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SATELLITE DATA TRANSMISSION IN HIGH-ENERGY PHYSICS

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SATELLITE DATA TRANSMISSION IN HIGH ENERGY PHYSICS

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Abstract

High energy physicists have today to perform their very complex experiments in large collaborations at the particle accelerators in only two laboratories in Europe, CERN and DESY, while carrying on their university responsibilities and the analysis of the experimental data at home. The whole experimental process forms a vast distributed data processing system, in which better data transmission should help the physicists to work together more effectively than today. The natural speeds for communication between people and around computing equipment are in the region of 50Kb/s through several Mb/s, and the PTTs are only now beginning to consider offering data services in this region. In the USA several firms are actively creating services based on satellite transmission between small earth stations on the 'customers' premises. In Europe, a small experiment, STELLA, has been set up to explore the interest of such services for the physics community, and to look at technical problems of achieving high speeds and low error rates. The CEPT is now considering whether to offer similar services using the forthcoming European communication satellites (ECS).

Introduction

CERN and several other European HEP laboratories have recently started an experiment in high speed data transmission called STELLA, using the prototype communication satellite OTS launched in 1978 by the European Space Agency, with small earth stations on each site to avoid long ground lines to central PTT earth stations. The aim of this paper is to analyse the motivation for this experiment, the role which high speed data transmission can have in the conduct of HEP research as the technical facilities become generally available, and to explain why satellite links using small earth stations are likely to be the best way to improve many types of interlaboratory communications. The paper has four main sections:

- General reasons for high speed transmission
 - Sociology of experiments
 - Communications needs
- Practical applications in High Energy Physics
- Transmission methods
 - Local links
 - Long distance: STELLA as an example
- Recent experience and future plans
 - In USA: the arrival of public systems
 - In Europe: plans and possible costs

General reasons for high speed transmission

----- The sociology of experiments -----

High Energy Physics has been steadily evolving in Europe over the past ten years towards extreme concentration of experiments around fewer and fewer accelerators, with the physicists being attached to a constant if not growing number of Universities and Research Institutes. At the same time the size of experiments, their duration, cost, and complexity imply that the groups of physicists working together on one experiment have to be larger and larger, with correspondingly worsening problems of communication between persons and with the computers which control their equipment and analyse their data.

The situation in 1978 has been studied in detail by the European Committee for Future Accelerators (ECFA), and can be summarized in the following approximate figures taken from the report of their enquiry (1):

- 2000 experimenters from
- 80 institutes were using only
- 2 accelerator laboratories (CERN, DESY) for
- 80 experiments at one time with
- 10-80 physicists in each, lasting up to
- 5 or more years to prepare, run, and exploit.

At CERN the trend is continuing: the start-up in 1981 of the proton- antiproton collider with a few enormous experiments displacing several smaller ones, and later on the construction of the electron-positron storage rings LEP, will reduce still further

the number of experiments which can be done at one time at CERN. At DESY, experiments around PETRA have also become much larger than those which used the original DESY machines, and there too collaborations of dozens of physicists are now the rule.

It is not difficult to see how this continuing concentration of accelerator resources and dispersal of user laboratories can cause growing problems for the physicists concerned, in both their professional and personal lives. Many of them have to organise and participate in experiments which require their presence at CERN or DESY, while trying also to carry out their teaching and administrative duties as University staff. For a considerable number, stays at the accelerator laboratory for months or years are necessary, and the effects of this on their family life and their childrens' education can be very discouraging. These difficulties have led to frequent requests to those responsible for planning and managing HEP to arrange for a larger proportion of the work to be done at the physicists' home laboratories, rather than at the accelerators, despite the better technical facilities these can often offer.

Various actions have been started to try to make life and work easier and more efficient for the physicists in face of these constraints, including promoting standardisation of data processing systems (2,3), better sharing of resources between laboratories, etc. One such topic is the improvement of all kinds of communications, so that people in different places can work together more efficiently in all phases of preparation and running of experiments. Data communications are becoming an increasingly important element in the physicists' work, as they spend more and more of their time working with computers of all sizes, from arrays of microprocessors collecting data from giant particle detectors to large machines running long Monte Carlo calculations and data analysis programmes, often in several collaborating laboratories. The ECFA survey referred to above showed that physicists spent more than half their time in one form or another of data processing (see Fig.1). Long distance data communications are clearly one way of helping people to work in one place and live in another, and for this reason the main HEP laboratories have been exploring how best to use the forthcoming slow and medium speed data networks which the PTTs have been developing over the past years, and in addition looking into less conventional possibilities such as satellite networks.

Communications needs

High Energy Physics in Europe can be seen as a continent-wide Distributed Data Processing System, whose components include highly developed particle detectors, computer systems, data stores, and hundreds of people. The communications between these components are today very diverse and often primitive when measured against the following aim:

Physicists should have equally good contacts with their colleagues, with their experiment, and with their data and processing systems, whether separated by 100 metres or 1000 kilometres, and at reasonable cost.

To reach this result, communications must be satisfactory for their particular applications in respect of speed, response time, quality, availability, and cost. There are three general classes of communication, each with its own set of technical requirements:

- To and from people, i.e. essentially the needs of human senses.
- Between people and computers
- Between computers.

For each class there are "natural" speeds etc. which allow the participants to work most easily and effectively, and communication links should be designed accordingly, unless there are serious technical or economic reasons for accepting an inferior quality of service.

The "natural" link requirements for these three classes can be summarized as follows:

	Speed	Delay	Quality
-To/from people:			
Conversation	30-50Kb/s	<0.3s	low
Vision (TV)	2-50Mb/s	<0.05s	low
-People and computers:			
Terminals	5-50Kb/s	<1s	medium
Facsimile	10-100Kb/s	secs	medium
Fast graphics	Mb/s	<<1s	high
-Computer to computer:			
File transfer	0.1-1Mb/s	secs	v.high
Channels	10Mb/s	nil	v.high
Bulk data	Mb/s	mins/hrs	v.high

Communication links meeting these requirements will not, in general, interfere with the smoothness of the interactions going on between the parties.

Three general conclusions can be drawn from this summary: firstly, apart from some types of terminal traffic, the minimum natural speed is around 50Kb/s, i.e. the speed of a telephone quality voice channel; secondly, computers and peripherals like disks, tapes, graphics stations all require Megabit per second links to work properly; thirdly, achievement of very low error rates becomes important as speeds increase.

Practical Applications for high speed transmission

(50Kb/s and above)

The short transmission times which high speed links permit can benefit high energy research in several ways: they will allow people at a distance to receive information on the running of experiments or on the analysis of data in time to participate in real-time decision making; the distribution of computing power and data bases can be radically decentralised or concentrated differently; types of communication between people like facsimile or TV can be used which were previously impossible. Figure 2 shows the various information flows in an experiment and the feedback loops in which long delays can slow up operations or exclude outside people from participation. Common operations where high speeds are needed for efficiency are:

- File transfers between central and experiment computers, and to 'smart' user terminals and 'personal' computers.
- High priority transfer of data recorded on tape, for control of running experiments
- Maintenance of frequently used distant data bases
- High quality graphics, eg. for interactive analysis of complex events
- Remote use of engineering design and diagnostic systems
- High speed report printing
- Voice and facsimile services
- TV monitoring of inaccessible equipment

Figure 3 shows by a few practical examples what speeds are needed in terms of the amounts of data to be sent and the desirable response or transmission times. They confirm the general conclusion given earlier that, for most applications in the future, 50Kb/s is a reasonable minimum speed to take advantage of the newer computing technologies, and for some 1Mb/s and above is appropriate.

The analysis so far has concentrated on peak speeds and delays: in almost all practical cases the mean speeds, averaged over hours or days, will be less, possibly much less, and means must be found to share link capacity among many users to avoid waste of capacity and excessive cost.

Transmission Methods

----- Local connections -----

Direct connections between components of a computing system over tens or hundreds of metres at any desired speed have been commonplace for many years. Recently high speed local networks interconnecting many machines and peripherals, possibly of different make, have been designed and are becoming available commercially. Two examples are the Xerox Ethernet and the Cambridge Ring. Both work with line speeds of 10Mb/s, and can carry a total real data flow of several Mb/s if the attached devices are able to handle these rates. They can operate over distances of up to a kilometre or so, and have intrinsically extremely low error rates. Another example is the SNC

Hyperchannel, which is designed primarily for very high speed connections inside large computer centres, the bus running at 40Mb/s. More conventional local packet switched networks are also in use in HEP laboratories, for example CERNET, which has a line speed of 2.5 Mb/s. These local nets can thus meet the technical needs of "natural" communications inside one laboratory, and at a reasonable cost. The main problem in their use is that of the lack of standard interfaces, both hardware and software, used by all manufacturers. Such standards are beginning to emerge, but mainly at speeds of 50Kb/s and below. In attaching new equipment to the net, the users of fast links will be in the hands of the network supplier, or on their own, for some years to come.

Long distance links

Until recently, fast long distance links in Europe have been limited in practice to fairly costly and not very error free 50Kb/s leased point to point circuits. Higher speeds have been possible, but very expensive unless heavily used for important traffic over short distances. In the last few years, packet and circuit switched networks such as Transpac in France, Datex in Germany, and Euronet have become operational, and some can offer 48Kb/s "call-up" connections, but are mainly aimed at 9.6Kb/s and below (4). In the long term the general introduction of PCM transmission, optical fibres, and electronic switching will technically allow 64Kb/s PCM telephone circuits to be used for data at 48Kb/s with low error rates; higher speeds, e.g. the standard 2Mb/s first level multiplex channel, may also become available as leased lines. For the coming 10-20 years however, it appears, particularly from American planning, that satellite links will be much more flexible and economical for a high speed network, provided the satellite is accessed from a small earth station directly on or very close to the user's premises. The most advanced US system, due to start operating early in 1981, is Satellite Business Systems, SBS, mounted technically by IBM and Comsat. Each SBS station can handle mixed traffic up to a total speed of 6Mb/s, so even low quality TV for teleconferencing will be possible over its links.

STELLA

In 1975 the Commission of the European Communities (EEC), the European Space Agency (ESA), and CERN made a proposal for a simple experiment to test out ideas, then very new in Europe, for Megabit/s satellite links between large computer users, in this case the big HEP laboratories. After several years of struggle on political problems, of which more later, the experiment was finally set up and is now in an active testing phase (5). The number of participants has grown steadily and is now nine, with two more under consideration. The nine are ESA, EEC (DG3), CERN, DESY(Hamburg), Rutherford(UK), INFN/CNUCE Pisa, Saclay/IRIA, U.C.Dublin, T.U.Graz. ESA has been responsible for the geostationary OTS satellite, the specification of the system as a whole and of the earth stations, the EEC for the political approval of STELLA and for some funding, Dublin and Graz are communication laboratories, and the others are High Energy laboratories collaborating closely with CERN.

The aims of STELLA, which is the acronym of Satellite Transmission Experiment Linking Laboratories, are of two kinds: firstly to check the technical performance of a system for data transmission using small earth stations in the newly opened 11/14 Ghz frequency band, and secondly to use the system for real life tests of user reactions as guidance for designers of future public systems, and to see what advantages they might have in collaborative research like High Energy Physics.

The block diagram of the STELLA system is shown in Figure 4, in the particular case of the CERN and Rutherford installations. Figure 5 shows in more detail the components of the CERN equipment. The system in essentials uses a normal mimicomputer, the Link Driving Computer (LDC), to read and write magnetic tapes, connected to the earth station via a specially built Communications Interface Module (CIM). The LDC and CIM together control the transmission and reception of data, which is blocked in 4Kbyte HDLC frames containing the standard Cyclic Redundancy Check bytes to allow detection of errors in the block concerned. Since the typical bit error rate on the satellite link itself is one in a million or worse, which is inadequate for a high speed data service, the data stream from the LDC/CIM is encoded before transmission to add 100% extra bits, doubling the bit rate to 2Mb/s. On reception, this redundancy permits a very efficient correction of almost all errors due to noise in the receivers in the satellite and in the earth station. The improvement in error rate can be by a factor of up to ten thousand. Any remaining errors will be picked up by the CIM noting a failure of the CRC at the end of the block, and the LDC will then retransmit the data from the failed block onwards. It is expected that under good conditions a full tape can be sent with few corrections, and that in any case the retransmissions, which can each take about a second because of the 1/4 sec. satellite delay, will not have a noticeable effect on overall throughput.

The earth station (see Fig 5.) consists of a 140 watt 14Ghz transmitter and a low noise FET receiver for the 11Ghz signals coming back from the satellite, together with the modem and codec which convert 1Mb/s data into encoded 2Mb/s phase-modulated RF at the Intermediate Frequency of 70Mhz, and inversely on reception. The antenna, which is a simple fixed mounted paraboloid of 3 metres diameter, is connected to the transmitter/receiver rack by a short length of waveguide and is mounted on the roof of the building. The connection to the LDC is by simple coaxial cables up to 100m. long.

Figure 4 shows how a pair of earth stations could be used to improve communications between a physics group running an experiment at CERN and their colleagues in the UK who use the Rutherford computer centre. Data can be sent to the LDC from the experiment either by hand carrying a tape, or, in smaller quantities, via the CERNET connection. This data can be sent in a few minutes at an average speed of 0.5Mb/s to Rutherford (if OTS time has been allocated!). It can then be analysed there by physicists in the UK or in CERN via the existing Remote Job Entry stations, and the results made available much more quickly than if the data had to be sent physically on a tape.

Recent experience and future plans

In USA: the arrival of public systems

An early example of the type of system described above was brought into use at end-1974 by American Satellite Corp., to connect five US Air Force bases at channel speeds of 1.344Mb/s using standard Westar satellites with 10m. diameter antennae at the users' facilities. In 1976 IBM, Comsat and Aetna announced Satellite Business Systems (SBS), a public system aimed at large organisations who could wish to have immediate communications of all types between a group of sites in the USA. The system will have its own two satellites using the 12/14 Ghz bands, with earth stations with 5-7 m. diameter antennae, and channel speeds up to 6.3Mb/s in a TDMA system to allow a number of stations to share each 40Mb/s repeater. The earth stations are to be placed at the user's premises to avoid any use of public ground lines. The services foreseen by SBS include the organisation's total internal telephone/telex traffic, 2 second per page facsimile, freeze-frame and full motion TV and other teleconferencing facilities, rapid data-base access and other computer/computer links, all multiplexed together. The first satellite is due to be launched at end-1980, and several large firms have already signed up for the service, which should start early in 1981. The initial capacity of the system is 300-400 stations, but a second generation of more powerful satellites is planned for 1986. SBS conducted a series of user evaluation demonstrations, Project Prelude, in 1977/78, which showed the interest of potential user organisations for such a system (6).

Several other communication firms have also proposed similar, though generally less ambitious services which should come into operation in the next few years. Xerox is offering Xten, with similar earth stations located in large cities and connected to nearby users by microwave links, thus sharing the costs between several users not needing more than 1/4Mb/s capacity each. SBS has recently also announced a demonstration of a similar system for early 1981. American Satellite Corp. is preparing SDX, with 5m. antennae working in the present 4-6Ghz band, and speeds up to 112Kb/s, and a smaller version, DDX, for up to 40Kb/s. At least two other companies, GTE and SPCC, are also asking for FCC authorisation for their own data satellites, with more advanced specifications than for SBS.

The total capacity of the satellites in the above proposals is almost 20 Gbits/s: this could be compared with the 1980 total for all kinds of long distance communications of 10Gbit/s in the USA. Even allowing for optimism and reserve capacity in the satellite figure, it is clear that the US industry sees a very bright future for these services.

In Europe: plans and possible costs

Until 1978 the European PTTs' collective position on small earth stations, and even on the need for the kind of services described above, was very lukewarm, to say the least. One common statement was that "Proliferation" of earth stations was to be avoided at all costs, putting them about on a par with nuclear weapons. It

took nearly four years before STELLA became accepted as an authorized user of OTS, despite support from various governmental and international bodies who could see wider interests than those related only to the more conventional communication monopolies. In 1978, however, the French and British PTTs came out with proposals for SBS-like systems: the French proposal was part of the reasons for the TELECOM 1 national satellite, and the British suggested how to graft such a system onto the coming European communication satellite system ECS. In both cases the earth stations would look quite like those for STELLA, with 3m. diameter antennae, except for being engineered to public service standards.

The CEPT is now studying a possible phased plan for introducing specialized data services using satellite links with small earth stations which might result in a start-up on a small scale in 1983/85 parasiting on the ECS satellites, to be followed by an expansion in 1985/90 if the demand warranted it. Even if the CEPT plans are approved, which is not certain for political reasons, the total satellite capacity in 1985 will be less than 1Gb/s compared with the USA figure of 20Gb/s noted above.

A crucial point will, of course, be the tariffs: it is notorious that communication costs in Europe are often several times those in the USA, and often bear little relation to the actual costs, because of the monopoly situation of the European PTTs compared with the competitive situation in the USA. An example of the comparative costs of conventional long distance circuits is shown in Figure 6, taken from a presentation by IBM to the CEPT in 1978. The PTTs tend to try to charge for any new service the same rates as for a comparable old version, even if a much cheaper new technology is to be used. This is to some extent understandable since the PTTs cannot afford to let a new technology take away revenue from existing equipment which has not been fully amortised; the same financial constraints must, however, also apply to the large carriers in the USA, and they do not seem to inhibit progress to the same degree there. The PTTs have not yet taken decisions on rates for satellite services, and it is to be hoped that, because they are potentially so different from normal leased lines or slow speed networks, the tariffs will be fixed independently, so as to encourage new applications. One set of USA rates has been published, for the first SBS customers: the rates are distance independent and have three components: rental of an earth station, satellite usage charge, and a connection charge. The figures given by SBS in their rate announcement for large customers having a station on their own site are:

Station rental	12,500\$/month
224Kb/s channel	2,100\$/month
Connection charge	up to 3,300\$/month

Thus a large user wanting 1Mb/s capacity for high speed bulk data transfers and many other services might have to pay up to 25,000\$ per month, which is not a major item in the budget of a large computer user. For comparison, the cost of a 9.6Kb/s leased line between Switzerland and the UK or other Northern European country is about 5,000\$/month. The cost per bit of the SBS service, which is the Rolls-Royce of the USA systems, is twenty times less than that of a European leased line.

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FIG. 1 DISTRIBUTION OF PHYSICISTS' WORK (ECFA/79/47)

FIG.2 CONTROL AND INFORMATION FLOWS IN A RUNNING PHYSICS EXPERIMENT

A = 1 PAGE OF TEXT
 B = 100 KBYTE PROGRAM FILE OR DETAILED GRAPHICS PICTURE
 C = SMALL DATA SAMPLE: 1000 EVENTS OF 10KBYTES
 D = 2 6250 BPI TAPES

FIG.3 SPEED AND RESPONSE TIME NEEDED IN DIFFERENT APPLICATIONS

FIG. 4 CERN-RUTHERFORD STELLA LINK SYSTEM

FIG. 5 CERN STATION BLOCK DIAGRAM

FIG. 6 COMPARISON OF TRANSMISSION COSTS

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