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The importance of being networked

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CERN

INTRODUCTION

Several branches of the physical sciences, and high energy particle physics in particular, have for many years made use of computer networks as a matter of routine. Indeed in some countries, such as the United Kingdom and Italy, the physics community has been a major force behind the development of computer networking for the whole national scientific and academic community. On an international basis, the last decade has seen the birth and growth of HEPnet - the high energy physics network - on a European and even intercontinental basis [1]. Indeed it clear to us that the current generation of major particle physics experiments, which are run as international collaborations, could not have come to fruition without computer networking.

It is therefore something of a surprise to discover that outside the Big Science communities of particle physics and space sciences, and even in some countries within those communities, all is not well in the European computer networking world. This paper explores the present situation in Europe and elsewhere, analyses the barriers to progress, and offers some suggestions for the future. It represents the authors' personal views although it draws on many fruitful discussions with colleagues at CERN and elsewhere.

THE NATURE AND POTENTIAL OF COMPUTER NETWORKING

Today computer networks are dominated by traffic to and from personal workstations of ever increasing power. The current distinction between workstations and personal computers will probably essentially disappear in the coming years, but in this paper we are thinking of the typical scientific workstation running the Unix (TM) operating system and with a computing power of 20 MIPS (million instructions per second) today and probably ten times this in the near future. The network must connect

workstations to each other, and also to massive storage devices and high performance computer centres. In international collaboration, there is no reason why communicating computers should be close together.

The familiar applications of computer networks, widely used in the physics community, are electronic mail, electronic news, remote file access and transfer, and remote interactive computing. These applications were all invented some years ago, when data transmission speeds were essentially limited by the quality of analogue telephone circuits. Today, the optical fibre revolution has removed most technological limits on transmission speed and accuracy; the remaining limits are in the efficiency of computer interfaces and of course in economics. Today the technology is well established to transmit 2.5 Gbit/s along an optical fibre with repeaters every 50 km and negligible errors, and this is less than one part in ten thousand of the theoretical capacity. Fully optical switches, and photonic amplifiers, will be ready for service soon. And for regions with difficult geography or lack of infrastructure, satellite transmission is a well established technology, although offering lower bit rates and more errors.

The "fax revolution" in business in the last few years has shown the power of digital transmission of images, even using very crude technology. Business (and high energy physics, especially the US Superconducting Supercollider project) has also made modest use of studio based video-conferencing, despite its high costs and relative inconvenience. It is widely expected that digital image transmission, as well as digital voice transmission, will merge with computer networking into a single technology within the next few years. There are many buzz words to describe this imminent revolution - remote visualisation, multi-media networking, computer supported co-operative work - to name but a few. The common point is that cheap RISC workstations, cheap mass storage, cheap graphics and high-bandwidth optical networks will combine to transform the working environment of scientists.

We confidently expect technology for local area networks to develop in step with the rest of computer technology, albeit at increasing relative cost. What are the prospects for the development of wide area networking?

USA AND PACIFIC

In December 1991, President Bush signed the High Performance Computing Act, which among other things sets the legal framework for the development of a National Research and Education Network (NREN). This Act is the culmination of several years of preparation by the computing and networking community in the USA, with the personal support of Senator Albert Gore junior (whose father steered the Interstate Highway legislation through Congress). It is predicated on the "Grand Challenges" theory - there

are a number of major scientific challenges, such as the human genome project or the SSC, which must be met for America to remain industrially competitive in the long term, and which require continent-wide cooperation in the use of high performance computers and networks. The Act appropriates \$2.9 billion over five years.

This is not just a statement of good intentions. The general purpose National Science Foundation network already runs across the continent at 45 Mbit/s. At the disciplinary level, the Energy Sciences network, used by particle physicists and fusion researchers, runs at 1.5 Mbit/s with active plans for an upgrade to 45 Mbit/s. These networks, and others including some 25 regional networks connecting educational and research institutions, are interconnected under the name "Internet". At least 2,500 sites, 300,000 computers or workstations, and up to 2 million academics and researchers are connected. American industry has not overlooked this valuable national resource. Increasingly, industrial companies are connected via the Commercial Internet Exchanges.

Meanwhile, even before the High Performance Computing Act was signed, American academia and industry, with limited government funding, had come together to create five testbeds investigating Gbit/s network technology on a wide scale, in one case truly trans-continental. Several physics laboratories, including the Los Alamos National Laboratory and the Lawrence Berkeley Laboratory, are involved in these testbeds. The involvement of industry, including the telecommunications carriers, is perhaps the most noteworthy aspect of the testbeds.

In the Pacific region, which of course faces enormous geographical problems in international networking, the situation is complex. Japanese industry is well placed in the development of Gbit/s transmission technology, but it is only within the last year that a single national approach to computer networking for the research community has arisen. Japanese researchers do not yet have the network bandwidth that is available to their American counterparts, but rapid progress can be expected. The particle physics community, as in other countries, has been obliged to set up its own national and international links. In Australia and New Zealand, national academic and research networks have been established recently, but again with modest bandwidth compared to the USA. However, given the size of the Pacific region, the international connectivity available is impressive, with Internet electronic mail from Europe to New Zealand now arriving in a matter of minutes on a good day.

EUROPE

Many European countries, and not only those in "traditional" Western Europe, have a national computer network used by their academic and research community. The oldest is JANET in the UK, and the youngest at the time of writing is RENATER in France. This illustrates that being a large, relatively rich country does not automatically lead to being at the forefront of networking for research; national political and organisational conditions have a major influence. The national networks, where they exist, are inevitably based on data links leased from the national telecommunications carrier, a monopolist everywhere but in the UK and Sweden. Bit rates on these lines vary widely, with trunk lines now up to 34 Mbit/s in some cases, but many universities are connected at no more than 64 kbit/s, i.e. less than 1% of the speed of the local area networks typically used on their own sites.

International research network connections in Europe are confused. There are several "disciplinary" networks, including HEPnet and the European Space Agency networks. There are several general-purpose networks with different constituencies: EARN (European Academic Research Network) which grew out of IBM-based computer centres in the mid-1980s; EUNET (European Unix Network) set up by the European Unix Users Group (now known as EurOpen); EASInet (European Academic Supercomputer Initiative Network) sponsored by IBM; COSINE (Cooperation for Open Systems Interconnection in Europe) which is a Eureka project; EBONE92 which is an ad hoc consortium attempting to consolidate a European backbone network; and NORDUNET which is a regional network for the Nordic countries. Adding together the bandwidth of all international data links operated by these networks, we obtain a total of about 17 Mbit/s. This is widely believed to be well below what is needed to support effective international collaboration. How much traffic actually flows internationally is not precisely known, but extrapolation from measurements at CERN suggests it to be of the order of 400 gigabytes/month.

The meaning of bandwidth

- An individual interactive graphics user needs anywhere from 50 kilobit/s to several megabit/s.
- A file transfer at the speed of a typical mainframe computer disc needs 35 megabit/s.
- Protocol overhead consumes up to 50% of the available bandwidth.
- Competition between many simultaneous users greatly increases the response time of a network, unless very generous spare bandwidth is available.
- For comparison, a digital telephone circuit runs at 64 kilobit/s, and a digital high-definition television channel will need at least 20 megabit/s.

A complex set of rules is needed to govern the way in which data are transmitted between two computers, and how transmission errors are detected and corrected. Such a set of rules is known as a protocol, and many different protocols exist. A large proportion of the traffic on the European networks uses the same protocols as the American Internet, known technically as TCP/IP, interconnecting at least 160,000 computers or workstations in Europe to those in the USA and the Pacific region.

Most of the above networks use international leased lines between major academic sites, but COSINE uses a special 64 kbit/s network provided on a pilot commercial basis by a telecommunications carrier. At the time of writing there are two plans for upgrading this, a short-term plan for a 2 Mbit/s European multi-protocol pilot service and a long-term plan for a commercially provided production service. Apart from the ad hoc EBONE92 there are no other plans for a European backbone network. In the academic research community, there are no Gbit/s testbeds comparable to those in the USA in geographical scope, despite several important national initiatives. The European Commission RACE programme has produced some very high quality technological development work but, so far, no successful international applications testbeds.

Some years ago, the various national research networks, as well as international networks and users, came together with the support of the European Commission to create an Association of European Research Networks, known as RARE from its French acronym. While attempting to support formal ISO standards where possible, RARE has the unenviable task of attempting to coordinate European research networking activities. Recently, as an attempt to raise political consciousness of the importance of the topic, a body known as the European Consultative Forum for Research Networking (ECFRN) was convened, and its steering group produced a policy document addressed to government officials in February 1992. Its principal recommendation is the creation of a high-level intergovernmental group to tackle the issue of research networking.

BARRIERS IN EUROPE

One may wonder why, in the year of European integration, the situation of continent-wide networking is still so confused. We believe that a number of specific barriers to progress can be identified.

** Telecommunications regulations*

There is a complex interaction of national and international regulations. Even within the European Community the national laws have not been adapted at a uniform rate to the EC Directives. For example, in the UK there is an effective competitive market for leased lines, and prices in Germany are becoming more directly related to costs, but prices are still artificially high in most of the Mediterranean countries. In any case the Open Network Provision (ONP) Directives have only partly opened the market, and the confusion is increased by an impending review of these directives and by manifest divergences between different departments of the European Commission. In any case, until now each country has been allowed to retain a monopoly on basic data transmission capacity, and all have done so except the UK (and, outside the EC, Sweden).

• Leased line tariffs

As a result of the monopoly, which de facto applies to international circuits, leased line tariffs have not been driven down by market forces except in the UK. Exact comparisons are dangerous due to rapid changes in official tariffs, and increasing signs of discounting, but tariffs for comparable services and distances are between three and ten times higher in Europe than in the USA. This is clearly a brake on the exploitation of future network technology by European science and industry.

** No pan-European carriers*

Because of the national monopolies, there have in the past been no telecommunications carriers operating on Europe-wide basis. This has serious technical and economic consequences - technically an international link may involve several different carriers with different makes of equipment; economically this technical complexity greatly increases costs. What Europe needs is the emergence of true international carriers, laying their own international fibre trunks.

** Conservatism*

Europe has a set of world-famous telecommunications manufacturers, with close relations with their "national" carrier (Alcatel with France Telecom, Siemens with Deutsche Bundespost Telekom, Ascom/Hasler with the Swiss PTT, etc.). The manufacturers and the carriers have developed a close relationship with the Information Technology Directorate of the EC, for example in the long development of 64 kbit/s ISDN or in the RACE programme. This relatively closed set of relationships, plus the PTTs' traditional expectations of rather slow growth in traffic, has led in our opinion to a very conservative approach to the exciting potential of computer networking. In particular, the research community has not been exploited as a source of ideas and experience.

** Protocol wars*

We will not dwell on this point, but an insistence on the use of formal international standards on the one hand, and an aggressive introduction of the Internet TCP/IP protocols on the other, have led to surprisingly bitter debate and competition over the choice of protocols. It is now clear that a multi-protocol network, allowing the use of any open, non-proprietary, protocol, is what is required. Even this approach leaves scope for technical debate.

** Where is the European scientific computer industry?*

A major stimulus for research networks in the USA comes from the existence of a lively industry of small and large companies developing computers and workstations for the scientific and technical market. Indeed the Gbit testbeds are the result of collaboration between academia, the computer industry, and the telecommunications industry. Currently, and pending a possible European High Performance Computing initiative following the Rubbia report [2], Europe is at a serious disadvantage. We reiterate that the critical issue is tri-partite collaboration between research, industry, and telecommunications.

** Lack of focus*

We mentioned above the difficult coordination task of RARE and the political initiative of the ECFRN. Indeed the main reason why the USA has been able to launch a continent-wide initiative, and Europe has not, is (from a European perspective) the clearly defined focal point of the Federal Government and its agencies. To illustrate the challenges, we mention that since we wrote the CERN internal report which inspired this paper, several more European countries have come into existence! In this situation it is not surprising that national, regional, and disciplinary networks (and not least HEPnet) defend their own interests without worrying too much about the overall picture. The telecommunications carriers operate on a national basis, and politicians seem to be unaware of the challenges and opportunities. The European Commission has not so far proved able to catalyse the creation and operation of an effective pan-European computer networking infrastructure, and sometimes seems unsure about what role it should adopt.

WHAT HAPPENS IF WE DO NOTHING?

We can clearly expect that within ten years, American scientists will have continent-wide access to all major computing facilities, enhanced by instantaneous image processing. This will set the world standard for how science is done, and in due course for industry and business too. If nothing is done to overcome the above barriers, European computer networking for research, for industry, and for business will in our opinion remain underdeveloped in the short term, and will then quickly be colonised by American companies, who have understood this fascinating market so full of opportunity for progress and profit. Put bluntly, we will have abandoned European computer networking to some combination of American computer and telecommunications companies.

A POSSIBLE WAY FORWARD

We do not believe that all is lost, but as in the USA the European research community has a vital role to play as a macroscopic testbed for future network technology. Although there are no simple solutions to such a complex problem, we offer the following suggestions towards a consensus.

- * There must be a strong focus at European level for academic and research networking, with a link to industry. Politically, only the European Commission, with the support of national governments throughout the continent, can create this focus.
- * The primary objective of network operators for the academic and research community must be the provision of multiple high quality services at economically attractive prices.

* Tri-partite collaboration between industry, academia, and telecommunications must be instituted.

* The confusing pattern of organisations involved in international research networks in Europe must be simplified, perhaps by re-constituting RARE.

* RARE has announced plans to stimulate the creation of an Operational Unit to take over various current international research network services. We support this move, as long as the Unit will support all open protocols.

* The re-constituted RARE should then be free to concentrate on strategic networking issues for the whole European research community.

* Over time, we believe that it will be desirable to create a dedicated European Non-Governmental or Treaty Organisation, with a remit covering the entire geographical area of the continent, to handle data networking for the research community.

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