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ABSTRACT: Within the Department of Computer Science at University College London (UCL), the INDRA research group has been investigating different aspects of computer networks over the last ten years. During this period increasing attention has been given to the area of network interconnection. As a result of this research, UCL now offers a network interconnection facility for use by scientists and researchers in the UK and the US. This paper describes the inter-network facilities we provide and shows how they developed out of the research. It outlines how it has been able to evolve with the change of protocols on the different sides of the Atlantic, and should move towards the incorporation of the emerging international Standards.

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## 1. BACKGROUND

The Communications research group at University College London has been involved in communications research since the early 1970s; as part of that research, it has had links to many computer networks. The first links were to the US Department of Defence's ARPANET network and to the UK Science and Engineering Research Council's Rutherford and Appleton Laboratory facilities. Since 1975 the group has extended the ARPANET link from a single network into a wider set of concatenated networks (the CATENET). At the same time, networks in the UK have expanded from a few interconnected computers to the public "Packet Switch Stream" (PSS) run by British Telecom which has many international links (IPSS), and a separate universities network (JANET); both of these use the X.25 protocol for access.

It was clear when the initial connection to ARPANET was proposed that other groups in the UK would wish to use the connection. These groups were mainly concerned to use the link to improve the communications between themselves and researchers working in the same field in the US. Therefore we have always allowed our facilities to be shared by other users wishing to access UK facilities from the US and vice-versa. These groups, on both sides of the Atlantic, have provided continuous feedback and further requirements on the experimental services we have provided. We have certainly learnt many valuable things from the effort to provide communications systems to a service standard rather than for one-off experiments.

Initially we provided only a terminal access service, but we have found that bulk transfers are essential between cooperating groups using their local computers. Some of the most serious users have been exchange visitors, who have used our facilities to continue work previously done locally. As networks have developed in the UK, users have wished to have more reliable or higher speed access by using the networks rather than the Public Switched Telephone Network (PSTN), or in some cases just more convenient or cheaper access. This applies to interactive use, but more importantly to bulk transfers where transferring files to users' own machines is vital. The development of mail systems in the UK has extended these requirements and mail forwarding forms a major component of current traffic.

## 2. THE INTERCONNECTION ARCHITECTURE

The Department has external connections to two X.25 networks and the DARPA CATENET, see Fig. 1. In addition we have been participants in the UNIVERSE Satellite project [1] and are starting a higher speed terrestrial successor (ADMIRAL); these involve further sets of networks and protocols within the Department, but are ignored in this paper.

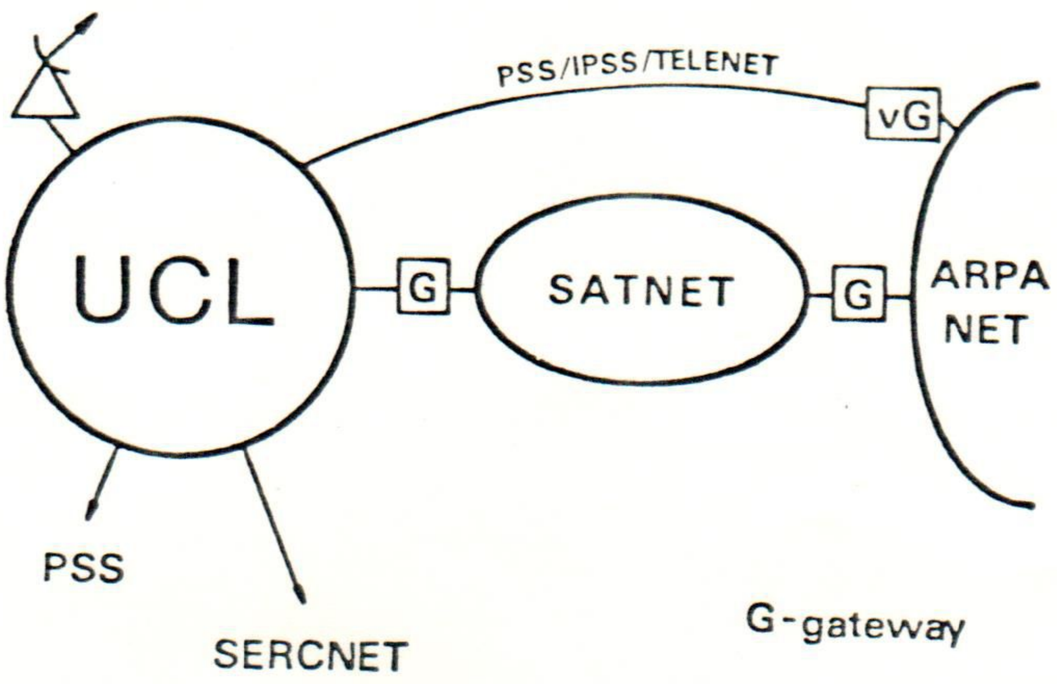



Fig. 1: Schematic of the UK-US International Connection

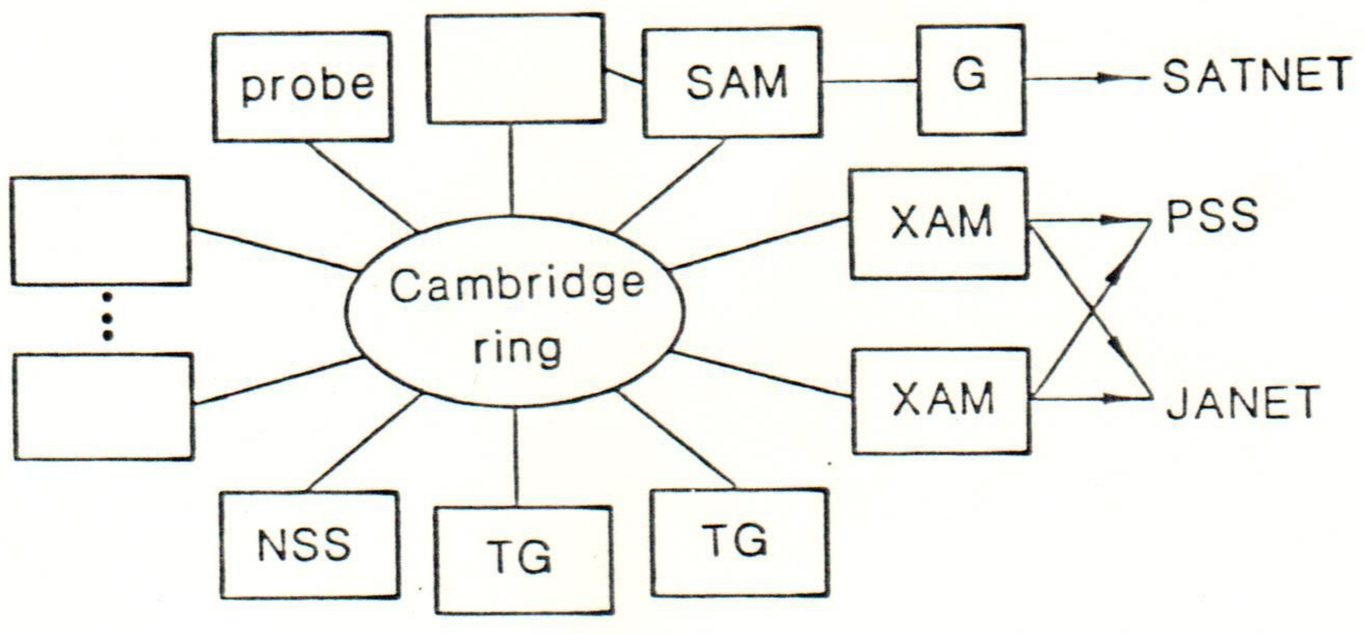
The two X.25 networks are PSS and JANET. PSS is a national public network from British Telecom (BT), which has an X.75 gateway to IPSS; from this last the national networks of other PTTs can be reached. JANET (Joint Academic Network) is a private X.25 network of the Science and Engineering Research Council (SERC) and the Computer Board. JANET links most of the UK universities and scientific research centres. These two networks use compatible X.25 access protocols. PSS uses the X.121 address scheme, JANET has its own numbering scheme. Within the UK we use a set of higher level protocols, agreed amongst the UK academic community and adopted by the Department of Trade for use pending suitable International Standards Organisation (ISO) standards [2].

The DARPA CATENET [3] is a research system, sponsored by the US Defense Advanced Research Projects Agency (DARPA). The CATENET consists of a number of distinct networks using various types of technology and network level protocols. The networks are inter-connected by gateways. Hosts participating in the CATENET use a common set of internet protocols based on datagrams (IP) [4] and a common transport protocol called TCP. Common application protocols are widely used for remote login, file transfer and computer mail. Finally the Public Switched Telephone Network (PSTN) is also available for several purposes. It is used for Terminal access to UCL facilities, which then allows

further access to facilities via the other packet networks mentioned. It is also used directly for relaying messages by a store and forward technique to sites bases not accessible via international packet nets, but reachable by the PSTN; the procedures used (USENET, UUCP) [8], are used on a world-wide basis on UNIX machines.

When we first considered using our hosts on external networks for mail, file transfer and remote login we wished to use the same host on all the external networks. At the same time we considered how we could arrange for a number of hosts to be available on all the networks. We soon realised that placing network connections and real-time protocol software in a multi-access host considerably degrades its performance to all the users. Running a number of different protocols in the same host would not be practical. The problems of multiple connections, multiple hosts and multiple protocols required a new approach.

To solve the multi-network/performance problem we started a research effort to use a local area network (LAN) with **access machines.** Each network connection is controlled by an access computer running the relevant network protocols - X.25 for PSS and JANET, TCP/IP for the CATENET. Each network protocol implementation has a standard interface to higher level protocol implementations, we call this interface "Clean and Simple" [5]. The applications protocols (mail, file transfer, and remote login) are run on the hosts. The access machines and hosts are all connected to a Cambridge Ring LAN. A special protocol, Interprocess Clean and Simple (IPCS), allows applications processes to control network connections in the access machines across the LAN. Figure 2 shows the internal networks, with the hosts and access machines. Communication between the hosts and the access machines uses specific UK Cambridge Ring network protocols. In this way each host is effectively 'on' PSS, JANET, and the CATENET.




XAM = X25 Access Machines
SAM = SATNET Access Machines
TG = Terminal Gateway
NSS = Network Services System (Mail, File, Relay)
G = CATENET Gateway
Probe = Monitoring Machine

Fig. 2: Schematic of the UCL Interconnection System

Our connection to the DARPA CATENET is via a gateway to the Atlantic Packet Satellite Network (SATNET) [6]). Our local area networks are a component of the CATENET. SATNET is the main communication vehicle of a collaborative project between a number of national defence agencies; as a result of this funding British Telecom have insisted that we do not use this network for civil traffic using our services, unless that traffic is sponsored by Defence agencies. To accommodate this restriction we also use one or more X.25 virtual calls to a special gateway in the US to reach the ARPANET [7]. This connection carries the IP/TCP protocol packets that would otherwise use SATNET. We call this connection an IP tunnel, it uses PSS, IPSS and TELENET in the US; Fig. 1 shows this path.

## 3. NAMING, ADDRESSING AND ROUTING

The position of UCL, astride several networks, not only provides wide connectivity for UCL hosts, but also allows UCL to act as a relay agent between differing systems. Both these activities require the communication facilities at UCL to be able to accommodate diverse sets of protocols, addressing structures and routing strategies.

For computer mail, UCL belongs to two separate mail domains: the DARPA CATENET system and the JNT system (Joint Network Team of the Computer Board and SERC) in the UK. Other mail domains which connect into these systems can also be reached from UCL. The largest single one reachable directly is USENET [8], a collection of computers using the UUCP protocols running on the UNIX operating system. The extent of USENET is truly world wide, and is reached via a series of store and forward paths at the Host level. Mail constitutes the widest address space dealt with by UCL. While mail addresses can be viewed as belonging to a single, flat, address space, the use of different message transfer protocols result in the need for mail relays to provide connectivity between them. UCL acts as a mail relay between the DARPA and JNT domains, and is used also as a relay to the USENET one.

At the network level, UCL belongs to at least four addressing domains: PSS, JANET, the DARPA Catenet, and the USENET network. Addresses on PSS conform to the X.121 format, with UCL represented as a 12 digit network address and 2 digits for local call demultiplexing. JANET uses separate network addressing, distinct from X121, without a demultiplexing ability. JANET hosts can, however, use the extended addressing capabilities provided by the Network Independent Transport Service (NITS) [9]. The DARPA Catenet uses a hierarchical 32-bit host address structure, within which UCL has defined its own internal addressing. USENET uses a complex source-routing host address structure; these host addresses are mapped directly at each stage into PSTN telephone numbers or Packet Data Network Host numbers.

The interconnection facilities at UCL aim to shield applications as much as possible from such network diversity. This is achieved in three ways: the use of host names at the user interface rather than actual addresses; the use of a standard transport interface for all destination networks (Clean and Simple); and the separation of network-specific functions into distinct network access machines.

For applications such as mail, file transfer and terminal traffic to be able to use host names rather than direct addresses, a table-based name translator mechanism [10] is used which produces the three components of an address needed locally within UCL: the network to be accessed, the address of the remote host on its network, and the service required. The first determines which network access machine is to be used; the latter two are supplied to the access machine for addressing and/or routing purposes, and possible forwarding.

The network access machine for the DARPA Catenet has two routes available to it: via SATNET and via the IP tunnel. The information necessary for correct routing, namely the user's affiliation, is initially available only at the user or application level. This has to be preserved across any name-to-address translation and must be passed down to the network level. In the absence of any other facility in the DARPA protocols, this information is embedded in the source address [11].

## 4. SERVICES

We offer three primary services to external customers, these are terminal access, file transfer and computer mail. The terminal access service uses its own resources and hosts, though these are all small micro-computers. The file and mail services use general purpose hosts, and run as applications on those hosts. All of the services use the shared network access machines to provide and obtain network connections. We provide accounts for external customers on a dedicated computer called the Network Service System (NSS). These accounts allow customers to stage file transfers and access computer mail where their local facilities are not suitable. The NSS is also used as the collection point for incoming mail.

### 4.1 Terminal Access

The terminal access facilities enable a user at a terminal, or host, to access an interactive host on the other side of the Atlantic. We find UK users logging into ARPANET computers as well as US users logging into JANET and PSS connected computers. The users host, or terminal connection, would be using quite different protocols to those used by the remote host, at all levels.

The terminal protocol translation is carried out on a dedicated machine called the Terminal Gateway (TG, currently a LSI11/23 with no backing store) attached to a Cambridge ring (see Fig. 2). Each connected network is represented by a separate process, whose task is to interface with the network using IPCS on one hand and translate the appropriate protocol on the other. The TG allows access, via the Cambridge Ring, from local terminal multiplexors.

In order to avoid the "N-Squared" problem of translating between N different protocols, it was decided to define a canonical internal protocol into which all the terminal protocols are converted on input and output. We have to deal with five terminal protocols; X.29 over PSS and JANET, ITP which is a protocol defined specifically for use on JANET, TELNET which is used on the DARPA Catenet, a null protocol for interaction with local terminals, and

another protocol internal to UCL for accessing local hosts over the Cambridge Ring. Due to the large differences between the protocols, it is not easy to convert protocol messages from one terminal protocol to another. Hence a simple subset of messages was defined, in particular ECHO/NO-ECHO is available which is necessary for providing host password privacy.

As one of the access paths to the US is over IPSS it is necessary to provide as economical a service as possible. Thus the preferred mode of operation of the TG is forwarding of data a line at a time with local echo.

Access control is necessary on this system, therefore it is required for users to "Login" to the TG before making a connection to a host computer. Login verification is done using the normal password file of a service host at UCL. A backup password file is kept on the TG in memory. Call accounting information is sent to the service host and stored in a database in order to produce accounting information.

## 4.2 File Transfer

We provide a facility at UCL whereby users may transfer files between local UCL hosts, UK hosts and hosts on the ARPANET. The file transfer protocol largely used within the UK community is the Network Independent File Transfer Protocol (NIFTP), whilst the DARPA community has a completely different file transfer protocol (FTP). Neither of these protocols provides for the user to specify addresses containing routes, in the way that the mail protocols do. To use these protocols directly for transfers between the UK and the ARPANET a user must stage the file transfer at a host which implements both the protocols. We encourage customers to use the mail facilities to transfer files to take advantage of the automatic relaying. However, mail systems do not always offer all the facilities needed for file transfers (e.g. binary transfers) hence we provide facilities for users to access the file transfer protocols directly.

The NIFTP system at UCL [12] is a spooled system in contrast to the majority of ARPANET FTP interfaces which do the transfer in real time. The spooling system allows us greater flexibility to use resources which are scarce, for example to do transfers when the IPSS Tunnel is open for terminal traffic etc. We have arranged that our NIFTP and FTP interfaces are unified to provide both spooled and real-time facilities.

Access control is provided by using the standard facilities of the UCL host. The NIFTP protocol includes parameters for user identification, for an incoming request these are checked before the transfer is accepted. For outgoing requests the user's permissions to use a particular network can be checked. In the case of the ARPANET, this mechanism is used to determine if the transfer is to occur over SATNET or IPSS.

## 4.3 Computer Mail

UCL provides two major types of mail service. The basic service enables local users to send messages, and to manipulate received messages. A selection of interfaces are provided, so that users may choose a system appropriate to their needs. The second service is to provide a connection to

remote message systems, which takes both the form of remote services for local users, and increasingly of relayed services. The major relaying service is between the UK Networks, and the DARPA CATENET, as discussed in sections 2 and 3. Another function performed by UCL is the handling of network mailing lists [13].

Within the Department we operate a number of Message Transfer Protocols, two of which are particularly important for the services provided. The first is the JNT Mail Protocol, which is based on a UCL proposal, and is now used extensively in the UK Academic Community, with NIFTP (see Section 4.2) used to perform the data transfer [14]. The second is SMTP (Simple Mail Transfer Protocol) used within the DARPA CATENET. A less important third one is the UUCP philosopy used in USENET. UUCP is much more than a simple protocol. It presupposes that it is possible to route messages over a concatenation of Packet Data Network and PSTN paths, by store and forward techniques. Many hosts throughout the world have adopted the UUCP protocols, and their collection is called USENET. While USENET does not provide the same level of reliability or error notification as JNT or ARPA mail, it does provide additional connectivity on a world-wide basis to Hosts using the UNIX operating system. We both run the UUCP PSTN protocols ourselves, and use other systems to relay our mail via their systems. Message level relay allows protocol conversion for the services offered to be performed in a straightforward manner. Besides the functionality of the system within one machine, it is also important to be able to utilise the flexibility of the interconnection architecture. An additional problem faced by UCL is in the differences between the UK and DARPA CATENET address specification. Some solutions are discussed in [15].

Message Level relaying also introduces another set of addressing problems on top of those discussed in Section 3. In essence, the syntax of the present mail protocols allows the specification of a user mailbox to be translated into a source route consisting of a number of mail relay hosts. The translation algorithms of Section 3 will be applied to the first host of the source route to identify a message level relay. In some cases, it is desirable for the Message Handling System to map a domain specification into a source route when there is no direct connectivity with the domain specified. This will hide complex connectivity from the user, and allow simple specification of mailboxes on remote networks.

The local mail system at UCL is not described here, suffice to state that it provides the needed functionality for a message relay. All the host machines at UCL run identical systems and derive connectivity information from a common set of tables. This consists of many thousands of lines of user and host mappings, and so for efficiency reasons, this information is loaded into a database on each machine which is accessed by the mailsystem. Some tables are updated manually, and others (such as the DARPA host tables) are automatically extracted from remote network databases. To allow machine dependencies, and connectivity to the various front end machines to be adjusted independently, a dynamic tailoring schema is used to allow variable mappings. This set up allows the various mail protocols to be used over different transport protocols in a simple manner. The JNT Mail Protocol implementation is also structured to allow protocol layering at the file transfer level, to allow dynamic configuration with alternative mail and file transfer protocols.

## 4.4 Protocol Structures Supported

The gammut of external protocols used is of clear significance. Figure 2 has already shown direct gateways to PSS, JANET, SATNET and the PSTN. The actual protocols used internally have been designed to suit our own purposes - they are not relevant externally, and change as we extend our internal technology. However, the protocols supported externally are relevant to others. It is convenient to divide these at the transport level. At first sight, the network access level (Interface to level 3 of the ISO structure) would seem the right point. Unfortunately at the network level some of our networks (the PSTN and the DARPA CATENET) use the connectionless service, whilst JANET and PSS provide the connection-orientated service. However at the transport level, all the networks use a connection-oriented service, hence we have chosen this as one of the protocol conversion levels [16]. A summary of the external protocols we use currently up to the transport level is shown in Fig. 3. Here the protocols used have been mentioned specifically earlier in this section. The common interface to the transport level is provided almost always by the Clean and Simple interfaces mentioned in Section 4.1.

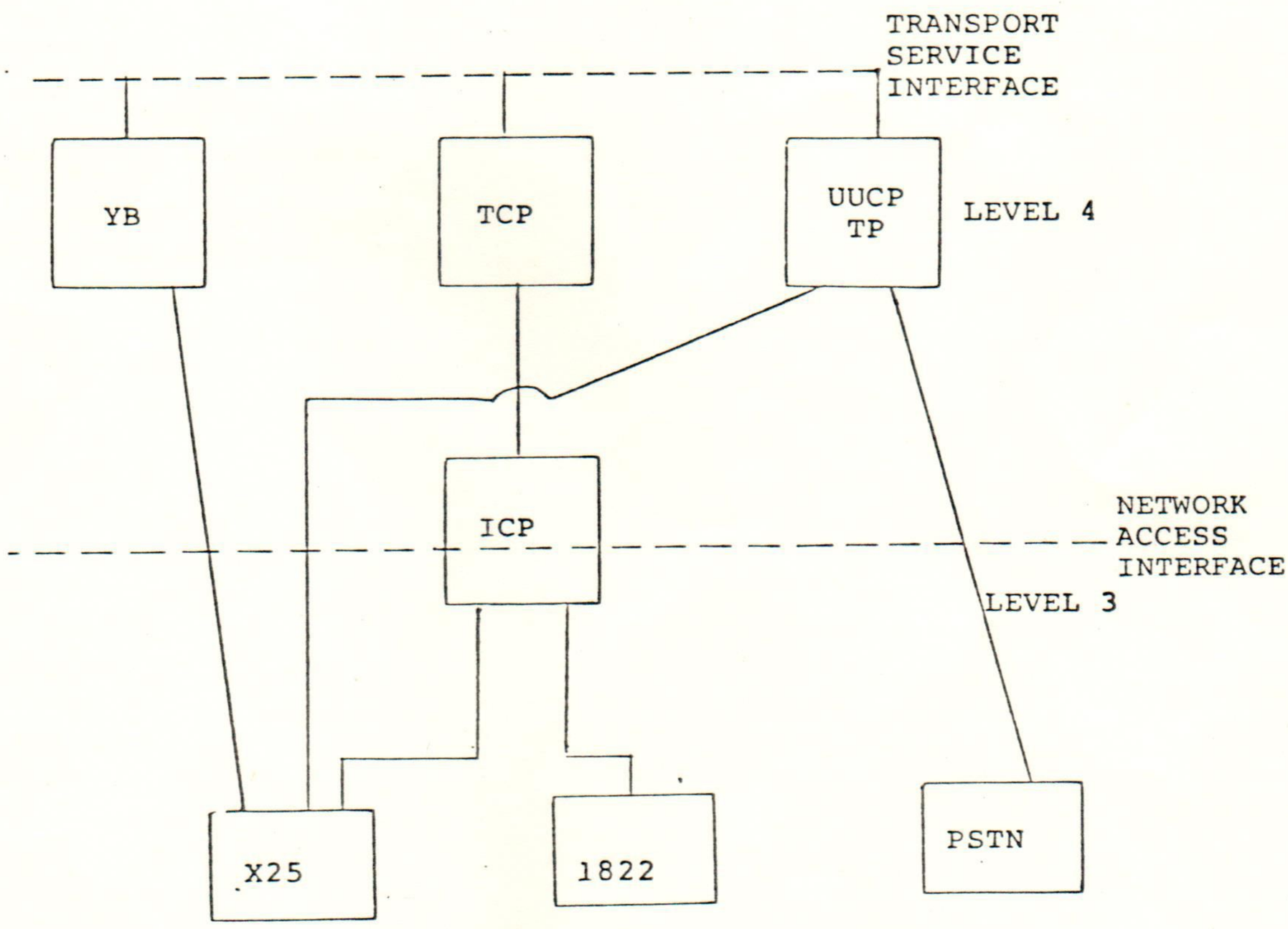



Fig. 3: The Protocols Used at the Transport Levels and below

For the high level functions, the specific protocols have also been mentioned already in the text. A schematic of their interconnection is shown in Fig. 4 for terminal facilities, and in Fig. 5 for file transfer and electronic mail.

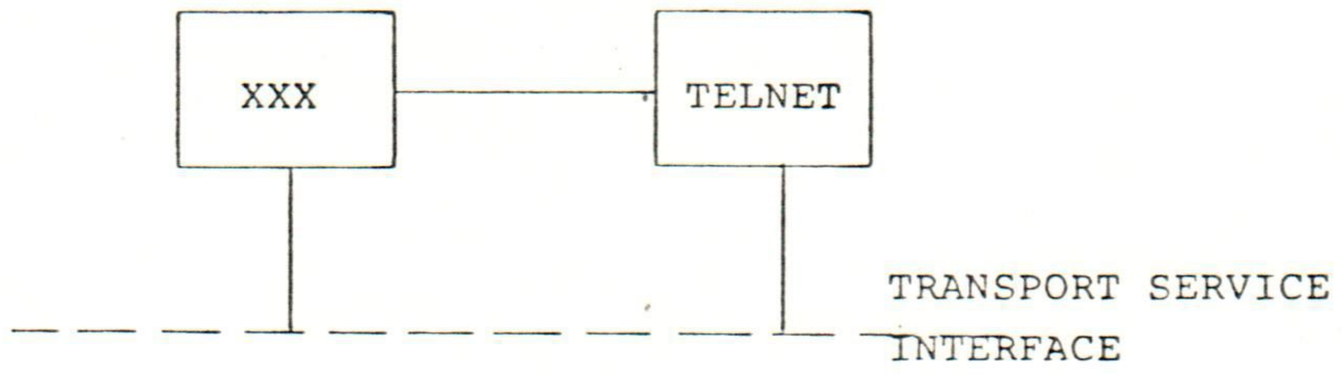



Fig. 4: Protocol Translation for Terminal Traffic

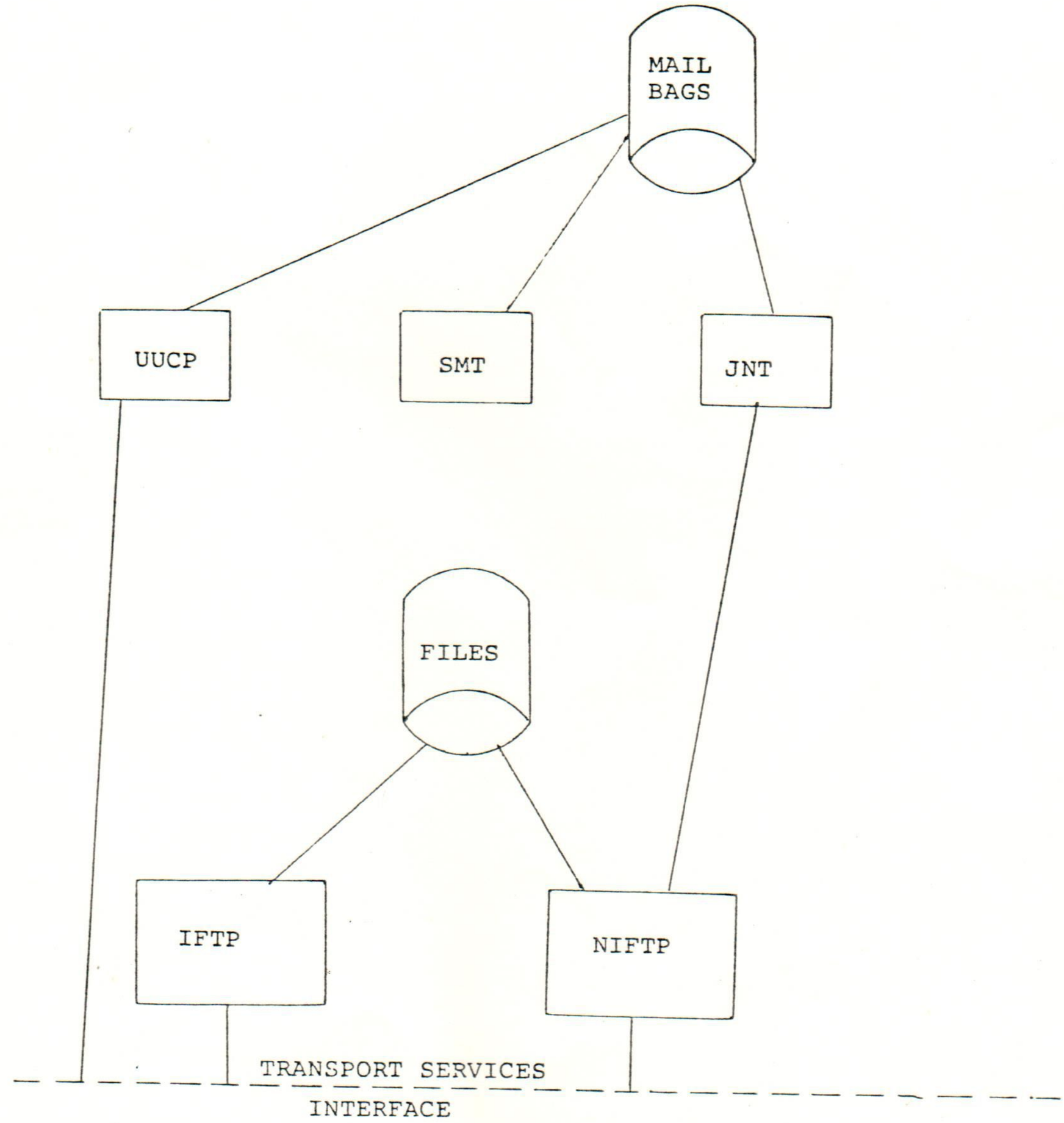



Fig. 5: The Protocols Used for Bulk Traffic

## 5. MANAGEMENT FACILITIES

The interconnection facility has considerable management problems, there are four areas in which we have provided support for managing the service:

(1) Daily operation - detecting failures and reconfiguring the resources.
(2) Access control and accounting.
(3) Flexibility for growth and parallel development.
(4) Performance measurement.

The interconnection service is run without operators. All of the network access machines and the Terminal Gateways are automatically rebooted when they crash. All the connected networks, and consequently the network access machines, are monitored so all crashes are detected and logged.

Access control is applied in both the Terminal Gateway and NSS by traditional password mechanisms. Access control is also applied to mail relayed through UCL by checking the sending and receiving addresses. Apart from limiting access to authorised users, we need to know who is using the facilities and how much resource they are consuming so that we can enforce charging. Data collection is extensive, but policy implementation is kept simple and in many cases manual, so that managerial decisions can be quickly effected but not triggered automatically.

The service has grown and developed over a number of systems. Use of the LAN and network access machine architecture has allowed test systems to run in parallel with production systems, and the easy reconfiguration of resources by adjusting tables. We now have two X.25 access machines, two Terminal Gateways and one TCP access machine. We can quickly reconfigure these to almost any combination required if any other component fails. There is room for further expansion of machines as the load increases or to introduce new services.

As part of our requirement to understand and improve the functions of the system, some facilities have been built in to measure throughput and delay at different levels. For example we regularly echo packets from distant gateways. Of course this is used to detect malfunctions; also, however, the time for the echo to return gives a measure of load and bottlenecks. This can be used, for example, to open additional X25 circuits over the packet switched networks or to arrange the increase of the speed of access lines. Where remote hosts implement high level echos, or provide time stamps, these can be used to monitor high level performance. Examples are relaying messages by different routes (eg. UUCP, SATNET or or PSS). From the time of the messages, we can determine whether the multiple relay host via UUCP result in unacceptable performance, or whether certain of the complex relay facilities are more expeditious. From the difference in delays in message arrival via SATNET and IPSS, we can determine if the underlying networks are overloaded. This overload may be the load on transmission or gateways; it may also be an excessive request for use of the transmission paths, leading to longer queue times in the UCL (or remote) spooling mailers.

## 6. LIAISON

To enable customers to make full use of the inter-connection facilities described above we also provide an Internet Liaison service.

The liaison provision is the difference between a 'service' to others and the mere provision of access to our facilities; personal contact is very important. Other members of the research group provide technical help but all contact with external customers is channelled through a single liaison person. Liaison can be contacted by an advertised telephone number, letter, or computer mail to a special mailbox. The tasks performed by liaison include:

- provision of technical information on using the facilities,
- dealing with specific questions or difficulties,
- ensuring adequate notification of forthcoming changes or breaks in service,
- helping potential customers apply for formal permission to use the service and provision of early support,
- writing and distribution of a monthly newsletter,
- ensuring all users have up to date applications and removing old users from the system.

On average some 10 queries are dealt with each working day from a user population of approximately 150 people, on both sides of the Atlantic.

Our system is continuously expanding, additional services are being offered, and poorer ones occasionally being replaced. While the USER notices help keep users informed of the changes and addresses, the documentation can easily become unwieldy. We try to hold as much HELP information on-line, to deal with this problem; it is very difficult to keep our written documentation for users up to date, and distributed in a streamlined form.

## 7. FUTURE EXTENSIONS AND INTERNATIONAL STANDARDS

It must by now be obvious that only in the use of Packet and Public Switched Telephone Networks, and one terminal protocol, are we compatible with the emerging international standards. To a large extent this is inevitable, because of our interconnection role; we cannot progress more rapidly than our interconnection partners. However we are committed to move towards international standards to the extent this is feasible and economic.

The British JANET is currently considering an "INTERCEPT" Strategy to move away from its "Coloured Books" service of protocols to the international standard ones. The progress will be slow. Many of the older computers will never be equipped with the newer standards, and one will have to wait until those systems are replaced. Even when incorporation of new standards is feasible, it will be expensive and take a long time to occur - after the standards are really accepted. For this reason, we expect that the major motivatation for us to adopt the new standards, other than research interest, is the desire to increase our connections with new communities. This was our real reason to add UUCP to our repertoire; it is no international standard, but a very prevalent pragmatic one.

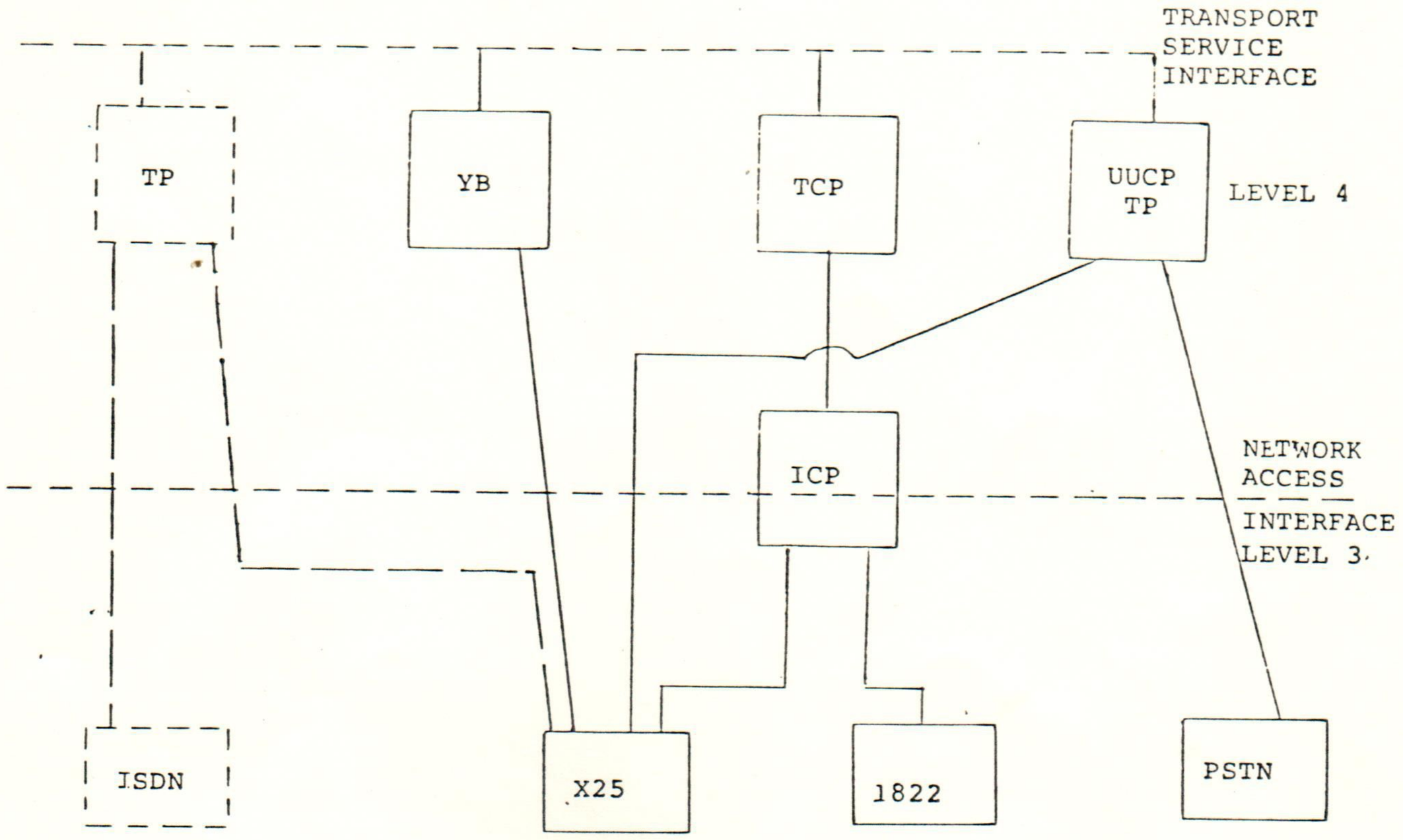
We are moving towards the international standards services in several directions. We already are implementing the X400 Message protocol [17]. One reason is to allow access from Teletex terminals; a second is to allow X400 interconnected with Canadian Academics [18], the ESPRIT community [19] and other European partners. Technically we could expect to provide an X400 relay service also within a year or so; we do not yet know whether we will provide a real service. We already have provided a Teletex service interface in a dedicated server on our LAN [20]. We have not provided a service here because we are more interested in Computer Based Message Services (CBMS) than a terminal-terminal Teletex Service; however we are interested in the X430 provision of access to our CBMS from Teletex terminals. We are also exploring whether the widely accepted KERMIT procedures [21] are a suitable service interface to our system.

A good guide to the emerging ISO standards is given in [22]. We are interested in the ISO Transport (TP) for several reasons. Of course it is fundamental to X400 and Teletex. It will be required for the international File Transfer Access (FTAM) when it is defined. The British JANET plans for FTAM are still undefined, so that aspect of Fig. 8 is shown with a question mark. Finally we have a research interest in the interoperatability between TP and TCP.

The move towards different universal terminal protocols we find interesting, and a subject for research. Its relevance to relay service is not clear to us at present. Not only are the relevance of those terminal protocols still under, but also whether they will be taken up by JANET or ARPANET has not even been raised.

We will certainly attach some of the newer network services experimentally. We already have ordered two lines to the UK Integrated Data Access (the Experimental ISDN) [23]. This will allow us to understand how its features can be integrated into our system; whether it will be part of any UCL interconnection service is premature to say. Finally, as part of a pure research programme [2], we will be attached to British Telecom 2 Mbps Megastream facilities. Again its relevance to the subject of this paper is unclear.

Thus the service extensions we will be exploring over the next couple of years are illustrated in Figs 6 - 8. We would hope that some of the existing ones can be stopped when new ones are introduced - otherwise the software maintenance would become excessive.




——— Implemented

—— —— Planned

Fig. 6: The Protocols used at the Transport Level and Below

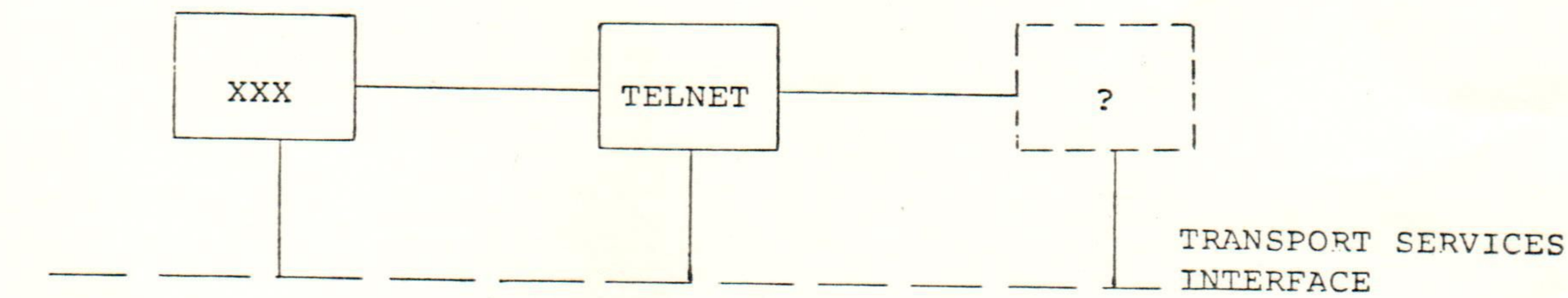



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Fig. 7: Proposed Protocol Translation for Terminal Traffic

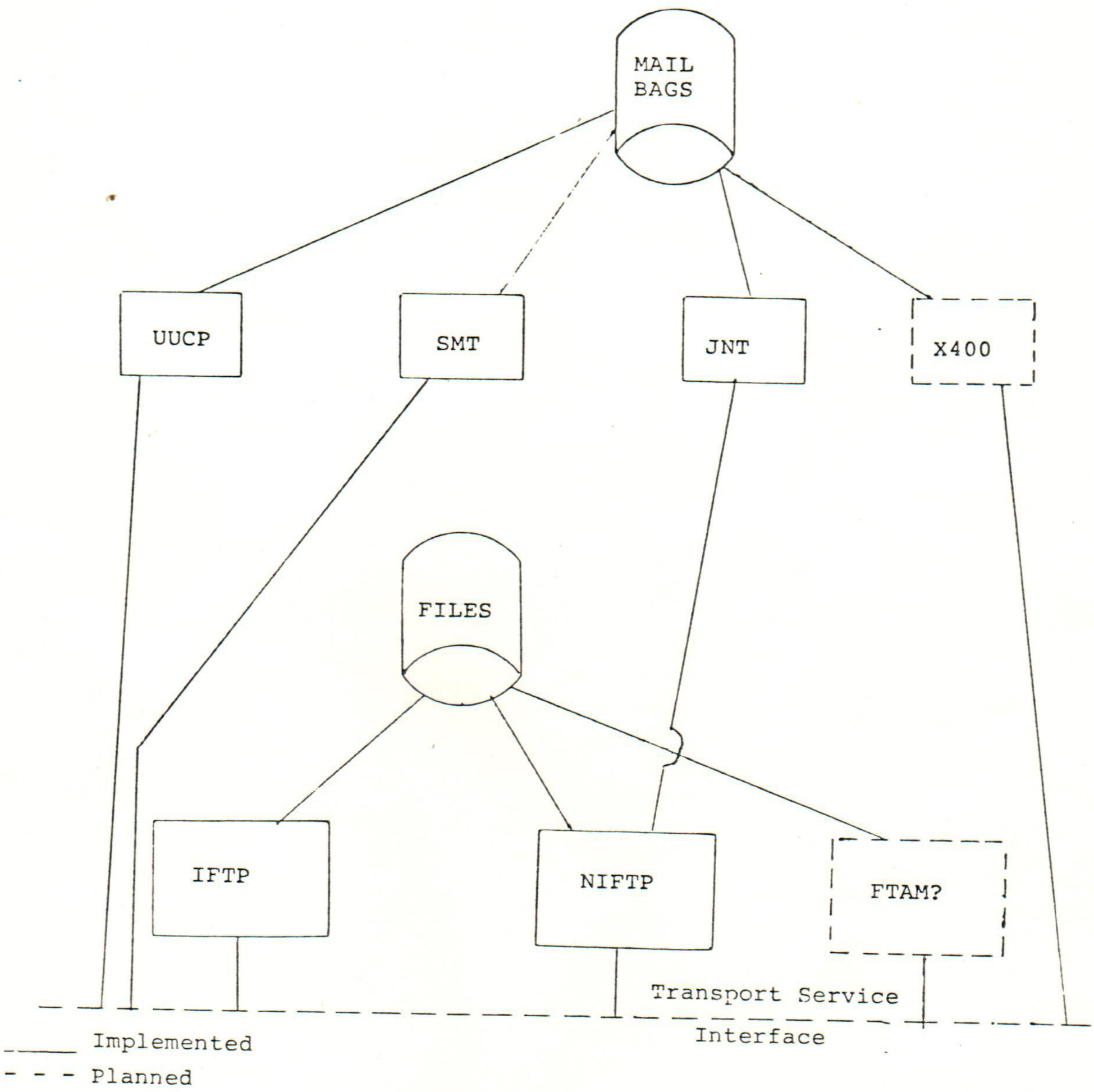


Fig. 8: Proposed Protocols for Bulk Traffic

## 8. FUTURE EXTENSIONS AND MANAGEMENT

Concurrently with protocol implementation, we intend an ongoing and high priority activity in Network Management and Control. As the new services are introduced, the need for monitoring, reconfiguration and performance measurement becomes ever more essential. As the interconnection alternatives increase, and the changes become better understood, automated methods of cost reduction will assume an increasing role. Regulatory issues must be considered, of course; in this context, the international aspect of our activity is of particular relevance [24].

Probably paramount in this management area is, however, that of Directory Services. Many of these will be distributed - for example the location, addresses and routes to specific services or individual. Some will be local - for example the authorisation, authentication, billing and facilities of the Users of our relays. Data Base Management facilities will be essential; we do not yet know to what extent the service requires different Data Base Management Systems. In some areas CCITT and IFIP are taking the initiative already; where we can we will participate in, and follow, their recommendations. Where they are not being treated yet in standard ways, we will make our own developments.

We are greatly helped in these newer areas by two initiatives - the UK Alvey programme [25] and the ESPRIT one [19]. We participate in both these programmes with industrial partners, who are initially interested in incorporating International standards and recommendations. We would wish to follow them in any case; our industrial partners would force us to even, if we wished something different.

## 9. SUMMARY

The Department of Computer Science is now offering a network interconnection service between the US and the UK for scientific users. The primary users of this service are research groups cooperating with co-workers on either side of the Atlantic. Most of the US groups use hosts on the ARPANET.

This service has grown from the very early provision of dial-in access on an experimental system to the provision of sophisticated terminal, file and mail relaying facilities. The problems of network inter-connection encountered in the provision of these facilities have been tackled through research; however the research has been directed by the service requirements.

This service has never remained static and frozen. It has been necessary to evolve the service facilities underlying protocols, hardware, management facilities and liaison services. To provide a technical and institutional architecture to allow this evolution has proved a demanding but feasible task. While further work is required both to improve the services and keeping with the external developments, there is no sign that the underlying architecture cannot meet these challenges.

While the emergence of international standards should make an interconnection service like the UCL one unnecessary in the future, there is no sign that this will occur within the next five years in the UK. It may well be politic to run such a service in a different organisation than that of an academic research group in Computer Science; the range of services will not be providable without both a service operator and a development group, with a strong interest in international computer communications services.

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