at the Espoo conference it was informally decided that the Nordic countries would try to get a joint connection to the United States: "However, at that time it was only a decision in principle, because we as yet had no partner in the United States, and we did not even know whether the US authorities would allow the building of such a connection."

In particular, connecting Finland to the NSFNET seemed at first to be a problem. This was because of the rather too healthy relations Finland had with the neighboring Soviet Union, the old cold war enemy of the United States. The Finnish-Soviet relationship was considered somewhat suspicious by the US authorities.

Later in the same year Heinänen was at a networking conference in New Jersey, United States, and found a possible partner for the Nordic connection: the John von Neumann Center (JVNC), a supercomputer center located at the Princeton University, was willing to set up a Nordic connection. Heinänen remembers: "At the meeting there was also Larry Landweber and Steve Wolff, a high executive of NSF, who – to my surprise – gave the green light for the project. When I got back to Finland, the NORDUNET staff began to prepare the US connection immediately."

Mats Brunell says that getting a connection to the United States was relatively easy for the Nordic countries. This was partly due to the fact that Nordic networking experts already had good relations with many networking specialists and universities in the United States. According to Peter Villemoes, the Nordic university network was held in very high esteem by the Americans from the very beginning and Swedish networkers, like Brunell and Peter Löthberg, had established good contacts: "Especially, Peter Löthberg, he is a genius in networking, and he had strong influence on the development of the Internet technology. He was admired in the United States."

There was also another reason why the Nordic connection was wanted by the NSFNET. Mats Brunell remarks that the Nordic network was actually considered "hot" by the US networking authorities. The reason for this was obvious: the Nordic network was ready to use the Internet protocol, TCP/IP, even though it was not accepted by other European networks and organizations.

The NORDUNET community had come to the conclusion that the Internet IP was the only feasible solution, and that was naturally appreciated by the US networking organizations: now they had an "ally" in Europe supporting IP.

The Implementation of the NORDUnet network

The X.EARN proposal was presented to the NORDUNET steering committee in January 1988 and it was accepted. The network name was changed, however, to a more suitable one, since the ideas for the network had already moved away from the original plan to continue the EARN service.

The X.EARN project group members had, right from the start, exchanged emails about the name issue, but the final decision was in the hands of the NORDUNET steering committee. Peter Villemoes recalls, that the steering committee was quite unanimous: "It should without any doubt be called Nordunet, but to distinguish it, it was decided to write it 'NORDUnet' and continue calling the program 'NORDUNET'."

The technical kick-off meeting of NORDUnet was organized in May 1988 and the lines and the equipment were ordered the following month. Although the original plan was to build on the existing EARN lines, in practice that was not possible. Instead, new leased lines of 64 kbit/s were obtained from Scandinavian Telecommunications Services, a company owned by the Nordic PTTs.

The form in which each host should be connected with each other, the network topology, was also discussed. Initially it was thought that a square would be the best model to connect the Nordic nodes, but later it became clear that it would be easier and less expensive to build a star topology with the Stockholm's Royal Institute of Technology, KTH, in Sweden as a center.

The lines between four Nordic countries were set up during the fall of 1988. The line between Stockholm, Sweden and Trondheim, Norway, was delivered at the beginning of September, and the line from Stockholm to Espoo, Finland, two weeks later. The line to Denmark was delayed, and was delivered in November.

The network was based on Vitalink Translan Ethernet bridges. The national research networks were connected to the Ethernet via routers and gateways, and the environment was thus kept isolated and protected from national traffic. This solution made it easier to maintain the network.

Using Ethernet internationally to connect several national networks was a new thing, something that had never been done on such a large scale. Previous experiences with Ethernet were, however, helpful: in Finland, for instance, FUNET had already built an Ethernet running both TCP/IP and DECnet between Espoo and Tampere. Harri Salminen recalls: "There were of course worries about how this wide-area Ethernet would work during congestion, but experience in national networks had already shown that it should work when we had the routers at the edges."

The technical solutions for multi-protocol service were successfully implemented. Einar Løvdal remembers that "the IP and DECnet services came up readily". The EARN solution was more com-

plicated, because the delivery of the new software was delayed. However, the most difficult part was the X.25. Løvdal explains: "Running X.25 over a wide-area Ethernet was not at all usual, I know of nowhere else where this was tried as an operational service. It came up, but with poor performance. Partly this may be due to limitations of the actual equipment or our use of it, but I think that there were more basic problems with X.25 running in the connectionless environment of the NORDUnet Ethernet."

The connection to the United States was already arranged in the same year. It was available for NORDUnet in August 1988, and testing was planned to start on 15 October. However, the US connection was not yet working in early November, which proved to be a lucky thing for NORDUnet. The first significant Internet worm, the Morris worm, was launched on the Internet at the beginning of November and NORDUnet was fortunate enough to avoid it. Soon after the Morris worm incident, NORDUnet got the Internet routing via a satellite link to the John von Neumann Center at Princeton, New Jersey. At first the connection was set up with 56 kbit/s capacity, which was standard in the United States, but it was later upgraded to 64 kbit/s.

The first connections to the other European networks were established at the beginning of 1989. In January 1989 NORDUnet installed the 64 kbit/s link to EUnet in Amsterdam. Via EUnet NORDUnet also had connectivity with CERN, the European Organization for Nuclear Research.

NORDUnet and EUnet also made an agreement that their US connections might serve as a backup for each other.

NORDUnet did not have to support UUCP in the multi-protocol solution, because EUnet began to use TCP/IP approximately at the same time as NORDUnet. As Maríus Ólafsson of Iceland's RHnet remarks, both USENET and EUnet in fact "migrated to IP without their users ever noticing the change in underlying protocol."

The Nordic connection to the American Internet was something exceptional and totally new for national research networks in Europe. There had been Internet connections between Europe and the United States for special projects such as SATNET, which provided connections for England and Norway. INRIA, a computer science institute in France, was also connected to the NSFNET. However, NORDUnet was the first international research network to get a connection to the Internet and to thus give university students open access to the network.

The Icelandic Connection

Icelandic networkers did not participate in the first X.EARN meetings, because it was decided not to continue the EARN service in Iceland any more. However, when it became obvious that X.EARN might lead to something more than the continuation of EARN, Icelandic members joined the planning efforts. Jóhann Gunnarsson participated in the work in the steering group, and Marius Ólafsson was working in the NORDUnet technical group in the final phase. Helgi Jónsson was on the NORDUnet board from the start.

Connecting Iceland to NORDUnet was more difficult and took a year longer than other Nordic connections. The main reason for the delay was the high cost of the Icelandic line. The NORDUNET program had good relations with other Nordic PTTs and had managed to get discount prices from them. However, the situation was different with the Icelandic monopoly PTT which charged very high prices. And because SURÍS did not get any financial backing from the Icelandic Ministry of Education there was simply a lack of funds.

Peter Villemoes understands the difficult situation of the Icelandic PTT. It was quite expensive to get services to reach a distant island with a low population: "I could understand why they charged these prices. They were government-owned, and if they gave this price to NORDUnet, they would have to give it to everybody – and the market would collapse."

NORDUNET did not finance the backbone part to Iceland in full but granted a certain amount towards the cost of leasing bandwidth to Iceland. SURÍS also received funding from the Research Council of Iceland and could purchase equipment for a gateway between the various existing networks. However, the technical solution for connecting Iceland to NORDUnet had to be different from the other Nordic countries: Iceland could not join the Vitalink-based Nordic Ethernet since the multi-protocol connections used by the other Nordic countries did not work well over satellite.

Marius Ólafsson points out that in fact Iceland did not need a multi-protocol solution: "There was basically only a UUCP-based network in Iceland and that had largely migrated to IP and thus the only 'plug' in the NORDUnet 'socket' we were interested in was the IP plug. In this respect the Iceland situation was thus quite different, as the other Nordic countries all had sizable EARN, DECnet, OSI/X.25 communities."

In July 1989 Iceland was connected to NORDUnet using IP over X.25. The 2400 bit/s connection was to UNI-C in Denmark because the X.25 charges were the lowest in Denmark and UNI-C had spare X.25 capacity. However, using X.25 made it hard to estimate the costs, and a year later the Iceland connection was moved to Stockholm via a leased line with 9600 bit/s capacity.

Reactions to "the NORDUnet Plug"

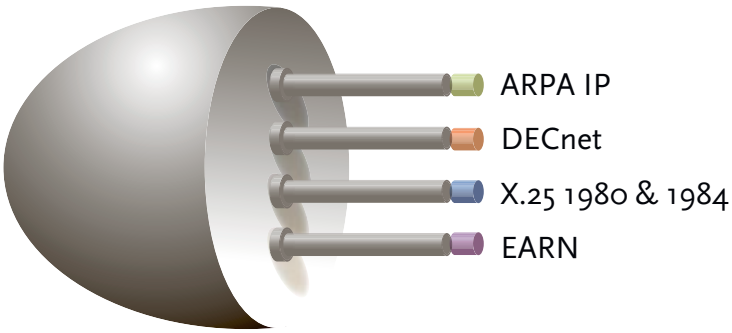
The NORDUnet network was the first international wide-area multi-protocol network in the world, supporting several communication protocols: TCP/IP of the Internet, X.25, NJE of EARN and DECnet protocols. This multi-protocol system made it possible to interconnect NORDUnet to several

networks.

The multi-protocol solution of NORDUnet became known as "the NORDUnet plug" when Einar Løvdal used the phrase to describe the technical aspects of the network: "I first used the term 'NORDUnet plug' and its iconographic representation at the NORDUNET conference in Reykjavik in September 1988, when I was presenting the NORDUnet idea and implementation status to Nordic networkers. I used it as a pedagogical tool to visualize the services which the backbone should provide to the national academic networks in the Nordic countries, each pin of the plug representing a particular service essential to the community."

Choosing TCP/IP as one of the protocols in the NORDUnet network was not welcomed by all the European networkers, and thus the whole idea of the NORDUnet plug received a mixed response.

A networkshop in Trieste in May 1989 was a memorable moment for Einar Løvdal: "I was on the program committee of the conference, and was due to deliver a talk on the NORDUnet idea and services, especially emphasizing the 'challenge of TCP/IP'. The basic message of my speech was that TCP/IP should be recognized as an important European service, not only a US service."



The NORDUnet plug.

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Einar Løvdal presented the term of NORDUnet plug for the first time in Reykjavik in September 1988 to describe the multi-protocol services of the NORDUnet network.

Løvdal pointed out in his speech that there were already a great number of unconnected IP networks in Europe and there was a need for European IP coordination. He also pointed out the scalability of the IP networks, as opposed to the OSI technology. "I still remember the tense and silent atmosphere during my talk, presenting these ideas to the several hundred European networkers – plus guests from overseas; the enthusiastic ap-plause from one half of the audience, the silence from the other half; and the intense discussions afterwards."

NORDUnet's solution was very controversial, especially considering that the Trieste networkshop was meant to mark the start of the COSINE implementation phase, leading to European OSI transition. However, many European networks were at that time planning and building IP networks. According to Løvdal these networks, like HEPnet and the Swiss and Dutch academic networks, were built 'in silence'. So in a way we NORDUNET people voiced the opinion of many networkers more concerned about user services than protocol wars and political issues.

Mats Brunell describes the NORDUnet plug as being "a very good marketing concept". Especially after Trieste 1989 the NORDUnet plug became the metaphor of the NORDUnet idea for a broader networking community. According to Lars Backström the metaphor was brilliant, because it both unified the Nordic networkers and maintained NORDUnet's credibility in the eyes of Europeans and Americans. "In fact, the NORDUnet plug was much more than a marketing concept," says Backström. "The concept was so strong because it was technically feasible. We were able to do it,

and it really was put into practice."

Einar Løvdal himself considers that the term NORDUnet plug served as a good metaphor for the NORDUnet idea. "I think that it is an advantage that the metaphor gives a service-oriented view, actually hiding the internal multi-protocol implementation issues. Actually the internal way of implementing the services was changed several times during the first years, while the services remained stable."

Looking back, Løvdal sees that "there was a lot of positive response toward the NORDUnet ideas, both in Europe and overseas. Of course the NORDUnet postion was welcomed by the US Internet community, marking the start of an era of close cooperation across the Atlantic, even opening up the doors to important Internet bodies to Nordic networkers. In Europe NORDUnet was to gain an important role in practical network coordination."

Supporting TCP/IP was controversial for many Europeans, but for the NORDUnet community it was not a political or economic question – it was the most practical thing to do. Peter Villemoes explains: "When we send technicians to work, we don't think politically – and things happen. We knew what we were doing. We were not driven by a desire to bring American industry into Europe but to get a functioning network into Europe, and we were convinced that was the way to do it."

The Achievements of the NORDUNET Program

The implementation of the NORDUnet network was completed during 1989. The official opening of NORDUnet was in October 1989 at the NORDUNET conference in Saltsjöbaden, Sweden. Although NORDUnet was the first large-scale IP network in Europe, the official network opening was not a big media happening. Mats Brunell tried to attract media and politicians to the inauguration, but there was no interest – the importance of the Internet was not yet understood by the general public.

And, unfortunately, it was not yet understood by all the European networking circles either. In many European countries the connection to the Internet was considered "improper". Although the Nordic Ethernet was working fine, it remained a unique solution, and was not imitated elsewhere – other Europeans were still backing the OSI model and in the United States they already had IP.

For Lars Backström, the NORDUnet network and especially the NORDUnet plug represented a victory in the protocol battle. "The finest moment of the NORDUNET program for me personally was when Einar Løvdal presented the concept of the NORDUnet plug at the RARE conference in Trieste in 1989. The arguing over OSI standardization at RARE meetings had troubled me for years, but now, it felt wonderful that the Nordic countries could present such a great synthesis."

Rolf Nordhagen also sees the multi-protocol network as a great achievement. With this solution, the Nordic countries could "avoid the European protocol war, which set several larger nations back for years." In addition, the ability to work together across borders, disregarding the different national

attitudes, is something that Nordhagen values.

Iceland gained a great deal by participating in the NORDUNET program. According to Jóhann Gunnarsson, the program helped to make the claims of the Icelandic networking pioneers recognized in Iceland. It was understood that funds and effort should be invested in networking activities to give Icelandic researchers better opportunities to work at the international level: "The fact that Iceland had access, albeit not the most perfect, to the NORDUnet network from the start above all gave Icelandic researchers an equal opportunity with their peers in other countries, an opportunity to enjoy the service of a leading networking organization and leading technology earlier and at a lower cost than they would have had if they had not participated in NORDUnet."

The Nordic cooperation implementing the NORDUnet network was unique in many ways. In other parts of the world international networks were usually mission-oriented, set up by special groups, organized by common profession or field of research, not by countries. But NORDUnet was an exception, and a successful one.

Harri Salminen is glad he could participate in "Nordic cooperation that really produced something useful. The collaboration between the Nordic countries worked extremely well. And we did not have the 'Not Invented Here' syndrome; national pride did not prevent the use of technically sound solutions."

Mats Brunell and Einar Løvdal have been much praised for their leadership during the planning and implementation period, but Løvdal himself sees the work was truly a cooperative venture and the credit for developing the NORDUnet idea should go to many persons, "including the planning group which developed the concrete X.EARN proposal during the autumn of 1987, the NORDUNET steering committee which with great enthusiasm and commitment welcomed and supported the proposal in January 1988, and the inter-Nordic implementation groups which made the services work. It was really a joint undertaking, undertaken with great enthusiasm, really bringing great inspiration and progress to all academic network projects in the Nordic countries."

Løvdal recalls the years 1987–1989 "as very inspiring and enthusiastic, not only for the NORDUNET organization and project, but also giving a boost and bringing rapid development to all Nordic national academic networks. There was an enormous will to reach consensus, we all felt that we were doing pioneering work, which would have great consequences for our countries. We were proud to present this work internationally, speaking with one Nordic voice on the networking arena both in Europe and in the US, in spite of all the controversy during these years of protocol wars and heavy political involvement in the network trade."

Løvdal points out, that the Internet service NORDUnet offered really became popular in the Nordic countries: "NORDUnet IP immediately became a great success, comprising 10,000 machines at the end of 1989, having then a growth rate of 150 % per year. This very early and deep penetration of the Internet and the early development of network infrastructure had a long-lasting effect, placing the Nordic countries top in the world as regards the number of Internet nodes per capita." Compared to the other European countries, the Nordic countries were pioneering: in the fall of 1990 NORDUnet traffic covered more than 50 % of NSFNET's total traffic with Europe.

Everyone in the NORDUnet community agrees that the NORDUNET program and taking part in the implementation of NORDUnet was a good school for Nordic networking specialists. According to Mats Brunell this "network of specialists is still very active and important in several key companies in the Nordic region today."

Nordic specialists and also university students were able to gain early experience of the Internet, earlier than in other countries in Europe. That early know-how about the Internet has been of great

From NORDUNET to NORDUnet A/S

In the early 1990s it was time to reorganize the official bodies responsible for networking cooperation in the Nordic countries. The NORDUNET program had already fulfilled its task by building the NORDUnet network and by creating good working relationships between Nordic networking specialists. Now there was a network to run, and the cooperation in other international organizations required coordination too.

The NORDUNET program continued until the end of 1991. Originally, the program had received financing from the Nordic Council of Ministers years 1985–89, but the program administration agreed to apply for more funds for continuation. The extra funding was needed to finish the implementation of the NORDUnet network and to organize future collaboration.

The Nordic Council of Ministers decided to grant financing for a further two years, 1990–91. In the application, the NORDUNET program had asked for four more years, but the two years continuation was satisfactory enough. Lars Backström remembers steering committee discussing strategy for the future: "It was important for us to show that the program had created something that would last, something that does not fade away when this funding stops. We wanted to prove that there was now an operational system that would be so important for cooperation among Nordic universities that the university community would be prepared to fund it in the future."

When the network was being planned in the late 1980s, the NORDUNET program already had organized bodies to run the project. At first, in 1985–86, Björn Grönlund of Nordforsk was in charge of the administration of the project. In 1986 Mats Brunell took over the task, and the administration was carried out by a secretariat, first located at QZ (the University Computing Center in Stockholm), then at SICS (the Swedish Institute for Computer Science).

When the implementation of the NORDUnet network wascompleted and the NORDUNET program was about to end in 1991, the NORDUnet administration was moved to the NORDUnet board. Peter Villemoes from UNI-C (the Danish IT Center for Education and Research) had acted as the Working Chairman of the NORDUnet board since September 1989, and now he was placed in charge of administration. At the same time, the secretariat was also relocated from SICS, Sweden,

to UNI-C, Denmark.

The NORDUnet administration had naturally looked ahead and made plans for the future. It was decided that NORDUnet would continue the work as a Danish limited company, to be jointly owned by the ministries in each of the Nordic countries. But even though these plans for the future organization had been made, it was clear that the company, NORDUnet A/S, would not be ready at the beginning of 1992.

Hans Wallberg, a long time member of the NORDUnet board, points out that "it is not easy for governmental organizations to own a limited company. At least in Sweden it was necessary for the matter to be decided in the Swedish parliament."

The situation was indeed very much the same in all the Nordic countries. Peter Villemoes recalls that although the ministries involved were very supportive, the many steps that had to be taken lengthened the negotiation process. "The share capital that was needed had to be approved in some countries by parliament and others at least by the government. And that of course took time."

During 1991 and 1992 the Finnish, Norwegian and Swedish ministries of education and governmental authorities reached the decision to become shareholders of the company. The Icelandic authorities made their decision in February 1993, and thus all the Nordic countries except Denmark had decided to be part of NORDUnet A/S. The Danish IT Center UNI-C, which was hosting the NORDUnet administration, hesitated over the decision, however, and negotiated about the matter with the Danish Ministry of Education for a long time. In the meantime, NORDUnet worked as a consortium.

Eventually, in June 1993, UNI-C also announced its intention to participate in NORDUnet A/S, but proposed some changes in the legal documents. Most of the proposed changes were accepted by other member organizations, and the forming of the company could begin for real.

From the very start, NORDUnet has been owned by the Nordic ministries of education or institutions under their control. The shareholders' agreement was signed by the representatives from all five Nordic countries on 14 December 1993. The original shareholders were: UNI-C, the Danish Computing Center for Research and Education, the Ministry of Education in Finland, the University of Iceland, UNINETT A/S from Norway and the National Agency for Higher Education from Sweden. Peter Villemoes was named as the General Manager of the new company.

The decision to create a limited company was taken on after legal advice. The NORDUnet administration had also considered other alternatives, since it would have been possible to create NORDUnet as a foundation or an international organization. However, the limited company seemed to be the most practical choice. Peter Villemoes explains that a company was the best form for an entity that would operate commercially and sign contracts with other legal bodies: "A limited company is a very well defined commercial concept, and that is why we made it a limited company."

Although the collaboration between the Nordic research networks was now to be coordinated by a company, it was important for Villemoes and others to maintain the original spirit of the NORDUnet community. "We are still very careful not to let the fact that we are a limited company make us operate among ourselves in the manner of a limited company. I still try to operate in the same spirit of collaboration as when we were not a limited company."

The Years of Expansion

Until the end of the 1980s the Internet was used mainly by special groups, scientific communities and governmental authorities, but in the early 1990s things began to change. The Internet became easier to use for even those without expert knowledge about networking or computers. The change was largely due to the invention of the World Wide Web, WWW.

The growing popularity of the Internet also meant extra demands for NORDUnet. The value of the Nordic research network with its Internet connection was increasing in the eyes of the users. With the growing interest, the amount of traffic also grew – and the expenses. Throughout the 1990s, NORDUnet strove to maintain its quality of service to national research networks and upgraded the capacity of the network. Sometimes NORDUnet was the only network in Europe that could give its users unrestricted access to the United States.

At the beginning of the 1990s, NORDUnet was clearly the most advanced IP network in Europe, and NORDUnet and the members of the NORDUnet community managed to make networking history on many occasions. One of these historical landmarks was the acquisition of the first official root name server outside the United States in 1991. Another remarkable achievement was the first 34 Mbit/s capacity connection across the Atlantic in 1995.

NORDUnet has had especially good relations with the networking organizations in the United States from the start, but during the 1990s collaboration in Europe also grew stronger. In the mid 1990s the "Protocol War" died down as the Internet Protocol, IP, became the de facto standard in Europe as well. Towards the end of the decade the national research networks in Europe learned to work together within a coordinating organization DANTE (Delivery of Advanced Network Technology to Europe) and connected with each other through several generations of pan-European research networks, TEN-34, TEN-155 and GÉANT.

NORDUnet Gets the Root Name Server

Every machine connected to the Internet has its own IP address. When the user of the Internet wants to connect with another computer, the machine connects first with a name server which transforms the address to the IP address. In turn, every one of these name servers on the Internet has to have access to at least one DNS (Domain Name System) root name server in order to carry out its tasks.

The Royal Institute of Technology, KTH, in Stockholm took care of domain names and IP addresses in the early 1990s, but was very dependent on the six DNS root servers, all situated in the United States. Björn Eriksen of KTH remembers well what that meant: "When DNS started to be used instead of the old static HOST.TXT tables we became very dependent on these existing root servers. In the event of an outage – like a cable cut – DNS information would eventually time out, and thus the DNS servers within NORDUnet would have problems. Things like email would not be queued with 'unreachable' but instead with 'host unknown' and then returned directly."

With the approval from the US networking authorities, the Swedish networking specialists set up an unofficial root name server to test out what it took to run a root server. According to Eriksen they had a strong motivation to set up the best possible server: "Being outsiders, we had to do the best we could to run a root server in such a way that no one could complain."

It turned out that there really was no reason for complaints. In fact, the server at KTH was managed better than some of the old servers in the United States. The KTH server trials were successful enough to impress the US networking authorities, too, and in July of 1991, Sweden and NORDUnet were authorized to have an official DNS root name server. The server was named nic.nordu.net.

After running unofficial root servers for some time, the Swedish networkers had proved that they were able to manage the service. The good reputation of NORDUnet in the United States also helped to gain official status for the server – by then, NORDUnet had already become an important player in the networking field and the authorities in the United States knew they could trust NORDUnet.

According to Björn Eriksen, getting the root name server in Europe, while it had above all practical benefits, also brought prestige for NORDUnet and Sweden. It opened a new era in Internet history; after this, it was easier for others to set up root servers around the world. "We broke the ice," concludes Eriksen.

The WWW and the Growth of the Internet

The story of the World Wide Web began in 1989 at CERN, the European Organization for Nuclear Research, in Switzerland. As a meeting place for physicists from all over the world, CERN needed a means of communication to allow them to share information about their research. The solution was invented by the physicist Tim Berners-Lee, who proposed a hypertext system in which the information would be organized by interlinked documents.

The World Wide Web began to draw attention among networking experts in 1991, when Berners-Lee presented the innovation at CERN and at the Hypertext91 conference. The NORDUnet community also got acquainted with WWW at an early stage: in 1992 Berners-Lee gave a lecture about the World Wide Web at NORDUnet's NETF (NORDUnet Engineering Task Force) meeting in Turku, Finland.

Peter Villemoes, the General Manager of NORDUnet, remembers the occasion in Turku very well. He had already seen a demonstration of WWW at CERN a year earlier and he was very enthusiastic about it: "I got the 'aha' experience of my life. I saw a glimpse what that implied." Unfortunately, the Nordic university networking community did not yet seem to share this enthusiasm. Villemoes recalls that the NETF audience listened to Berners-Lee rather passively. "Everybody went home and continued with Gopher, which was a much more restricted facility but with a better user interface at the time. I was much disappointed."

The success of WWW was at first limited by the lack of suitable browsers, and for that reason Gopher appeared to be a better document retrieval system for most users. The use of WWW began to grow considerably only after the NCSA (National Center for Supercomputing Applications) in 1993 introduced the Mosaic browser developed by Marc Andreesen and Eric Bina.

Mosaic soon attracted a wide audience, and the number of Web users began to grow fast. In early 1993 there were about 100 WWW servers in the world, but by the end of the year the number was over 600. One year later the number of servers had exceeded 10,000. The year 1994 was a real breakthrough for WWW, and its success brought a lot of attention to the Internet. The information highway was now paved for the general public.

At this point data networks also began to arouse interest in the media. Considering the early achievements of the NORDUnet community, that seemed almost unfair. Even though NORDUnet's connection to the American Internet at the end of 1988 was a historical landmark, the press was not at all interested at the time. And this same lack of interest was evident in many NORDUnet press conferences in the early 1990s.

In the early days of the NORDUnet, the project manager Mats Brunell did a lot of work to get media attention, but in the late 1980s and the first years of 1990s the Internet and networking in general were of no interest for ordinary people or for the media. According to Peter Villemoes, networking did not attract media "until the World Wide Web came with the real browser. Then we could read in the newspapers about what we had been doing for years!"

Upgrading the Connections

From the early 1990s on, the increasing interest in data networking services and the growing number of users put great demands on the networks. Constant upgrading of line capacity was the great theme of the early years of NORDUnet – and would be for the many years to come.

In trying to maintain a quality service, NORDUnet also had to face the ever rising costs. Petter Kongshaug, the UNINETT representative of the NORDUnet board, points out that line upgrading was to a large extent an economic problem: "The exponential traffic increase meant more capacity

while we still lived in a period of tele monopoly which would last for several years in Norway and Denmark. Exponential capacity increase brought near exponential cost increments that significantly troubled our funders."

Because the upgrading was very expensive, it was done little by little, whenever the traffic congestion started to be a problem and slowed down the connections. Especially the popular US line had to be constantly upgraded, because NORDUnet wanted to take good care of its Internet connection. Peter Villemoes remarks: "The users' productivity required acceptable response times. If not, the already big costs might have been wasted."

The Story of the US Connection

NORDUnet's US line between Stockholm and the John Von Neumann Center (JVNC) at Princeton, New Jersey, was set up at the end of 1988. At first the line had a capacity of 56 kbit/s, but was upgraded to 64 kbit/s in August 1990. The following year the capacity was doubled to 128 kbit/s, and by the end of 1992 it was already up to 512 kbit/s.

The end point of the US line varied during the years. The original link was established to Princeton, but in 1991 the National Science Foundation gave the International Connections Management (ICM) services to the US telecommunication company, Sprint. The access point of Sprint was at Cornell University and for that reason NORDUnet set up a new connection to Cornell. In 1992 Sprint moved their access point to Washington D.C. and then NORDUnet's US line was connected to Washington.

Towards the mid nineties the pressure for upgrading grew stronger with the rising number of users and traffic, and 1995 turned out to be a historical year for NORDUnet. At the beginning of 1995 NORDUnet's connection to the United States was of 4 Mbit/s capacity and plans were made to upgrade the connection to 8 Mbit/s. But these plans soon changed when a more ambitious scheme emerged.

Swedish networking specialist Peter Löthberg was determined to get a 34 Mbit/s connection between Sweden and the United States for the IETF (Internet Engineering Task Force) meeting in Stockholm in July. The idea of such an enormous upgrade sounded almost unbelievable, because at time there were no connections between Europe and the United States that could exceed even 6 Mbit/s.

Curiously enough, the record-breaking upgrade was also installed in record time: it took only about a month from planning to completion. Löthberg worked actively on both continents to get things ready in time, and the 34M link became operational in 12 July 1995, a few days before the IETF meeting. The work was accomplished in collaboration with the Swedish and American telecommunications companies, Tele2 and Sprint, and with the National Science Foundation (NSF) in the United States.

NORDUnet bought 24 Mbit/s of the 34 Mbit/s capacity and connected to Pennsauken in the United States. The link was used both for research and general purpose traffic.

Less than a year later the link was already overloaded. In November 1996 Tele2 carried out tests of a 155 Mbit/s line to the United States and NORDUnet served as "a guinea-pig" for the tests. During these tests the input to NORDUnet reached 51 Mbit/s capacity and the service to the United States was significantly improved. In December and early 1997 NORDUnet used 155M connection for all its US traffic, and the 34M connection served as a backup.

This 155M link was the first implementation of the "Packet over SONET" technology (POS), developed by Peter Löthberg. Later it became the dominating technology for long distance high speed IP transmission.

However, the test of 155M was not a permanent solution, and in early 1997 the IP capacity between NORDUnet and the United States was upgraded to 50 Mbit/s, and later in the same year to 85 Mbit/s.

NORDUnet's US collaboration changed considerably in 1997. NORDUnet had had good cooperation with the National Science Foundation (NSF) from the very beginning and NSF had also paid a share of NORDUnet's US connection within the ICM program, the International Connections

Management to NSFNET. But in October 1997, the ICM contract was about to end. In the United States the commercialization of the Internet had moved the responsibility for the network away from the governmental authorities, and the NSF saw no need to fund commercial traffic.

However, the NSF was still willing to support research networking and was planning a new program to handle international connections. The new program, High Performance International Internet Services (HPIIS), was created to provide a basis for the development of next generation networking applications. Naturally, NORDUnet was very interested in taking part in the program.

The European organization DANTE put forward a proposal to the NSF on behalf of the European research and education networks, but at that time the European networks did not have enough coordination to reach a common approach. The NSF ended up making collaboration agreements only with certain European networks – NORDUnet being one of them. Only NORDUnet, SURFnet from Netherlands, Renater from France, CERN and Israel participated in the Eurolink project and received support in the HPIIS program.

The Eurolink project provided a connection to STAR TAP (Science, Technology, And Research Transit Access Point) in Chicago, where the American research networks, vBNS (very High Speed Backbone Network Service) and Internet2's Abilene could be accessed. In February 1998 NORDUnet's US link, the connection to Teleglobe Inc. in New York, was upgraded to 155 Mbit/s. A year later NORDUnet had two connections to American research networks, one to Abilene in New York and another to STAR TAP in Chicago. The capacity to the United States was doubled to 310 Mbit/s.

By the end of 1999 the total US capacity was upgraded to 465 Mbit/s with a third 155 Mbit/s link. In New York the links were connected to the Abilene research network (Internet2) and to the commercial operators. A circuit from New York to STAR TAP Chicago connected NORDUnet to vBNS and other research networks in Canada and also in the Far East.

The three 155 Mbit/s connections were provided by Teleglobe, and in the beginning of 2000 NORDUnet gained additional capacity through the arrangement with GTS (Global TeleSystems Group) / Ebone. The US capacity reached now 622 Mbit/s. When a second GTS connection was put into operation in April 2000, total capacity reached 777 Mbit/s. By early 2001, total capacity had been increased to 1.4 Gbit/s.

The KPNQwest Incident

Because of its early start, NORDUnet had much more developed solutions for networking than many commercial providers. And for that reason, NORDUnet did not need to use commercial networks when they began to appear. Instead, NORDUnet connected to the IP providers in the United States and used its own transatlantic links. Peter Villemoes explains: "The reason it took so long before we used commercial networks for providing connectivity to NORDUnet, was that they could not give as good a service. Their networks were not good enough compared to what NORDUnet had – we always had better. Until the year 2000 NORDUnet's connectivity to the United States was better than most of the other providers' connectivity. We did not overbook our lines."

In the summer of 2001 the situation changed and NORDUnet contracted the European data

communications company KPNQwest to provide connectivity to the United States. KPNQwest was to supply IP transit and managed broadband services to the US with back-up connectivity to Europe. The system would give NORDUnet access to the general Internet, to the US research networks and to STAR TAP.

NORDUnet chose to change its strategy and use KPNQwest because in the early 2000s a decrease in the price of IP transit services was already evident. The KPNQwest service was also considered to be technically safer because of greater physical redundancy. In July 2001 KPNQwest's 1.9 Gbit/s service to the general Internet was put into operation.

At first, everything went fine and NORDUnet was pleased with the service. However, the price decrease in the IP transit services was not simply a fortunate thing – it was an expression of turmoil in the market and led to series of bankruptcies. In spring of 2002 the NORDUnet administration became worried: could this also happen to KPNQwest?

KPNQwest was formed by KPN, partly owned by the Dutch government, and by Qwest Communication International Inc., and they appeared to be strong and big enough to survive the financial crisis. However, NORDUnet decided to formally ask about the viability of the company. The reply was that there was nothing to worry about.

But in May 2002, one of the managers of KPNQwest contacted the General Manager of NORDUnet Peter Villemoes and said: "Peter, you better go out and find another provider, because we will fold very soon."

The information was a great shock to Villemoes: "That just pulled the rug out from under me! We had just subscribed to two gigabits of IP from them, and you don't go out and find it just like that." The situation was the worst experience of Villemoes' career. He knew that if the service folded that would have been the end of NORDUnet – the one million users could no longer trust NORDUnet to provide the services they needed. "The whole house would have collapsed."

However, the early warning about the coming bankruptcy gave some time to reorganize the connections. And NORDUnet was lucky to have friends among networking specialists. Within a week, Peter Löthberg managed to organize new connection for NORDUnet. A 2.5 Gbit/s backup connection was connected to Sprint International in Copenhagen. It became operational on 30 May, one day before KPNQwest filed for bankruptcy. On 6 June another 2.5G connection was set up to Telia in Stockholm.

The KPNQwest incident was a harsh lesson for NORDUnet. Since then NORDUnet has decided to have two providers of IP transit services. That gives physical redundancy, and also a safety net if market trouble occurs.

The End of the US Direct Link

NORDUnet has a long history of collaboration with the US research networks. The cooperation with the National Science Foundation began with the setting up the first link to Princeton and to the NSFNET in 1988. After that the termination point of the US link varied, but for NORDUnet it was important to have a direct link to connect to the research networks.

NORDUnet participated in the NSF's international programs: ICM (the International Connec-

tions Management to NSFNET) in the years 1991–97 and HPIIS (High Performance International Internet Services) in years 1999–2003. Within these programs NORDUnet was able to keep up a close relationship with US networking organizations and people, and participate in network development. NORDUnet also benefited from the programs financially, because the NSF was paying a share of the connections.

In 2000 NORDUnet began to reconsider the need for the direct link. It seemed that GÉANT, the pan-European research and education network, might later provide suitable connections to the United States. But at that point NORDUnet was still determined to maintain its own connectivity – until such time as the GÉANT services were up with sufficient capacity and their quality recognized. In 2001 NORDUnet organized better connectivity to the US research networks, Internet2's Abilene and STAR TAP in Chicago, when a 622 Mbit/s connection to New York was set up. A NORDUnet router in New York was connected to Abilene at 622M, and to Chicago at 155M.

But in the end, it came time to give up the direct link. There were convincing enough reasons for this. By 2003 GÉANT had established good connections to the United States: GÉANT and Abilene were interconnected with 5 Gbit/s capacity and would soon be upgraded to 10G. Furthermore, there was the financial factor: using GÉANT connections would be much cheaper for NORDUnet. The US research network connectivity was already included in the GÉANT subscription fee, so all the costs of NORDUnet having its own link were saved.

The long story of the direct US link had come to an end. NORDUnet's 622 Mbit/s connection to the research networks in the United States was terminated on 22 July 2003. Since then NORDUnet has used GÉANT to reach the research networks in the United States.

Connecting to Western Europe

In the early 1990s most of the European data networks were not very well developed, and NORDUnet was clearly a leading network as regards technical applications and the building of the Internet. Harri Salminen, the technical coordinator of NORDUnet in 1991–92, remembers seeing connectivity maps of the early 1990s which gave a good picture of the situation – Northern Europe had a neat star topology, but "the other European networks were a mess at that time."

The Internet in Europe had not gained a strong foothold outside the Nordic countries in the early 1990s. There were some IP nets in Europe but they were not interconnected, and the traffic between them had to go via the United States.

The battle over protocols continued, and many European PTTs were still backing OSI and X.25. The German PTT, Deutsche Telecom, was an especially strong OSI supporter. And because the influential German research network, Deutsche Forschungsnet (DFN), had a long-time agreement with Deutsche Telecom, there seemed to be no future for a large-scale European IP network.

However, the isolated European IP nets acknowledged the need for interconnections and plans were made to solve the connection problems. In 1991, NORDUnet and SURFnet, the research network in the Netherlands, began to work on the first pan-European IP backbone, Ebone. The first meeting to plan the technical and operational aspects was held in September of the same year. It was

decided to create a kernel backbone in 1992 by combining the existing facilities of those networks intending to be a part of Ebone.

The following year the interconnections were built in cooperation with university networks and commercial Internet operators. The Ebone backbone connected Stockholm – Amsterdam – Geneva – Paris – London – Stockholm, Bonn – Stockholm and Bonn – Geneva. In September 1992 the final link of Ebone, London – Montpellier, was set up, and Ebone was working as a pan-European IP backbone.

There was no governmental funding for the network and the costs were shared between the members. Ebone's role was especially important in providing better connections for Europeans, but also to some extent to the United States. The sharing of the costs also made it possible to get higher capacity for the trans-Atlantic connections.

Slowly but surely, the European research networks began to realize the benefits of the TCP/IP protocol. The COSINE project, initiated in the late 1980s, had aimed to build a research network based on OSI protocols. Within the project, the IXI (International X.25 Infrastructure) network was created to connect 18 European countries by using circuits mainly of 64 kbit/s capacity. However, very soon it was understood that this was not enough – IP services were also needed.

In 1992 and 1993 IXI was replaced by a new network providing both X.25 and IP at a speed of 2 Mbit/s, and its name was changed to EuropaNET. The service was provided by Dutch telecommunications organization KPN, and operated by the Unisource company. A new pan-European company, established by European research networks, DANTE (Delivery of Advanced Networking Technology to Europe), became the manager of EuropaNET.

Many networks moved from Ebone to EuropaNET, and NORDUnet also decided to connect to EuropaNET in 1994. In 1995, British Telecom began to provide the EuropaNET service under the name IBDNS. NORDUnet then had 2 Mbit/s access to IBDNS, and peering agreements with Ebone and EUnet. NORDUnet also interconnected directly to the UKERNA in the United Kingdom and to SURFnet in the Netherlands – this "Triangle" of three national research networks had a 2 Mbit/s capacity at the end of 1995.

In the mid 1990s, the European research networks began to plan a new pan-European research network, the TEN-34 project (Trans-European Network at 34 Megabits per second). TEN-34 was launched in May 1997 and at the first stage it linked the national research networks in the Nordic countries, Germany, Netherlands, Spain, Switzerland and UK. NORDUnet was connected to TEN-34 with a 22 Mbit/s capacity.

The TEN-34 project was coordinated by DANTE and funded by the European Commission. The funding from the EC was essential: in the Nordic countries the prices for connections had already come down, but in some other European countries the telecommunications operators charged very high international prices. The European Commission was paying 40 % of the costs, which made TEN-34 possible in the first place.

According to Peter Villemoes, TEN-34 was the first usable pan-European research network: "TEN-34 was a major breakthrough. When we succeeded in building the European 34 Megabit network, that was when there really started to be order in our European house. So that was a great leap ahead, and there we can thank the Commission. Because, you know, when people can not agree and you put a pot of honey on the table, they soon agree to eat it together."

Since then, DANTE has coordinated several projects to upgrade and to improve the European research connections. The next step from TEN-34 was TEN-155 (Trans-European Network at 155 Megabits per second), which became operational in December 1998. NORDUnet connected to it

in two connection points, in Amsterdam and in Frankfurt – both of these with 155 Mbit/s capacity. Later the Amsterdam connection was replaced by a similar one to London. In December 2000 NORDUnet doubled the capacity of TEN-155 connection to 310 Mbit/s.

TEN-155 was succeeded by the GÉANT network in 2001. NORDUnet was connected to it in October of 2001. At first the connection was via two 2.5 Gbit/s circuits, but two years later it was upgraded to 10 Gbit/s.

GÉANT is a collaboration of 26 national research and education networks (NRENs) which represent 30 countries in Europe. In all, 33 countries are connected directly to the GÉANT network. The GÉANT project also supports development and testing of new networking technologies. The planning of the next generation network is under way: the GÉANT2 project began in September 2004 and the transition to GÉANT2 is expected in 2005.

The Eastern Connections

The NORDUNET program had already established good relations with networking institutions and people in the United States and in Western Europe in the 1980s. In the early 1990s, NORDUnet received new friends from the East.

After the dissolution of the Soviet Union, the new Baltic states – Estonia, Latvia and Lithuania – were building information infrastructures and were interested in setting up data networks. Nordic networking specialists came to establish close working relationship with networkers in the Baltic countries.

The first contacts with Baltic computer scientists were created when the NORDUNET program was still going on. Members of the NORDUNET community were active in this new collaboration. In Finland, FUNET was contacted by Estonian scientists interested in building data networks. In Sweden, SICS (Swedish Institute for Computer Science) was approached first by the Latvians. And in Norway, Rolf Nordhagen from the University of Oslo, cooperated with the Lithuanians. Nordhagen recalls, that in fact the first outside network connection from a Baltic country was established from Vilnus, Lithuania, to the Norwegian UNINETT via satellite already in 1991.

Mats Brunell, the project manager of the NORDUNET program, was working at SICS when the Latvian Institute of Electronics and Computer Science contacted the Swedish to establish research collaboration. Later, Brunell and SICS were also approached by Estonian and Lithuanian research institutes. The Baltic researchers expressed their interest in getting a connection to NORDUnet and via NORDUnet also to the Internet.

In the early 1990s the communications infrastructure in the new independent Baltic states was poor, and these countries had insufficient financial means to improve this situation. At first, therefore, financial support from the Nordic countries was also necessary.

Brunell began to organize a project for Nordic–Baltic networking collaboration. After a visit to Riga, Latvia, in May 1991, Brunell initiated the BALTnet project with the objective of establishing communication services with the Baltic states, primarily for the research and education community. The funding for the project was sought and received from the Nordic Council of Ministers, which

granted 7.5 million Danish crowns for BALTnet.

The BALTnet project was established in 1993, and Mats Brunell was named project leader. He continued in this task until 1995. Then the BALTnet project was moved from SICS to the University of Oslo and Rolf Nordhagen took over the management.

The goal of BALTnet was to support the development of Baltic education and research networks. The work was accomplished by organizing seminars for Baltic networkers, buying equipment for research institutes and financially supporting international connectivity. In addition, the Nordic networking specialists helped Baltic scientists to establish contacts with other European networkers and with networkers in the United States.

Most of the Nordic–Baltic networking collaboration was organized through personal contacts involving individual people, the Nordic universities and the national research networks. NORDUnet's major role in this collaboration was providing the connectivity.

At the end of 1991, the NORDUnet board agreed to establish connections to the Baltic countries. Even before that, FUNET in Finland had already decided to create a connection between Helsinki and Tallinn, Estonia. Therefore, in 1992, three connections between NORDUnet and Estonia were set up: Helsinki–Tallinn using microwave, and the satellite connections between Stockholm and Tallinn and Stockholm and Tartu.

Lars Backström from the University of Helsinki sees that the first connection, in particular, between Finland and Estonia, had an inspiring effect: "The connection between Helsinki and Tallinn made things real. It was not just talking about the network, but it was something one could use. This was also noticed in Latvia and Lithuania: it was realized that the cooperation really meant the possibility of getting a first connection to the western Internet, and that really motivated collaboration in these countries."

By 1995 all three Baltic countries had signed an agreement with NORDUnet, and they had connections to the NORDUnet network. However, both Latvia and Lithuania were also intending to carry commercial traffic in their academic networks. That was against NORDUnet rules, because NORDUnet was to carry traffic for research purposes.

In 1996 NORDUnet had Baltic connections to Stockholm and Helsinki. Latvian LATNET had a 384 kbit/s connection and Lithuanian LITNET a 512 kbit/s connection to Stockholm. Estonian EENet was connected to Helsinki with 256 kbit/s capacity. Of these three Baltic research networks, LATNET was considering using only commercial providers. LITNET decided to restrict its traffic to research and education use.

Both LATNET and LITNET gave up their NORDUnet transit service by the end of the 1990s, but Estonian EENet continued to be connected to Helsinki until 2002, when it was connected directly to the pan-European research and education network GÉANT. Nowadays all three Baltic states are directly connected to GÉANT, and the NORDUnet service is no longer necessary for them.

Peter Villemoes considers that the NORDUNET community played a very important role in the Baltic countries when the three countries were building their first research networks. According to Villemoes, the early collaboration and connection to NORDUnet and to the Internet had a beneficial effect on Baltic networking – collaboration with the Nordic countries ensured that "of the former Soviet states, the Baltic countries became the most advanced in networking."

NORDUnet also has had a long-standing collaboration with the Polish research network NASK. Polish researchers worked actively at the end of the 1980s to get Poland connected to the EARN network. At that time it was problematic, because in the United States the government prohibited the exporting of computer and telecommunications technologies to the Eastern Bloc countries. In 1990

the US authorities finally lifted the ban and Poland was allowed to connect to EARN.

An IP connection was established between NASK and Copenhagen in 1991, and by the end of the year NASK was fully connected to the Internet. NORDUnet was the most important international service provider for the Polish Internet, until in 1999 the Polish network POL-34 was given the job of connecting Polish research networks to the pan-European TEN-155. Nowadays Poland also has a direct connection to GÉANT. The NASK connection to the NORDUnet served as a backup for the research institutions around Warsaw until the end of 2004.

In the mid 1990s NASK was also supporting the satellite connection between Stockholm and Lviv in Ukraine. The Ukrainian Academic and Research Network UARNet was attached behind the Polish NASK and the traffic was counted as NASK traffic, but NORDUnet also had an interconnection agreement with UARNet. The connection to UARNet was paid for by NASK until the end of 1996. After that UARNet took over the funding. The NORDUnet service for UARNet ended in February 2002, when UARNet connected to a commercial IP provider.

Collaboration with Russia

In the early 1990s NORDUnet established also networking collaboration with the Russian research networks. The first contact came when Professor Vladimir N. Vasiliev from the Institute of Fine Mechanics and Optics in St. Petersburg visited the University of Helsinki in search of consulting services over networking issues. Lars Backström convinced him that there was in fact no need for special consultation: "I told Vasiliev that these matters could be handled by talking to the right contacts. And concerning the European and the United States networking connections, the best contact would be NORDUnet, and in Finland, FUNET. So, what on earth did he need a consultant for!"

This advice led NORDUnet to a long and still continuing collaboration with the Russian research networks. In 1994 there were three Nordic connections to Russia: from Helsinki to St. Petersburg, from Helsinki to Petroskoi and a connection from UNINETT, Norway to Apatity, the scientific center of the Kola Peninsula. The first stage in formal collaboration was complicated, however, because in St. Petersburg there were two research networks, RUNNet (Russian Federal University Computer Network) and RUSNet (Regional University and Science network), both wanting a connection to NORDUnet.

In 1995 NORDUnet made an agreement with RUNNet, but at the same time RUSNet installed a 64 kbit/s line from St. Petersburg to FUNET in Helsinki. Later in the same year RUNNet and RUSnet were interconnected in St. Petersburg. However, RUNNet did not find the connection via RUSNet satisfactory and asked NORDUnet for another connection. In October 1995 RUNNet set up its own 256 kbit/s line from St. Petersburg to Helsinki.

Since then, RUNNet has been NORDUnet's closest Russian collaborator and has continuously upgraded the connection to NORDUnet. NORDUnet serves RUNNet in the same way as the Nordic national research networks by providing RUNNet with a transit service to the general Internet and also to the pan-European GÉANT.

Today, the Russian Backbone Network, RBnet, also connects to GÉANT, but Russian research networks have agreed that they need two connections. Therefore RUNNet continues its collaboration with NORDUnet. The NORDUnet connection is RUNNet's primary connection to the networks out-

side Russia, and the connection also serves as a backup for the other Russian research networks.

In November 2004 RUNNet moved its network node from Helsinki to KTH in Stockholm. At the same time the connection was upgraded to 1 Gbit/s capacity and most of the IP transit traffic was removed from it.

Peter Villemoes feels NORDUnet has very good collaboration with Russia: "It has meant a lot to them, and it has meant a lot to us. I know when I visit Russia they give me fantastic treatment, meetings with ministers and so on – and that's not for Peter, that's for NORDUnet."

The Nordic Backbone

The Nordic backbone NORDUnet began its operations in 1988 by connecting four Nordic countries with 64 kilobits per second capacity. Sixteen years later, in September 2004, NORDUnet completed its 10 Gigabit upgrade.

During the years, the Nordic national research and education networks (NRENs) have worked together in NORDUnet, but they have also had their own projects and plans to fulfill. The close Nordic collaboration has supported those projects: experience and knowledge have been shared with others. Naturally, there has also been friendly competition between the Nordic NRENs. As Hans Wallberg of SUNET notes: "We have always wanted to build the 'smartest' national network."

According to Petter Kongshaug of UNINETT, the competition of the Nordic NRENs has evolved especially around the capacity of the national networks. Kongshaug remarks, that the competition has always been friendly, "because we did not fight for the same money. However, this also meant friendly cooperation and support that eventually resulted in national convergence."

Peter Villemoes, the General Manager of NORDUnet, has seen how Nordic collaboration and competition has also been apparent in NORDUnet board meetings: "When the board members saw that one network was going ahead quite fast in some direction, that was used as an argument in another country: 'See, look, look what they are doing!' So, sometimes one country was the first to develop bandwidth and services, but in the long run it leveled out."

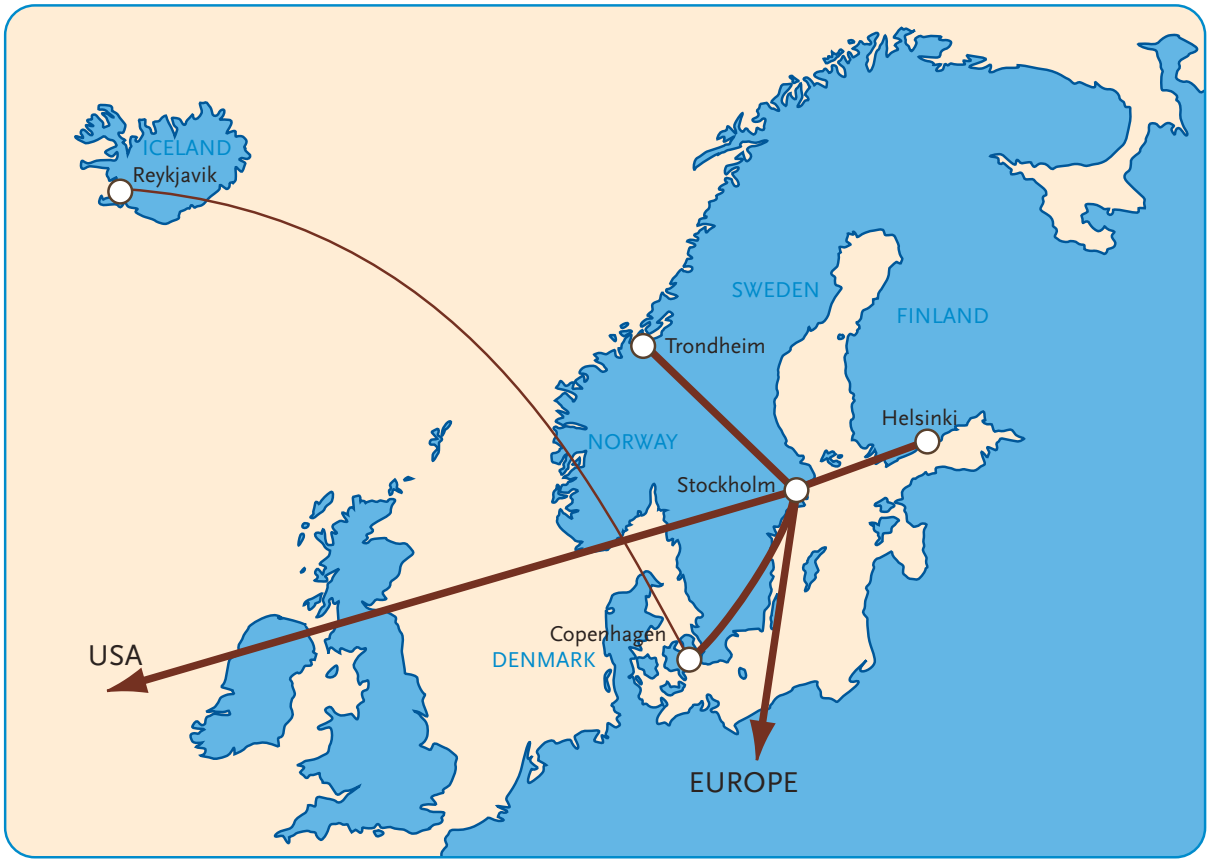
Villemoes also points out that differences between the Nordic NRENs have added to the benefits of collaboration. There have been different views on various areas of networking technology, but that has been useful in the end. "The diversity of solutions and doctrines in different countries made it all together a much more interesting system, as one could gain experience from another country."

From 64 kilobits to 10 Gigabits

The NORDUnet network was implemented in 1988, at first connecting Denmark, Finland, Norway and Sweden with a capacity of 64 kbit/s. In 1989, Iceland was connected to UNI-C in Denmark with a satellite line of 2400 bit/s capacity. A year later, Iceland too was connected to

NORDUnet NOC in Stockholm, and the capacity was upgraded to 9600 bit/s.

Of the Nordic lines, the line between Sweden and Finland needed frequent upgrading in the early 1990s. The situation was curious, since overload on the Finnish line differed from on the other Nordic lines: outgoing traffic was bigger than incoming traffic. The overload on outgoing traffic was mainly caused by the popular FTP service, NIC.FUNET.FI, set up in 1990 for freely distributable files. The load on NIC.FUNET.FI became even heavier after the first Linux version was released on the server in 1991.



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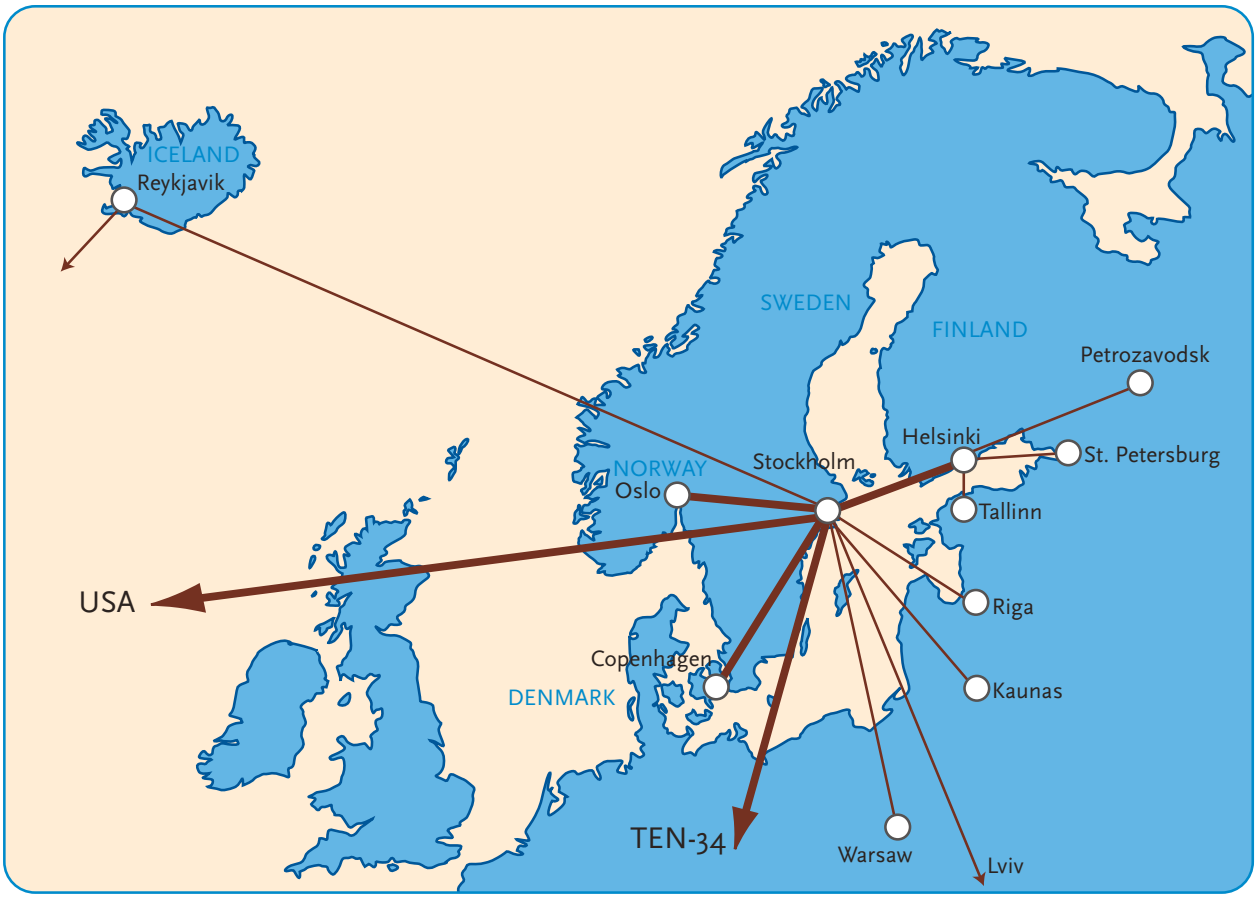
NORDUnet 1989.
The connections of NORDUnet in 1989.

The network connection to Iceland has required special arrangements over the years. Because of the geographical distance and the small population – less than 300,000 inhabitants – the Icelandic telecommunication companies and research community were forced to have different solutions in building and organizing network connections for Iceland. And consequently the Iceland connection has been more difficult and more expensive to accomplish than the other Nordic connections.

In 1988 RHÍ (the computer center of the University of Iceland) began to use TCP/IP on its backbone. In the following year it took over the operation of ISnet, the Icelandic Unix network, in the name of SURÍS. The network also had commercial institutions connected to it, which was against NORDUnet's rules, but it was tolerated because of the small size of the country – it was not sensible to have several networks set up in Iceland. But later, this became to be a problem, because funds from the NSF and the European Commission could not be used to support private industry.



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NORDUnet 1997.
The connections of NORDUnet in 1997.

Jóhann Gunnarsson, the Icelandic member of the steering committee of the NORDUNET program, explains: "Although SURÍS actually ran the network, it was not a company. It had to rely on the goodwill of the University of Iceland, which lent it a business environment, cash flow adjustments and corporate image. This arrangement persisted until 1995. By then the operation had become too big to be managed in such an informal manner so a limited company was established to take over

the operation and assets of SURÍS. All users were offered shares in INTÍS, Internet á Íslandi hf, based on their share of the business volume."

INTÍS was thus established in 1995 and NORDUnet continued to serve it as a new member organization of NORDUnet. In the same year the line to Iceland was moved from a satellite link to the CANTAT-3 sea cable and the capacity was upgraded to 1 Mbit/s. The other Nordic lines were at that time upgraded to 8 Mbit/s, and the 34M system was already being planned.

In March 1996 NORDUnet launched the first international European 34 Mbit/s line between the

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NORDUnet 2005.
The connections of NORDUnet in January 2005.

NORDUnet NOC in Sweden and FUNET in Finland. The line was established in collaboration with telecommunication operators Telia in Sweden and Telecom Finland. The second Nordic 34M link was installed in December 1996 between Sweden and UNINETT in Norway. The Nordic upgrade was completed when the 34 Mbit/s link was established between Sweden and the Danish research networks, DENet and Sektornet in March 1997.

In the meantime, INTÍS of Iceland established a direct connection to the American Internet by implementing a 2 Mbit/s line from Reykjavik to TeleGlobe's Internet in Montreal, Canada. The direct connection to North America was arranged at lower cost and with better quality of service than indirectly via Stockholm because Iceland is geographically nearer North America than the other Nordic countries.

By the mid 1990s the network services of commercial operators were sufficiently developed for the research networks to purchase basic services from the operators and focus their own work on specialized services and network development. But even though the telecommunication monopolies of the Nordic countries were breaking up during the 1990s, the prices did not go down as fast as customers like NORDUnet were hoping. These high prices of connections forced NORDUnet to investigate alternative solutions.

In 1997 the universities of Copenhagen in Denmark and Lund in Sweden were developing their "Virtual Øresund University" collaboration. To further enhance the project the universities needed a connection over Øresund, the strait separating Sweden and Denmark. NORDUnet wanted to upgrade the link to Denmark to 34 Mbit/s, but received an offer of 14 individual 2 Mbit/s links at a very high price.

Instead of buying an overpriced service, NORDUnet put into effect an exceptional plan to build a connection of its own. Jan Engvald of the Lund University envisioned the idea of building a microwave link, which was set up in Barsebäk, and from there in cooperation with Tele2 to Stockholm. Lund and Copenhagen universities got their direct link, and NORDUnet leased two lines, both of 155 Mbit/s capacity – at a very reasonable price.

The microwave link was set up by Zone Systems, a small Danish company just entering into the telecommunications business. Today, the company is called Global Connect, and it has grown into a major telecommunications supplier in Denmark.

In 1999 NORDUnet signed a contract with Swedish company Telia. The Nordic lines between member networks, provided by several operators, would be switched to Telia in 1999–2000 and the bandwidth of 155 Mbit/s would be doubled. But the planned bandwidth was not enough: in the fall of 2000 NORDUnet was already testing between Sweden and Forskningsnet in Denmark a 2.5 Gbit/s connection – the first in Europe of this capacity. By March 2001 the Nordic backbone was upgraded to 2.5 Gigabit.

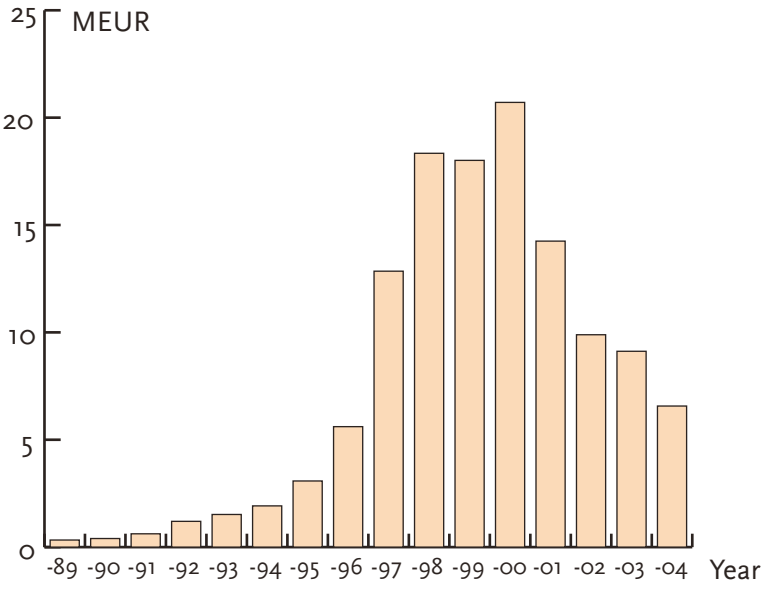
In Iceland the research network situation changed again at the turn of the millennium. The Icelandic telecommunications company Islandssimi bought INTÍS in the spring of 2000. The University of Iceland sold its INTÍS shares and was preparing a new organization to connect the Icelandic research organizations to NORDUnet, because NORDUnet could not serve a commercial company. In the fall of 2000 the Icelandic network for research and education, RHnet, was connected to NORDUnet in Denmark at 45 Mbit/s capacity and it became the new member of NORDUnet.

NORDUnet's 10 Gigabit upgrade was completed in September 2004, when the Danish connection of Forskningsnet was upgraded. By the end of 2004 NORDUnet was providing a 10 Gbit/s service to Denmark, Finland, Norway and Sweden, and to GÉANT. At the end of the year RHnet in Iceland was connected to NORDUnet via 155 Mbit/s link, with a backup to Teleglobe's service in New York at 100 Mbit/s, but a new upgrade to 2.5 Gigabit was planned for 2005.

The Rising Costs

During the 1990s the growth of the Internet was explosive. It attracted more and more users, the number of nodes increased – and the new applications constantly demanded more bandwidth. Although this expansion seemed amazing, the traffic growth was not a surprise for anyone in the networking field. Peter Villemoes points out: "Right from the start of NORDUnet, traffic kept growing. It was simple enough to understand: more users got connected, students came, universities got better connected, national networks got better connected. We were perfectly used to traffic growth. We could not see that stopping."

Although networking experts were prepared for traffic growth, it was difficult to deal with the rising costs. From 1994 on, the demand for capacity doubled every year. At the same time, the unit prices decreased only about 40 % per year. The price decrease was thus not enough to keep the costs down.



The expenses of NORDUnet.

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The explosive growth of the Internet meant increasing costs and bigger budgets for NORDUnet until the year 2000. After that, the prices of bandwidth began to fall, which directly affected the expenses of NORDUnet.

NORDUnet was proud of the good service it was giving to national research networks. In particular, the connection to the United States was considered vital. However, maintaining the quality of service grew more difficult every year during the late 1990s. Peter Villemoes explains: "Yes, this was our struggle. All the way to 2000 it was a fight to get enough money to pay for a growing amount of bandwidth. Sometimes we couldn't keep up, but most of the time we were the only network in Europe that could give our users unrestricted access to America. And we had to pay according to the listed price, and that was expensive."

In planning the budget for 1996, NORDUnet had to prepare for several upgrades. To match Nordic networking services with the international services, the central Nordic countries had to upgrade

their connections to 34 Mbit/s, because the same capacity was planned for the links to Europe and was already in place for the links to the United States. When the preliminary budget of 1996 was first shown at the board meeting, some members were shocked to see the costs almost doubling from 23 million Danish crowns (3.1 MEUR) to over 40 million (5.6 MEUR). More than 90 % of the expenses in the budget for 1996 were line costs, which covered both the bought-in network services and the leased lines.

The situation was no easier a year later when the budget for 1997 was being planned, because the collaboration with the United States was about to change. During the early 1990s NORDUnet had gained a lot from the good collaboration with the National Science Foundation in the United States. Since 1991, NORDUnet had been participating in the NSF's ICM program (International Connections Management). Within this program the NSF was paying a part of NORDUnet's US connection; in the mid 1990s the sum was 10 million Danish crowns per year – a larger share than for any other European partner.

But the long collaboration with the NSF was about to change, because the NSF would not fund general purpose traffic any more. The NSF was to concentrate its support on higher speed research connections only, and end its ICM program in October of 1997.

For NORDUnet that meant increasing costs: at the end of 1996 it seemed that in order to maintain the 34 Mbit/s capacity to the United States, NORDUnet would have to pay twice the unit cost. All in all, the line costs were about 95 % of the budget for the year 1997.

The end of the 1990s was a difficult time for NORDUnet. Peter Villemoes recalls: "Almost all of our money was spent on USA connectivity, about 80 %. Those were dark hours, we paid out so much money. I really didn't like sitting there and spending our money on just one single thing."

Denmark Gets Worried

In the late 1990s there seemed to be no end to the rising costs. When Peter Villemoes made predictions for the future budgets there was no light at the end of the tunnel. Quite the contrary: expenses seemed to be growing exponentially. "Those predictions scared everybody – including myself," says Villemoes.

It was no wonder that the funders of NORDUnet, the Nordic ministries, became worried. The Ministry of Education in Denmark was especially afraid of the growing costs. Peter Villemoes could understand that, because the ministry had had problems with other projects: "The Ministry of Education had had some IT projects which had run wild and given them a lot of problems. So, they were clearly very sensitive to other IT projects that might run wild."

The year 2000 was especially difficult for NORDUnet. The costs reached their all-time high, 154 million Danish crowns (20.7 MEUR). One reason for the rise was that NORDUnet had to pay its biggest expense, its US connections, in US dollars, and the dollar was then 30 % higher in value than at the time the contracts were made.

In 2000 the Danish Ministry of Research (Forskningsministeriet) asked NORDUnet for a note about its price competitiveness compared to commercial providers. Up to this point, the cost of

NORDUnet services had been shared between two Danish research networks, Forskningsnet and Sektornet. Now Sektornet was considering using a commercial service provider, because NORDUnet's price was estimated to be too high.

In 2001 the Danish Ministry of Education advised UNI-C to denounce the shareholder agreement of NORDUnet. That meant that one Nordic country would leave NORDUnet, and give up Nordic cooperation in networking. Peter Villemoes remembers the feeling of disappointment: "That of course was a deep deep low for the Nordic collaboration."

This difficult situation led to a series of negotiations and investigations of NORDUnet. The Nordic Council of Ministers set up a working group, Kontaktgruppen, to evaluate NORDUnet and to consider the consequences if Denmark were to withdraw. Forskningsnet also hired a private consulting company, Fischer & Lorenz, to examine NORDUnet's competitiveness.

Peter Villemoes believes that one reason for this episode was that the tasks of NORDUnet were seen as too simple. NORDUnet was compared with commercial providers, although that did not give the whole truth. As Villemoes puts it, the non-specialists' view of the networking seemed to be that "you log on to the Internet and you browse, and that's networking. And if that's the view, and if this is what you want to do, you can get it much cheaper by taking out a subscription to a commercial provider. But NORDUnet is not for that. The primary purpose of NORDUnet is really to give researchers more than that, because it's a fact that the commercial Internet cannot fulfill – because they don't make money from it – the real needs of research and education. And that's what NORDUnet is for."

NORDUnet explained these views in its reply to Kontaktgruppen: "The demands made by research traffic and by commodity traffic are different because the advanced high bandwidth re-search applications, which that are essential for the development of the Internet and the piloting of new services, need a larger ratio between capacity and load than does the commodity traffic."

NORDUnet also made clear in its response, that it was not only a service provider, but also a body for Nordic networking collaboration: "NORDUnet provides an infrastructure for collaboration within research and education in the Nordic countries. This infrastructure also constitutes a Nordic platform for collaboration with the rest of the world."

The consulting firm came to the conclusion that if Denmark wanted to continue provide good networking services for research and education institutions in the future, the country should continue collaboration in NORDUnet.

Peter Villemoes believes that this report from an independent consultant probably had some influence on the Danish authorities, but ultimately it was a question of money. While the continuation of Nordic networking collaboration was under consideration, NORDUnet had some good luck after all. The enormous price increase that had been predicted earlier never materialized. On the contrary, at the turn of the millennium the prices of bandwidth began to fall. This radically affected the expenses of NORDUnet: in 2000 they amounted to 154 million Danish crowns (20.7 MEUR), but in 2001 they suddenly sank to 105 million (14.3 MEUR). Peter Villemoes recalls this with relief: "That was the big price decrease of the general Internet. That was really what settled it."

At the end of October 2001 Denmark cancelled its withdrawal from NORDUnet's shareholders agreement. Some internal changes in Denmark's ownership of NORDUnet were, however, made: at the beginning of 2002 the new Ministry of Science, Technology and Innovation took over the Danish shares and responsibility for NORDUnet.

In the end, the crisis even made NORDUnet collaboration more intense and nowadays NORDUnet has more contacts with the shareholders than before. Peter Villemoes sees the positive outcome of

this difficult period: “Because of the problems with Denmark and the rising costs, we intensified our relationship with the Nordic governments. So we now have shareholders meetings every year, where we present four-year budgets. And that started more or less when prices started to fall. So we are rather popular with the funders now.”

NORDUnet in International Collaborations

NORDUnet provides connectivity for the Nordic national research and education networks, but it also has another fundamental function: to serve as a platform in international collaborations. This has been an equally important task throughout the 25-year history of Nordic networking cooperation.

During the early 1980s when the NORDUNET community was forming, networkers in the Nordic countries learned to work together for a common goal. These early contacts became vital in the mid 1980s, when European collaborations began to take shape. Nordic networkers were very active in these early collaborations and as a group they were a stronger force than a single participant from one country would have been.

In the 1980s, the first significant European collaborations in the networking field were EARN (European Academic and Research Network) and RARE (Réseaux Associés pour la Recherche Européenne / European Association of Research Networks). NORDUNET and the Nordic NRENs participated in both of these, but in the late 1980s the Nordic networking community decided to move in a direction that departed from the views of many other European networks. In building the NORDUnet network, the NORDUNET community was determined to carry the TCP/IP protocol in the Nordic backbone. But the Internet protocol used in America was not accepted as a part of pan-European networking plans. The difference between the Nordic stance and that of other European organizations meant that NORDUnet was closer to its American collaborator, the National Science Foundation (NSF).

In the early 1990s NORDUnet was a driving force in bringing the Internet Protocol to Europe, and was one of the initiators of the first pan-European IP backbone, Ebone. Nowadays, NORDUnet's major platform in European cooperation is DANTE (Delivery of Advanced Network Technology to Europe), which manages the pan-European research network GÉANT.

Over the years, members of the NORDUNET and the later NORDUnet communities have participated in international working groups and in projects developing new networking technologies. Today, network development activities have become even more crucial for NORDUnet. NORDUnet

has been involved in valuable collaboration with the Internet2 project in the United States since the end of the 1990s. In Europe NORDUnet has participated in the large 6NET research project, testing IPv6, Internet Protocol version 6. And most recently, NORDUnet has become an active member of GLIF (Global Lambda Integrated Facility), an organization dedicated to developing optical networking.

EARN – First Steps in European Collaboration

In the mid 1980s, the European research communities were energetic in setting up new collaborations to ensure networking development and standardization in Europe. The NORDUNET program began in 1985, the same year as the EARN association started its operations.

EARN (European Academic and Research Network) was initiated in the early 1980s by computer manufacturer IBM, which had already sponsored the BITNET network in the United States. In 1984, IBM began to donate hardware to European universities, and meetings for computer scientists were organized to plan an academic research network in Europe. In February 1985, the EARN association was established.

The Nordic countries took part in the EARN collaboration from the very beginning. Already in 1985, Denmark, Finland, Norway and Sweden were connected to EARN, and Iceland established its connection in 1986. Because networking collaboration had already begun within the NORDUNET community, many representatives from the Nordic countries knew each other already. The friendly relations created within Nordic networking circles were also evident in the EARN collaboration. According to Frode Greisen, the former EARN president, it was therefore natural that Nordic participants talked with each other more than with other Europeans, but "there was in no way a Nordic block within EARN."

In its early years, the EARN network proved to be an important service. Although EUnet had already been built by UNIX users in Europe, for many academics it was EARN that gave them the first chance to send email to and network with other researchers. Peter Villemoes, the General Manager of NORDUnet, recalls that at this early stage, EARN was the major backbone in Europe: "EARN was the basic service for universities in Europe, without any doubt."

The EARN network, however, used provider-specific technology, the NJE (Network Job Entry) protocol and RSCS (Remote Spooling Communications Subsystem), created by IBM. The European research networks could not base their future activities on proprietary technology; they had to consider other alternatives.

EARN was supported by IBM for four years, but in 1988 the funding was to come to an end. Nordic networkers began to plan ways of using the EARN lines, and the X.EARN project was established. Soon the project evolved into a more ambitious model: a network that would carry multiple protocols to connect the Nordic national networks.

Frode Greisen considers that EARN helped the development of Nordic networking: "Nordic researchers benefited from having a service before the Internet developed internationally. To some extent bandwidth provisioned for EARN was used to carry other protocols, too, which probably

facilitated Internet development in the Nordic countries. It was easier to get bandwidth for EARN, since it was providing a real email and file transport service for the established mainframe user community, than it was for development for the initially smaller numbers of Internet users."

For Nordic networkers, the EARN service was a vital stepping-stone in the development of their own Nordic infrastructure, the NORDUnet network.

RARE – Harmonizing European Development

The EARN project gave European computer scientists a chance to collaborate, but at the same time plans were made to establish a new cooperative organization. EARN had been set up by a computer manufacturer, IBM, which meant dependency on the products and standards of one company. For the European academic community, that could not be a solution for the future. European researchers therefore considered ways of harmonizing the development of networking protocol standards to ensure the interconnection of the national networks. With this purpose in mind, European networkers established a new association, RARE (Réseaux Associés pour la Recherche Européenne / European Association of Research Networks).

Peter Villemoes points out that RARE was clearly established as a reaction to EARN: "RARE was to some extent set up to make sure that we got a non-provider specific technology for European backbone networking – that is still the goal we have today. We set up RARE because we couldn't just rely on one provider to decide the future."

RARE has its roots in Germany, where computer scientists were trying to organize the development of networking protocols in the early 1980s. German scientists organized international meetings to address the problem, and in May 1985, a workshop was called in Luxembourg to consider future collaboration. The workshop was hosted by the European Commission and attended by representatives from the European academic community.

In the Luxembourg meeting it was decided that a unified network infrastructure should be set up to support research and academic collaboration. It was also proposed that an association should be established to foster European research networking. The Dutch Ministry of Education and Science provided an interim secretariat for the association and RARE was formally founded in June 1986 under Dutch law. The RARE secretariat was opened a year later in Amsterdam.

The NORDUNET community, which had just began the planning of the Nordic network, was very active in establishing RARE. According to Peter Villemoes, NORDUNET was a main contributor in setting up RARE. "And RARE meant a lot to us. That was our relation to the rest of the Europe in the early years."

However, towards to the end of the 1980s the Nordic position in RARE was weakening. The reason for this was the difference in views on protocol standards. In 1987 a number of European countries with the European Commission established the COSINE initiative, Cooperation for Open Systems Interconnection Networking in Europe. As the name indicates, the purpose of COSINE was to build a pan-European network based on OSI protocols. RARE became the contractor of the work and promoted OSI in Europe.

In the meantime, Nordic networkers had come to another conclusion: they could not wait for OSI standardization, but rather the Nordic research network, NORDUnet, would include several protocols – including the American TCP/IP, which was not accepted by other Europeans.

Peter Villemoes says that Nordic collaboration in RARE progressed smoothly while the NORDUNET program was officially committed to the OSI model. The situation changed, however, when NORDUnet clearly moved to TCP/IP and "RARE maintained their purpose of setting up OSI networking in Europe. So when we diverted from that path we had some problems with the management of RARE – and became some kind of opposition within RARE."

The COSINE project eventually managed to build the IXI (International X.25 Infrastructure)

network, which connected 18 countries together. However, the need for IP services was already understood in most countries, and IXI was succeeded in 1992 by EuropaNET, which supported both X.25 and IP protocols.

EuropaNET was the real outcome of RARE and COSINE, but it was not the only one. Within RARE and COSINE collaboration it was realized that Europe needed an operational unit to provide a European backbone, and the national research and education networks established a new organization for that: DANTE (Delivery of Advanced Network Technology to Europe), founded in 1993.

After setting up DANTE, the mission of RARE was in some ways fulfilled and it had to look for another role. In 1994, RARE and EARN were merged to form TERENA (Trans-European Research and Education Networking Association). TERENA has basically taken over the same tasks that belonged to RARE: it carries out technical activities and provides a platform for discussion to develop research networks. The Nordic countries continue to participate actively in the work of TERENA.

Ebone – The First Pan-European IP Backbone

At the beginning of the 1990s, the protocol war was still going on in Europe. The Nordic national research and education networks had chosen to include the TCP/IP protocol of the Internet in their Nordic backbone NORDUnet, but in many European countries the belief in the OSI model was still strong.

NORDUnet was the most developed IP network in Europe in the early 1990s, connecting the five Nordic countries to the Internet in the United States and to the European networks. In other parts of the continent there were some isolated IP networks, but they were not interconnected and the traffic between them had to go via the United States.

To get the European IP networks connected, an idea for a pan-European IP backbone, Ebone, emerged. The plan was initiated by SURFnet, the network for higher education and research in the Netherlands, and by the members of the NORDUnet community, especially networking experts in Sweden.

As Kees Neggers, the Managing Director of SURFnet, sees it, the need for Ebone was evident at that time: "The reason for Ebone was simply the inability of the pan-European backbone services based on the X.25 protocol to cope with the volume of research traffic demands for IP. A native IP backbone was needed."

Neggers sent out the Ebone 92 proposal in September 1991, suggesting a pan-European multi-protocol backbone "for Internet IP services and ISO-CLNS pilot services by combining and enhancing the existing facilities." Even though the goal was to create an IP service, one had to take OSI into consideration and thus Ebone was designed as a multi-protocol network. Neggers explains that the reason for this was the fact that "official EU and national governments' policy was to only allow OSI and X.25 networking."

Ebone was set up during 1992. It connected Stockholm – Amsterdam – Geneva – Paris – London – Stockholm, Bonn – Stockholm, Bonn – Geneva and London – Montpellier, thus making IP connections between many European countries possible. Peter Villemoes, the General Manager of NORDUnet, says that Ebone "meant a lot to our ability to provide services to our users. To begin with, it solved our problem of getting good IP connectivity to other countries in Europe – also to some extent to the United States, but mainly to Europe. So we benefited a lot from Ebone."

According to Kees Neggers, Ebone also served as an example for future European backbones: "Ebone really showed that native IP networking on a European scale was possible and needed. Within a year the COSINE Policy Group agreed to officially allow native IP next to OSI networking as part of the COSINE project. This finally released a lot of money for pan-European IP backbone networking and for the creation of EuropaNET. Without Ebone, stagnation might have gone on for many more years."

The Ebone initiative also brought NORDUnet and SURFnet closer together and strengthened cooperative ties, a relationship that continues today. According to Peter Villemoes, SURFnet, and especially its Managing Director Kees Neggers, have been great friends of NORDUnet during the years.

Kees Neggers considers that the good collaboration of NORDUnet and SURFnet is based on "our common mindset towards research networking." Both NORDUnet and SURFnet are driven to translate new technologies into better services for the research networks. "In this approach we usually are

ahead of the rest of Europe. Most notably is the introduction of new and better transport backbone services, both intra Europe and to the United States. But also on the middleware and application level we have had and still have several good collaborations."

NSF – The American Connection

The National Science Foundation (NSF) is an independent agency of the United States government that has played a pivotal role in the history of the Internet. The agency was originally established in 1950 to promote the progress of science, health and welfare and to secure the defense of the country. In the 1980s, NSF took on the task of financing new computer networks to provide better networking services for computer scientists.

The ARPANET network was financed by ARPA, later DARPA (Defense Advanced Research Projects Agency), but the universities that had no defense research were not included in ARPANET. In the early 1980s, these universities without DARPA support turned to NSF to get funding for a new network. The plan was looked upon positively by NSF, and it sponsored the building of the CSNET (Computer Science Research Network) in 1981. In the mid 1980s, NSF decided to establish a new network to link the supercomputer centers in the United States. The NSFNET (National Science Foundation Network) came online in 1986.

Towards the end of the 1980s, other institutions and networks, like the CSNET, began to connect to the NSFNET making it the major networking actor of the US academic community. Eventually, the NSFNET became the main governmental network and the backbone of the Internet. The ARPANET was dissolved in 1990 and the responsibility for the Internet passed to NSF.

Nordic collaboration with NSF began at the end of the 1980s. As the first international research and education network outside the United States, NORDUnet was connected to the NSFNET at the end of 1988. From that time on, NORDUnet has had a special relationship with NSF.

Steven Goldstein, formerly NSF Program Officer for International Networking, was the primary NSF contact for NORDUnet for many years. In his view, NORDUnet in the early 1990s was clearly distinguished from other European networks: "NORDUnet seemed to be the only networking organization in Europe that understood the real world. The rest of Europe at the time was mired in omphaloskeptic network protocol politics over the OSI suite, PTT monopolistic intransigence, and hierarchic government sponsor control. I can recall one NORDUnet meeting in Helsinki where one of the speakers kept referring to 'NORDUnet and Europe' – down there, pointing as if there were a map on the whiteboard – as if they were very separate and distinct entities."

NSF established an ICM program (International Connections Management to NSFNET) to take care of international Internet connections, and NORDUnet also participated in the program in 1991–97. NSF contributed funds for the NORDUnet connection, in the mid 1990s a bigger share than for any other partner. According to Steven Goldstein, NSF was willing to co-fund the connection, "because NORDUnet was a real partner. In the end, NORDUnet contributed an even greater share to our collaboration than our meager budget would permit us to contribute."

NSF managed the Internet in the early 1990s during its phenomenal growth. However, by the

mid 1990s the privatization of the Internet had become evident, and the role of the NSF changed. NSF stopped the funding of the NSFNET and the backbone was decommissioned in 1995. Instead, NSF would fund the universities directly to enable them to buy services from commercial providers.

The ICM program also ended in 1997. At the time of its ending, the General Manager of NORDUnet, Peter Villemoes, and Steven Goldstein of NSF exchanged emails thanking each other for the long collaboration. In his message to Villemoes on 30 September 1997, Goldstein wrote: "This is a 'bittersweet' day for me. ICM, which has been so much a part of my life, sees its last light today. ICM provided us unprecedented leverage to build a global foundation for the Internet. I don't think that we shall ever have as much opportunity again. But, the Internet world has matured around us, and it is indeed time for the ICM star to fade. I, too, look forward to continued collaboration with you, personally, and between NSF and NORDUnet in the NGI and Internet2 arenas. Long-time partnerships, proven throughout the years, are to be honored and preserved."

And the collaboration did continue: when ICM ended, NSF was already preparing a follow-on program, focused on advanced networking. The NSF HPIIS program (NSF Program for High Performance International Internet Services) ran in 1999–2003, and NORDUnet was one of the few European research networks accepted as a participant.

The HPIIS program was created to provide a basis for the development of the next generation of networking applications. An integral part of the program involved organizing a connection to STAR TAP (Science, Technology, And Research Transit Access Point) in Chicago in order to meet the American research networks, vBNS (very High Speed Backbone Network Service) and Internet2.

Today, both NORDUnet and NSF participate in international GLIF collaboration (Global Lambda Integrated Facility), continuing the development of network technologies. According to Peter Villemoes, the long history of collaboration with NSF and American networking organizations has made NORDUnet a wanted partner in international cooperations and NORDUnet is well recognized among the networkers in the United States: "Everybody knows what NORDUnet is. So, all doors are open to NORDUnet, and that is why we can easily join such things as GLIF. We don't have to explain where we come from. We just walk in and the doors are opened – because of our history."

DANTE – Coordinating European Networking

Today, DANTE (Delivery of Advanced Network Technology to Europe) is the major organization coordinating pan-European research networking. It was established as a non-profit limited company in 1993 in Cambridge, United Kingdom, and it is owned by the European national research and education networks (NRENs). DANTE works in collaboration with the European Commission, which grants funding for DANTE projects. The mission of DANTE is to plan, build and operate pan-European research networks and to provide the infrastructure for networking research projects.

DANTE and TERENA (Trans-European Research and Education Networking Association) are the principal collaborating bodies in European research networking, and they both have their origins in RARE (Réseaux Associés pour la Recherche Européenne).

The idea of DANTE emerged in the context of RARE's COSINE project. In the early 1990s, COSINE was building a pan-European research network based on OSI principles. Peter Villemoes explains, that this was the time the NRENs in Europe began to realize the need for new organization: "We – the research networks – proposed a European operational unit which should provide a European backbone, and that became DANTE. DANTE started taking over what COSINE had produced and made that slowly into an IP network in Europe."

The outcome of COSINE, the IXI (International X.25 Infrastructure) network, was further developed in 1992 to include IP services and was renamed EMPB (European Multi-Protocol Backbone). When DANTE was established in 1993, it chose the name EuropaNET for its backbone services, which were based upon EMPB.

At that time NORDUnet had the Ebone service for IP connections to Europe, so there was no immediate need to migrate to EuropaNET, which did not have enough capacity. However, by the fall of 1993 it became clear that EMPB's IP service was functioning, and several countries decided to leave Ebone to move to EuropaNET. For example JANET of Britain and SURFnet of the Netherlands migrated from Ebone in 1994 and decided to use DANTE network services. NORDUnet also considered it, and decided to connect to EuropaNET in 1994.

According to Peter Villemoes, the real turning-point in European networking came when the European Commission began to support a 34 Megabit network in Europe. "Of course the European networks asked DANTE to implement that. And from then on it has been the main service provider for us."

The planning of TEN-34 (Trans-European Network at 34 Megabits per second) began in 1995 and the network became operational in 1997. In less than two years, it was replaced by a new network, TEN-155 (Trans-European Network at 155 Megabits per second), which was launched at the end of 1998. The current pan-European research network is GÉANT, which began operations in 2001, at first with 2.5 Gbit/s capacity. In 2003 GÉANT was upgraded to 10 Gbit/s. The successor is going to be GÉANT2 in 2005.

Peter Villemoes admits that during the first years of DANTE there was "a period of suspicion, but now there is a period of collaboration with DANTE." DANTE is nowadays the major cooperation platform that NORDUnet has with other European research networks.

Internet2 – Towards New Applications

NORDUnet and Nordic networkers have had collaboration programs with American networking institutions for a long time. So it was only natural that NORDUnet was also interested in establishing collaboration with Internet2, and its backbone network Abilene, when they were initiated in the late 1990s.

Internet2 is an American consortium set up in 1996 to develop advanced network applications and technologies. It is led by over 200 universities, which work together with governmental and industrial partners to ensure the transfer of new applications to the global Internet. Internet2 is therefore not to replace the general Internet, but to provide testing facilities for new technologies. For this purpose, the Internet2 community has created the high-performance backbone network Abilene. The Abilene network began operating in February 1999, and its deployment was completed by the end of the same year. An upgrade to 10 Gbit/s was accomplished in 2003.

NORDUnet was the very first research network outside the United States to begin negotiations with Internet2 over a connection to Abilene, even before Abilene was put into operation. At the last minute, NORDUnet was "beaten" by SURFnet of the Netherlands, which signed the contract first. Thus NORDUnet was the second European research network to do so when it signed the Memorandum of Understanding with Internet2 in September 1998.

The Abilene connection was implemented in 1999 as a 155 Mbit/s ATM link between a NORDUnet router and an Abilene router in the Teleglobe building in New York. The link was dynamically shared with SURFnet.

Heather Boyles, the Director of International Relations for Internet2, sees NORDUnet as "an important peer and partner, and Internet2 has benefited from its partnership with NORDUnet throughout the last six years." According to Boyles, the partnership has focused on working collaboratively in several areas: NORDUnet and Internet2 have first of all provided interconnection for advanced higher education and research networks, supported collaboration between faculty, researchers and students, and developed new technologies and services.

Boyles recalls especially an early demonstration of this collaboration. In the summer of 1999, the interconnectivity of NORDUnet and Abilene was tested with high-quality audio and video conferencing. New technology was employed to have Internet2's President and CEO Douglas Van Houweling speak at the NORDUnet conference in Lund, Sweden, from his office in Michigan. Boyles points out, that "the network engineering that it took at that time to make such a high-quality, high-bandwidth video-conference over our respective networks possible was significant and the NORDUnet and Internet2 network engineers and applications developers learned quite a lot together."

NORDUnet's direct connection to research networks in the United States was terminated in 2003, after which NORDUnet began to use the European GÉANT for US research traffic. But even though NORDUnet traffic now goes via GÉANT, the research collaboration with the Americans is still organized directly. Peter Villemoes, the General Manager of NORDUnet, points out that this has been NORDUnet's traditional practice. "We have good understanding about Internet2 because we were connected to it. And we have collaboration – maybe not too formalized now – on network performance with them."

Inspired by Internet2, NORDUnet also proposed a Nordic program Nordunet2 in 1998. The

networking projects within the program ran until the end of 2002. According to Peter Villemoes, one of the most significant achievements of Nordunet2, was NorduGrid. "It is essentially the only functional grid in the world! And it was started as a Nordunet2 project."

Another program, Nordunet3 was initiated in 2003. It was approved by research councils in all five Nordic countries in November 2004.

The 6NET Project – Testing IPv6

The largest European Internet research project of recent years has been 6NET. The project was initiated in 2001 by networking company Cisco Systems, Inc., DANTE and a number of national research and education networks. The goal of the project was to operate an international IPv6 network to gain more knowledge of IPv6 by testing new applications and services.

IPv6, Internet Protocol version 6, has been created to replace the current Internet Protocol IPv4. The ever-growing popularity of the Internet has led to a shortage of IP addresses, and the main purpose of IPv6 is to find a solution to this problem. The 6NET project was aimed at testing how IPv6 would work in realistic conditions when used in a large-scale international network.

The 6NET project started at the beginning of 2002 and it is expected to continue until July 2005. During these years, the project has built an IPv6-based network which connects sixteen countries. Over thirty partners, both institutions and organizations from the research sector and private companies, have taken part in the project. The total investment in the project has been 18 million Euros, of which 11 million has been support allocated by the European Commission.

NORDUnet and the Nordic member networks have been active participants in IPv6-related development projects, including 6NET. NORDUnet has been one of the principal contractors of the project and provided the Nordic part of the 6NET network. During the project NORDUnet has also organized workshops and conferences, thus disseminating the experiences gained from 6NET.

The 6NET backbone network was set up in the central Nordic countries in 2002 with 155 Mbit/s links from Stockholm to Frankfurt and London, and links from Stockholm to Copenhagen, Helsinki and Oslo. In summer 2004, NORDUnet upgraded the Nordic 6NET links to 1 Gbit/s.

At the end of 2004 the 6NET project had continued three years, and the project was about to end in mid 2005. For three years, the 6NET project had been a learning experience for European networkers. Jari Miettinen, the 6NET project coordinator for NORDUnet, believes that the 6NET project has hastened the deployment of IPv6 in the Nordic countries. "It offered a large-scale international testbed which could be used to construct a realistic routed network and test the network's behavior in the field. In this way, the personnel of the Nordic network operations centers gained experience and the router hardware and software matured."

Although this European research project on IPv6 is ending, Miettinen sees that "the future of the IPv6 is bright. The co-existence with IPv4 will stay for decades, but the gradual deployment of the new protocol and the extinction of the IPv4 address space will broaden the IPv6. The next step will be the IPv6ization of the network services."

GLIF and Lambda Networking – The New Light

The most recent network development activity of NORDUnet is the testbed for lambda networking, NorthernLight. The testbed has a star topology from Stockholm to Nordic capitals Copenhagen, Helsinki and Oslo. A link to Amsterdam, Netherlands, connects NorthernLight to other lambda structures in Europe and in the United States.

NorthernLight is a part of GLIF (Global Lambda Integrated Facility) collaboration, a worldwide virtual organization supporting research and development of LambdaGrids. Lambdas are considered by many to be the next major phase in the Internet evolution, leading the way towards optical networking. The idea in lambda networking is to use different wavelengths of light, "lambdas", in optical fibers for separate connections. Each user community has its own individual set of lambdas, and because it is possible to send multiple wavelengths on one fiber, the potential capacity of network is increased.

As in the early days of the Internet, experimental work and the development of new innovations is fostered by research networks. The history of global lambda collaboration began in 2001, when SURFnet, the network for higher education and research in the Netherlands, and TERENA (Trans-European Research and Education Networking Association) organized the first LambdaGrid meeting in Amsterdam. The first research-only lambda was set up between the Dutch NetherLight and the American StarLight in Chicago.

SURFnet's Managing Director Kees Neggers has been the initiator both in Ebone and now in GLIF. Neggers sees similarities in these two collaborations: both were started, because it was time for a new paradigm. The European IP backbone Ebone was established in the early 1990s because it was realized that OSI and X.25 would not be a solution – GLIF was established in the early 2000s because "routed IP was no longer enough to serve the needs of the research and education community. Direct lambda or light path connections may be a better way forward to serve the most demanding users."

NORDUnet is now an active participant in GLIF collaboration, but it took some time to join in. According to Neggers, NORDUnet was at first skeptical about lambda development. In Europe, the first collaborators to work with SURFnet were CESNET of the Czech Republic and UKERNA of the United Kingdom. NORDUnet stepped in as the fourth European partner.

In 2002, Tom DeFanti of the University of Illinois in Chicago suggested that NORDUnet consider having a lambda connection to SURFnet's StarLight link and taking part in the collaboration. At this point NORDUnet was not yet ready to use lambda because of potential problems in scalability. The idea was, however, taken into consideration, and when General Manager Peter Villemoes suggested in March 2003 that NORDUnet should join in the lambda experimentation and set up a link between Stockholm and Amsterdam, the proposal was accepted.

A 2.5 Gbit/s link between Amsterdam and KTH NOC in Stockholm became operative in August 2003, connecting NORDUnet to the Dutch NetherLight. Amsterdam in turn connected to CERN in Geneva, CzechLight in Prague and StarLight in Chicago with 10 Gbit/s links, and later also to UKLight in London.

NORDUnet was ready to extend lambda connectivity to other Nordic countries and thus create

the NorthernLight. The links for a 2.5 Gbit/s system from Stockholm to Copenhagen, Helsinki and Oslo were installed in December 2003, but because of the new technology involved it took a few months to get the network up and running.

Kees Neggers points out that nowadays "NORDUnet is fully part of GLIF and one of the European driving forces." In fact, the GLIF organization was formally established in a meeting hosted by NORDUnet. In August 2003 the Global LambdaGrid Workshop was arranged as a part of the NORDUnet conference in Reykjavik, Iceland. In that conference, GLIF was formed.

The members of GLIF are national research and education networks, countries, or institutions which have enough bandwidth for production traffic and have extra capacity for scientific testing purposes. Because bandwidth is not so expensive as it used to be, many research and education networks now have enough capacity and can make it available for computer scientists studying lambda networking.

GLIF collaboration seems to grow every year: in 2004 the GLIF meeting in Nottingham, England, was arranged by invitation only. Sixty people were invited, networking managers from major research networks from all over the world. From Europe, the participation was restricted to SURFnet, UKERNA, CESNET and NORDUnet. The interest in future collaboration was great, and TERENA began to prepare secretariat support for GLIF.

Peter Villemoes sees lambda collaboration as "the driving one" when creating tomorrow's networks: "As a consequence of this collaboration we now see the GÉANT2 network in Europe, for instance, implementing lambdas in their design – and Abilene is working hard on that too."

NORDUnet, together with SUNET, is also planning a fiber lambda network to take over from the present one in 2006.

The Benefits of NORDUnet

The history of NORDUnet spans in all 25 years, counting from 1980, when the NORDUNET community was formed at the first conference in Sweden. During the first five years the Nordic networkers got to know each other and managed to agree on common goals – the most significant of them being the planning of a Nordic network.

The NORDUnet network was implemented in 1988–89. In its first months in the fall of 1988 it already connected the central four Nordic countries, and also provided a connection to the American Internet – a remarkable accomplishment at the time, when only a few individual institutions or projects in Europe had an Internet connection.

All veterans of the NORDUnet community seem to share the same opinion: one of the greatest achievements of NORDUnet during its history has been that the NORDUnet network provided an advanced service from the very start and offered an early connection to the Internet for the Nordic national research networks. It has had a huge influence on development in the Nordic countries and greatly increased knowledge in the IT field, which has been vital for Nordic industrial competitiveness.

Marius Ólafsson, administrator of Iceland's RHnet, puts all these views together in describing the NORDUnet's early impact: "It is largely through the early installation of a working production network that the Nordic countries now fill the top spots in almost all measurements of network penetration and use in the world. The impact of this on their economic and general technical competitiveness should not be underestimated."

Markus Sadeniemi represented the Finnish national research network FUNET on the NORDUnet board until the Fall of 2004. As a long-time member of the board, he witnessed the beginning of NORDUnet and the effects of the early Internet connection on Finnish society: "NORDUnet brought the Finnish – and the Nordic – research community the Internet as an everyday tool. At least in Finland, students had fairly free access to the network from the start. Thus, from the early 1990s on, the people coming out of Finnish universities were able to use and understood the benefits of the Internet. I think this has been a significant reason for the fact that Finland has been at the leading

edge in that area."

As an example Sadeniemi mentions that before commercial Internet services were available, people from the mobile communication company Nokia and the Finnish PTT (later Tele, nowadays TeliaSonera) were members on the FUNET steering board. At the time FUNET also offered Internet services for the R&D departments of Tele and Nokia. "At least Tele began to offer IP services based on the experience they gained from FUNET."

Petter Kongshaug, the director of Norwegian UNINETT, sees the increased technical competence as the greatest benefit of NORDUnet. In addition, he values the enthusiasm NORDUnet brought to Nordic networking – this enthusiasm has been shared by those who actually built the networks, and also by the NORDUnet board over the years.

Hans Wallberg of Swedish SUNET lists three major ways in which NORDUnet benefits the Nordic countries. "Firstly, we share the costs of communication in a situation were you get a lower price per unit if you buy more – it is very good economy. Secondly, we can share the competence between the countries and together the Nordic countries have expertise in every field. And thirdly, we can act together on the European research networking arena and be much stronger than if each of the Nordic countries acted by themselves."

This last point on Wallberg's list is by no means the least: international collaboration both in Europe and other parts of the world is one of NORDUnet's principal functions – as it has been from the beginning.

Lars Backström of the University of Helsinki participated in the planning of the NORDUNET program and was a member of the program's steering committee. At the same time he also represented Finland in many European collaborations, both in EARN (European Academic and Research Network) and RARE (Réseaux Associés pour la Recherche Européenne). For Backström the benefits of Nordic collaboration in international organizations became evident already in the 1980s: "The collaboration gave us an opportunity to maintain contacts with those actors on the world stage who were developing networking. So, we were in the front line all the time. We were big enough as the NORDUNET community; alone we would have been left on the sidelines. When we gathered our resources we could send at least one person to all the important meetings and working groups. And because of this collaboration, the knowledge gained spread widely – that would not have happened if the person had only had contacts with his own organization. I don't think we can measure the worth of all this in terms of money."

Over the years, NORDUnet has participated in several international organizations and research projects, and recently the networking development sector in particular has gained even bigger importance in NORDUnet collaboration. In the 1990s the research networks had to struggle with increasing costs, and large shares of funds had to be put into upgrading connections to ensure the quality of service. It was only at the beginning of 2000 when the prices of bandwidth began to decrease and allowed the research networks to concentrate more on network developing activities. Nowadays NORDUnet uses about 10–15 % of its budget for network development.

The situation now much resembles the early days of the Internet: it is the academic community that is experimenting and developing new networking technologies, which in the future will be transferred for wider use to the general Internet. This is the basic idea of Internet2 in the United States, and the same doctrine has been adopted in other research networks around the world.

The role and the future perspective of dedicated research networks has changed within the last ten years. In the mid 1990s, the governmental institutions in the United States were giving up the control of the Internet to commercial providers. It was expected that the dedicated research networks

would eventually disappear, replaced by commercial services. The National Science Foundation decided not to fund networking services, but to grant money for universities to buy the services from commercial providers.

But soon it became apparent that the research community needed more advanced services than the commercial sector was able to provide. The commercial services turned out to be insufficient, and dedicated research services were needed after all both to provide the research community with the quality of service it needed and to allow experimentation and development of new technologies.

The American idea of using the commercial providers instead of dedicated research networks was also familiar, of course, to European networkers, but since Europe always was a few years behind the United States in networking, the funders in Europe did not follow the American example. It was not even possible, because the commercial services were not yet well enough developed in Europe. Peter Villemoes, the General Manager of NORDUnet, considers this to have been very fortunate for European research networks, because the Europeans could see the drawbacks of the solutions adopted in the United States. "We saw that breakdown, we saw Internet2 being set up as a reaction to that. And we agreed to the basic philosophy of Internet2: that the real development of the Internet in the wider sense comes from the research community. That logic was accepted and that is one of the reasons why we have research networks and NORDUnet today."

Now the research networks are heading towards new challenges in networking development. One of the best examples of this is the GLIF collaboration (Global Lambda Integrated Facility), supporting development on LambdaGrids. For Peter Villemoes, the idea of grid computing means "going back to the roots of networking, to computer-to-computer communication. The World Wide Web was just pulling one way information out of databases of the Internet, but the Internet was really meant for computer-to-computer communication. That's what the grids are now resurrecting and can do, because prices are going down so much now."

The decrease in price levels has made testing and experimenting possible in a way one could not have imagined a few years ago. Villemoes explains: "When networks become production networks, the operational aspects take over more and more importance, because you design and operate networks that are always there: the users don't accept cuts in networks. The operational aspects were so overriding, even in NORDUnet, that there was just no place to be found for the experimentation with disruptive network technology that is necessary in order to make progress. You couldn't just throw away one million users because three users wanted to do something specific."

Now NORDUnet is exploring new ways of networking. It continues to provide first class connectivity for Nordic national research and education networks, but at the same time it is also willing to reserve bandwidth for experimenting with new technologies – technologies that in the future will be for everyone to use.

GLOSSARY

Abilene High-performance backbone network of Internet2 in the United States.

ARPA Advanced Research Project Agency, renamed DARPA, Defense Advanced Research Project Agency, in 1972. US organization funding military research.

ARPANET The first large-scale packet switching network. Set up in the United States in 1969. Shut down in 1990.

Backbone Top level of a network that connects other networks.

BALTnet Networking project funded by the Nordic Council of Ministers in the 1990s to establish communication services in the Baltic countries.

Batch processing Program process that takes a set – a batch – of commands and executes them on a computer.

bit/s Bit per second. Bit rate is used to describe the capacity of a network. 1,000 bit/s = 1 kbit/s; 1,000,000 bit/s = 1 Mbit/s; 1,000,000,000 bit/s = 1 Gbit/s.

BITNET Because It's Time Network. (Also "Because It's There Network") An academic and research computer network based on IBM's protocols. Built in the early 1980s. Merged with the CSNET in 1989 to form CREN.

Bridge Device that forwards traffic between networks or network segments.

Browser Application used to access information (in the Web).

BSC Binary Synchronous Communications protocol by IBM.

CCITT Comité Consultatif International Téléphonique et Télégraphique. Consultative Committee on International Telegraphy and Telephony.

CDC Control Data Corporation. A computer company, best known in the 1960s and 1970s.

CEEC Central and East European Countries.

Centernet Danish networking project in 1977–83.

CERN Conseil Européen pour la Recherche Nucléaire. European Organization for Nuclear Research.

CESNET Operator of the national research and education network of the Czech Republic.

COSINE Cooperation for Open Systems Interconnection Networking in Europe. A project initiated in the late 1980s to build an OSI infrastructure in Europe.

CREN Corporation for Research and Educational Networking in the USA. Formed in 1989, when BITNET and CSNET were merged under one authority. Dissolved in 2003.

CSNET Computer Science Research Network. Built in the USA in the early 1980s, sponsored by the NSF. Merged with the BITNET in 1989 to form CREN. CSNET services were discontinued in 1991.

DANTE Delivery of Advanced Network Technology to Europe. Limited company and non-profit organization which plans, builds and operates pan-European research networks. Established in 1993, owned by European national research and education networks. NORDUnet is one of the shareholders. DANTE has managed four generations of research networks in Europe: EuropaNET, TEN-34, TEN-155 and GÉANT.

DATAPAK Public X.25 service used by FUNET in the mid 1980s.

De facto standard Standard in practice, so common that it is used like an authorized standard.

DEC Digital Equipment Corporation. A computer manufacturer.

DECnet Network protocol designed by Digital Equipment Corporation.

DECUS Digital Equipment Computer Users Society.

DENet Danish Educational Network.

DFN Deutsche Forschungsnet. German research network.

DNS Domain Name System (or Server or Service). An Internet service used for translating domain names into Internet IP addresses.

EARN European Academic and Research Network, sponsored by IBM in the 1980s. Connected to BITNET in the USA. EARN merged with RARE to form TERENA in 1994.

Ebone European backbone. The first pan-European IP backbone set up in 1992.

EENet Estonian Educational and Research Network. Founded in 1993. NORDUnet provided international connectivity to EENet in 1994–2001.

EMPB European Multiprotocol Backbone, successor of IXI.

Ethernet Technology created to build local area networks.

EUnet The European Unix network.

EuropaNET Pan-European research network in the early 1990s, previously called EMPB (European Multiprotocol Backbone). Provided both X.25 and IP services, was managed by DANTE. Later called also IBDNS, when British Telecom (BT) provided the service.

FFI Forsvarets forskningsinstitutt. Norwegian Defence Research Establishment.

FOA Swedish Defence Research Institute, Försvarets Forskningsanstalt.

Forskningsnet Danish Research Network. A member of NORDUnet.

FRN Forskningsrådsnämnden. Swedish Council for Planning and Coordination of Research.

FTP File Transfer Protocol. A standard that allows the transfer of computer files.

FUNET Finnish University and Research Network. A member of NORDUnet.

Gateway Device that connects different networks.

GÉANT A multi-gigabit pan-European data communications network. Managed by DANTE. Successor of TEN-155. Years 2001-2005.

GLIF Global Lambda Integrated Facility. Collaboration supporting the development of LambdaGrids.

Grid Set of network-connected resources, e.g. computers and servers.

HAFRO Hafrannsóknastofnun. Marine Research Institute in Iceland.

HEPnet Network for high energy physicists. Connected CERN computers to a number of physics institutions.

HPIIS High Performance International Internet Services. A NSF program in the late 1990s and early 2000s.

IBM International Business Machines. American computer company.

ICANN Internet Corporation for Assigned Names and Numbers. Non-profit corporation preserving the coordinating functions of the Internet, e. g. managing the domain name system and allocation of IP addresses.

ICCC International Conference on Computer Communications.

ICM International Connections Management to NSFNET. A NSF program to manage the international connections to NSFNET in the 1990s.

IETF Internet Engineering Task Force.

INRIA Institut national de reserche en informatique et en automatique. The French National Institute for Research in Computer Science and Control.

Internet Global network of the networks. Internetting technologies developed in the 1970s, and the Internet was "born" in the 1980s. Nowadays referred to as the general/commodity/commercial Internet to distinguish it from dedicated research networks.

Internet2 Consortium led by over 200 US universities to develop advanced network technologies.

INTÍS Internet á Íslandi hf. Icelandic limited company established in 1995 to take over the operations of SURÍS.

IPv6 Internet Protocol version 6.

ISnet Icelandic Unix network.

ISO International Organization for Standardization.

ISO-CLNS International Organization for Standardization (ISO) Connectionless Network Service (CLNS). A network layer standard part of the Open System Interconnection (OSI) protocol suite.

IXI International X.25 Infrastructure. Network built by the COSINE project.

JANET Joint Academic Network. Network for education and research in the United Kingdom.

JvNC John von Neumann Center. Supercomputer center at Princeton, New Jersey, in the United States.

KOM Computer conferencing system used at the Stockholm University Computing Center in 1976–1990.

KTH Kungliga Tekniska högskolan. The Royal Institute of Technology, Stockholm, Sweden. The location of the NORDUnet network operations center (NOC).

Lambda Wavelength of light.

LambdaGrid Extension of a grid, based on multiple lambdas.

LAN Local area network.

LATNET Latvian Research Network.

LITNET Lithuanian Academic and Research Network.

Mainframe "Big" computer. The term was invented in 1970s to distinct larger computers from "minicomputers".

NASK Research and Academic Computer Network in Poland. Established in 1991. Connected Polish universities and research institutes with NORDUnet.

NCSA National Center for Supercomputer Applications in the United States.

NETF NORDUnet Engineering Task Force.

NEUCC The Computing Center of the Danish Technical University in Lyngby.

NGI Next Generation Internet.

NJE Network Job Entry. Protocol created by IBM.

NOC Network Operations Center. NORDUnet's NOC is located at the KTH in Stockholm.

Node Location on a network, connection point at which several lines come together.

NORDATA Conferences organized in the 1970s and 1980s by the national data processing associations in the Nordic countries.

Nordforsk Nordic cooperative organization for applied research. Founded in 1947. Promoted Nordic cooperation on technical and scientific research by arranging seminars and conferences and established contacts between researchers and scholars.

NORDUNET Nordic University Network program in 1985–91. Also "NORDUNET community", Nordic networkers working in cooperation since 1980.

NORDUnet Nordic research and education network created within the NORDUNET program, implemented in 1988–89. Also a limited company NORDUnet A/S, founded in 1993, situated in Denmark. From the early 1990s "the NORDUNET community" referred as "the NORDUnet

community".

NORDUnet plug The multi-protocol solution of the early NORDUnet network, that supported several communication protocols.

NORSAR Norwegian Seismic Array. Originally a project established to verify the compliance of the nuclear-test-ban-treaty. Nowadays an independent research foundation specialized in geophysics and seismology.

NorthernLight Nordic testbed for lambda networking.

NR Norsk regnesentral. Norwegian Computing Center.

NREN National research and education network.

NSF National Science Foundation, USA.

NSFNET National Science Foundation Network. Founded in 1986. Replaced the ARPANET in 1990 as the US government research network. NSFNET was dissolved in 1995.

NTNF Norges Teknisk Naturvitenskaplige Forskningsråd.The Royal Norwegian Council for Scientific and Industrial Research.

OSI Open Systems Interconnection. A networking protocol model created by ISO.

Packet switching Method to send data through a network by breaking blocks of information into smaller pieces, "packets".

PAXNET Danish public national X.25 network.

PRNET Packet Radio Net, built by DARPA in the 1970s.

Protocol Set of rules governing the data transmission across a network

PTT Public Telephone and Telegraph (also Postal Telegraph and Telephone). Term for state owned telephone companies.

QZ University Computing Center in Stockholm, Sweden.

RARE Réseaux Associés pour la Recherche Européenne. European Association of Research Networks. Merged with EARN to form TERENA in 1994.

RBnet Russian Backbone Network.

RECAU The Computing Center of the University of Aarhus.

RECKU The Computing Center of the University of Copenhagen.

RHÍ Reiknistofnun Háskóla Íslands. The University of Iceland Computing Center.

RHnet Rannsókna of háskólanet Íslands hf. Icelandic University Research Network. A member of NORDUnet.

Root name server High-level domain name server (DNS) that enables the domain name system to work. Every name server has to have access to at least one DNS (Domain Name System) root name server.

RSCS Remote Spooling Communication Subsystem. A networking system used in BITNET and EARN.

RUNNet Russian Federal University Computer Network. Connects to NORDUnet.

RUSNet Regional University and Science network. Local research network in St. Petersburg.

Scannet Nordic packet switching network. Project that organized remote access to library databases in the 1970s.

SATNET Atlantic Packet Satellite Network, built by DARPA in the 1970s.

SDAC Seismic Data Analysis Center.

SICS Swedish Institute for Computer Science.

SITRA Finnish National Fund for Research and Development. Suomen itsenäisyyden juhlarahasto.

SNA Systems Network Architecture, developed by IBM.

STAR TAP Science, Technology, And Research Transit Access Point in Chicago, US.

STU Styrelsen för Teknisk Utveckling. Swedish Board of Technical Development.

SUNET Swedish University Computer Network. A member of NORDUnet.

SURFnet The network for higher education and research in the Netherlands.

SURÍS Icelandic organization founded in 1987 to run the research network. In 1995 a limited company, INTÍS (Internet á Íslandi hf), was established to take over the operation and assets of SURÍS.

TCP/IP Transmission Control Protocol / Internet Protocol. Standard communication protocol of the Internet.

Telenet Commercial packet switching network in the United States. Began its services in 1975.

Telepak Packet switching network of Swedish PTT in the early 1980s.

TEN-155 Trans-European Network at 155 Megabits per second. Pan-European research and education network. Successor of TEN-34. Operational in years 1998–2001.

TEN-34 Trans-European Network at 34 Megabits per second. Research and education network managed by DANTE. European Union project. Years 1997–98.

TERENA Trans-European Research and Education Networking Association. Promotes the development of networking infrastructure for the European research community. Formed in 1994 with merging of EARN and RARE.

TIP Terminal Interface Processor.

Topology Layout of a network.

Tymnet Commercial computer network in the United States in the 1970s.

UARNet Ukrainian Academic and Research Network.

UCLA University of California, Los Angeles, USA.

UKERNA United Kingdom Education and Research Networking Association. Manages the JANET network.

UNI-C The Danish Computing Center for Research and Education.

UNINETT Norwegian research network. A member of NORDUnet.

USENET Unix Users Network. Created by users of Unix operating system in the United States in 1979. Used UUCP protocol in the beginning.

UUCP Unix to Unix copy. Unix protocol. Also a network connecting Unix computers.

vBNS Very high-speed Backbone Network Service. A testing ground for new Internet technologies. Sponsored by the NSF.

WWW World Wide Web. Hypertext system for information retrieval.

X.EARN Nordic networking project established in 1987 to study the future use of EARN lines. The project lead to the planning of multi-protocol network NORDUnet.

X.25 A standard protocol suite, developed by CCITT and approved by ISO as a part of OSI model.

6NET European research project in the early 2000s for IPv6 testing and research.

Interviews

Persons interviewed or/and persons who provided information for the history. Most of the interviews were performed via email:

Backström, Lars
: Member of the NORDUNET steering committee 1985–91.

Boyles, Heather
: Director of International Relations for Internet2.

Brunell, Mats
: Project manager of the NORDUNET program 1986–91.

Daling, Unn Kristin
: Historian in Norwegian University of Science and Technology; one of the writers of Internett si historie i Noreg (The history of the Internet in Norway).

Davies, Dai
: General Manager of DANTE

Eriksen, Björn
: Systemspecialist at KTHNOC.

Goldstein, Steven N.
: Formerly NSF Program Director for International Networking.

Greisen, Frode
: Former president of EARN.

Gunnarsson, Jóhann
: Member of the NORDUNET steering committee 1985–91.

Hansen, Klaus
: Associate Professor, DIKU (Department of Computer Science, University of Copenhagen)

Heinänen, Juha
: Former member of FUNET steering board; adviser during NORDUnet's planning and implementation period.

Kongshaug, Petter
: Director of UNINETT, member of NORDUnet board.

Lande, Tor Jørgen
: Veteran of Norwegian UNIX User Group.

Løvdal, Einar
: Technical coordinator of NORDUNET in 1985–90.

Madsen, Ole Brun
: Centernet project leader in 1977–81.

Miettinen, Jari
: 6NET project coordinator.

Neggers, Kees
: Managing Director of SURFnet.

Nordhagen, Rolf

One of the initiators of the NORDUNET collaboration, former director of the computing center of the University of Oslo.

Ólafsson, Maríus

Member of the technical planning group of NORDUnet during the implementation period; member of the NORDUnet technical team, RHnet network administrator.

Sadeniemi, Markus

Former director of FUNET and a member of NORDUnet board.

Salminen, Harri

Member of X.EARN project group and NORDUnet's technical planning group 1987–88; NORDUnet's technical coordinator 1991–92.

Villemoes, Peter

General Manager of NORDUnet.

Wallberg, Hans

Manager of SUNET, member of NORDUnet board.

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http://www.nsf.gov/
http://www.6net.org/
http://www.uninett.no/
http://www.rhnet.is/
http://www.forskningsnettet.dk/

Key Figures in the NORDUNET Program and NORDUnet

Steering Committee of the NORDUNET Program 1985–91

Denmark:	Christian Gram	
	Peter Villemoes	
Finland:	Lars Backström	
	Martti Tienari	
Iceland:	Jóhann Gunnarsson	
Norway:	Alf Engdahl	(1985–86)
	Arild Jansen	
	Roald Torbergsen	(1986–91)
Sweden:	Birgitta Carlson	
	Sven Tafvelin	

Associate Members:

Norway:	Rolf Nordhagen	
Sweden:	Björn Grönlund	
	Björn Pehrson	(1991)

The NORDUNET Project Administration 1985–1991

Björn Grönlund	(1985–1986)
Mats Brunell, project manager	(1986–1991)
Einar Løvdal, technical coordinator	(1985–1990)

The NORDUnet Network Board 1989–1993

Working Chairman: Peter Villemoes

Denmark:	Jan P. Sørensen
Finland:	Markus Sadeniemi
Iceland:	Helgi Jónsson
Norway:	Petter Kongshaug
Sweden:	Hans Wallberg

General Manager of NORDUnet A/S

Peter Villemoes	(1993 –)

NORDUnet A/S Board 1993 –

Denmark:	Ole Carsten Pedersen	(1993 – 1997)
	Tor Bloch	(1997 – 2001)
	Dorte Olesen	(2001 – 2002)
	Bent Schmidt-Nielsen	(2002)
	Steen Pedersen	(2002 –)
Finland:	Markus Sadeniemi	(1993 – 2004)
	Janne Kanner	(2004 –)
Iceland:	Helgi Jónsson	(1993 – 2000)
	Sæþor L. Jónsson	(2000 –)
Norway:	Petter Kongshaug	(1993 –)
Sweden:	Hans Wallberg	(1993 –)