The Present and Future of System Support for Distributed Multimedia Applications

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With recent advances in networking and workstation technology, a variety of distributed multimedia applications are now becoming feasible, e.g. multimedia desktop conferencing and distance learning. However, the deployment of such applications has so far been rather limited. In the authors' opinion this limited deployment is largely explained by the immature state of distributed multimedia system support technologies rather than any lack of creativity on the part of application developers. The present paper therefore attempts to increase awareness of the relevant support technology issues by presenting a discussion of the state of the art in the key technologies of multimedia communications and distributed systems. It is argued that, while significant advances have been made in specific areas such as high performance transport protocols and real-time process scheduling in operating systems, considerable research is still required to produce a complete, integrated solution to the support of distributed multimedia applications.

Keywords: Distributed Multimedia, High-speed Networks.

1. Introduction

Multimedia systems provide an integrated environment for the creation, storage and presentation of a variety of media types (e.g. text, graphics, audio and video). Recently, multimedia systems have received a great deal of attention and a number of successful prototype applications have been developed. However, it is important to draw a distinction between multimedia applications which run on a single workstation and those which can span a networked environment. This paper focuses on the emergence and technological requirements of *distributed multimedia applications* which operate in an environment of multimedia workstations interconnected by one or more networks. Examples of such applications are distance learning, multimedia information systems and desktop conferencing utilities.

The paper discusses the state of the art in technology support for distributed multimedia applications with particular emphasis on the key areas of *multimedia communications* and *distributed systems*. In more detail, the aims of the paper are:

i) to highlight the technical problems raised by distributed multimedia computing,

ii) to discuss the state of the art in communications and distributed systems support for distributed multimedia computing,

iii) to identify significant advances in key underlying technologies, and

iv) to highlight important areas which, in the authors' opinion, require further research; and to point to ongoing research in these areas at Lancaster University.

It is important to note that this paper is mainly concerned with future high quality multimedia applications beyond those currently available in, say, the Internet environment. Existing Internet applications (e.g. those running in the context of the World Wide Web hypermedia support infrastructure) certainly include multimedia information such as video and audio, but these are typically low quality and 'best effort' — i.e. at the mercy of unpredictably and dynamically varying system/network loading.

The paper is structured as follows: Section 2 discusses the requirements that distributed multimedia applications impose on underlying technologies. Section 3 then examines the state of the art in technology support for these applications. The areas covered are multi-service networks and network interfaces, communications and operating systems support, distributed systems platforms and, finally, quality of service management. An overall analysis of the state of the art in then presented in section 4. Research at Lancaster is introduced in section 5; this section presents a number of specific projects which are addressing technology support for distributed multimedia applications. Finally, section 6 contains some concluding remarks.

2. Requirements of Distributed Multimedia Applications

In this section we consider system support requirements derived from a wide ranging study of distributed multimedia applications [Williams92]. Specific requirements are considered under the following headings:

i) quality of service support,

ii) synchronisation, and,

iii) support for inter-operability.

2.1. Quality of Service (QoS) Support

The various forms of media in a multimedia system can be categorised as either *static* or *continuous*. Static media are those which have no temporal dimension. In contrast, continuous media (e.g. video and audio) do have an implied temporal dimension: they are presented at a particular rate for a particular length of time. In addition to being resource intensive, continuous media applications require *predictable* performance from their underlying support technologies so that their temporal nature can be preserved. Furthermore, different media require widely different levels of predictable performance. For example, an uncompressed full colour video application requires up to 220 Mbps of transmission bandwidth (i.e. 720x512x24 frame x 25 frames/sec), in comparison to only 64 Kbps for a telephone quality audio application [Davies,91a].

It is common to characterise the diverse resource needs of such applications in terms of different levels of *Quality of Service (QoS)*. With this level of diversity, there is a requirement for systems to support a configurable range of QoS levels and to allow application programmers to request QoS levels appropriate to their particular needs. Note that QoS support is not possible with many currently available system components such as Ethernet and UNIX (see section 3.3.1). Both of these technologies are non deterministic in operation and have no support for dedicating resources to particular applications so as to be able to meet QoS guarantees.

It is important to note that, within a multimedia system, QoS levels must be maintained on an *end-to-end basis*, i.e. from the information source to the information sink [Coulson95]. Applications need to abstract away from the QoS levels supported by individual system components and configure QoS levels for a complete end-to-end session, e.g. from a remote video storage server to a local window in which the video is being displayed. However, underneath this abstraction, all the system components involved must be co-ordinated to ensure that the abstract QoS levels are maintained. Typical components in the end-to-end path are shown in figure 1.

Quality of service configurability is also applicable to control information sent between system components. Control messages with bounded delay characteristics must be available to allow the system to react to real-time events

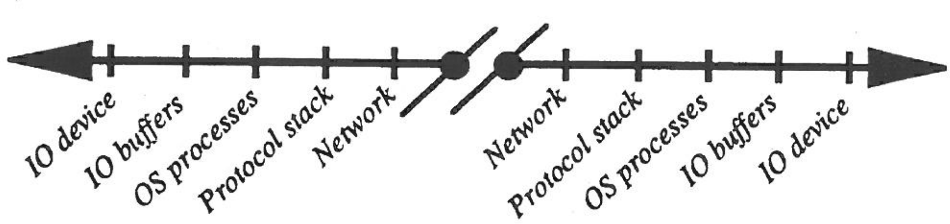

Fig. 1. End-to-end Path of Distributed Continuous Media

in a timely manner. Again, control messages require end- to-end guarantees of service which take into account all the system components on the message's path.

2.2. Real-Time Synchronisation

Multimedia applications require *real-time synchronisation mechanisms*. Real-time synchronisation is required to control the event orderings and precise timings of multimedia interactions. In analysing the requirements of multimedia applications, two styles of real-time synchronisation can be identified [Coulson92a]:

i) event-driven synchronisation, and

ii) continuous synchronisation.

Event driven synchronisation occurs when it is necessary to initiate an action (such as displaying a caption) in a distributed system. The timing of this action may correspond to a reference point such as a particular video frame being displayed.

Continuous synchronisation arises when data presentation devices must be tied together so that they consume data in fixed ratios. The primary example of this type of synchronisation is a 'lip-sync' relationship between a video transmission and a separately stored soundtrack.

The support of these styles of synchronisation builds on the provision of QoS guarantees discussed above. It is clearly important that the communications services used to implement real-time synchronisation are timely in themselves. This applies to both local communication within an operating system and remote communication over the network.

2.3. Inter-operability

Many classes of distributed multimedia application involve users at remote sites inter-working and exchanging information across a network. In the real world, it is unlikely that all users will share a common infrastructure, especially when information is being communicated across organisational boundaries. It is therefore important to provide support for users to share information across different types of networks, operating systems, workstations and media formats (e.g. JPEG, MPEG or H.261 video formats [Campbell95]).

Standardisation obviously has an important part to play in the solution of inter-operability problems, and a number of standards have already been developed in this area. These include the ISO's Open Systems Interconnection and Open Distributed Processing standards, and the CCITT standardisation work in the area of B-ISDN. These existing standards, however, are not necessarily applicable to the use of multimedia information [Coulson92a]. This is largely due to the lack of provision for QoS and real-time synchronisation. It is therefore important that standards evolve to support these emerging requirements.

3. Assessment of the State of the Art

3.1. Elements of Distributed Multimedia Computing

Based on the requirements set out in section 2, it is clear that distributed multimedia applications place heavy demands on many areas of systems technology. Given the inadequacies of existing technologies in this regard (e.g. UNIX and Ethernet as mentioned above), it is important to develop new technologies which can meet these demands. Furthermore, it is essential that these technologies can be integrated into an overall and coherent distributed systems architecture. The various components in such an architecture are illustrated in figure 2.

At the bottom level, *multi-service networks* are required to provide communication links for continuous media alongside more traditional data services. New approaches to *network interfacing* are also required to cope with the stringent real-time demands of continuous media traffic. On top of this, *operating systems* must be adapted to deal with the full range of media services. For example, existing approaches to communications protocol implementation and CPU scheduling must be re-examined in the light of the demanding requirements discussed above. In the above architecture, a distributed systems platform is used to provide a common means of accessing services in a heterogeneous networked environment. Again, the facilities offered by current platforms (e.g. DCE [DCE92] or CORBA [CORBA91]) must be reconsidered

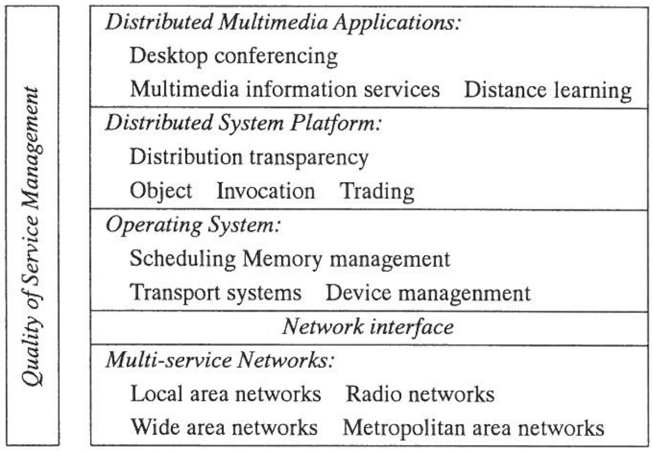

Fig. 2. Key Technologies in Distributed Multimedia Computing

in light of these new requirements. Finally, it is now recognised that network and distributed system management must be extended; in particular, support must be added for *quality of service management* across all layers of the systems architecture to meet the need for end-to-end QoS support.

Each layer is considered in turn below.

3.2. Multi-service Networks and Network Interfaces

Significant Developments

High-Speed Networks The development of high-speed networks capable of carrying multi-service traffic has progressed rapidly. In the local/ metropolitan area, the central technologies are the Fibre Digital Data Interface (FDDI) [Ross90] and Distributed Queues Dual Bus (DQDB) [IEEE90] networks. FDDI is an ANSI standardised 100 Mbits/sec token ring based metropolitan area network which supports about 500 workstations over a distance of 200km. The more recent FDDI-II standard explicitly supports continuous media data by partitioning the available bandwidth into 'isochronous' (for continuous media) and 'non-isochronous' (for conventional data) parts. DQDB is an IEEE standardised MAC layer protocol which uses a pair of optical fibre buses for added reliability. Again, support is provided for both isochronous multimedia data and more bursty asynchronous traffic. Both types of network also support multicast communications to support applications structured around groups of users.

In the wide area environment, the Integrated Services Digital Network (ISDN) [dePryker89] is becoming widely supported by telecommunications providers. ISDN is a digital network standard intended to replace current telephone networks, and to carry a variety of multimedia data in addition to digital telephone signals. *Basic rate* ISDN, intended for domestic use, provides a pair of 64Kbps bearer channels and a 16 or 64Kbps signalling channel. *Primary* rate ISDN is intended for consumers with heavier requirements and specifies 30 x 64Kbps channels together with a signalling channel. *Broadband* ISDN (B-ISDN) [Spears88] is a development of ISDN which offers far higher data rates (e.g. 150Mbps or 620Mbps). B-ISDN is implemented with Asynchronous Transfer Mode (ATM) [dePrycker91] packet switching which uses small fixed sized packets (or *cells*) and allows variable numbers and capacities of connection, each with varying QoS properties. ATM uses a connection oriented call set up procedure at which time resources are allocated in network switches to support the particular throughput, latency and cell loss requirements of each connection. Higher level services called ATM Adaptation Layers (AALs) are also defined. These are specifically tailored for particular media types and offer facilities such as fragmentation and reassembly of large packets into/from ATM cells, error checking and correction, and a choice of isochronous or non isochronous delivery.

Network Interfaces As a result of the developments in networking, research has been directed towards increasing the capability of end-systems to handle the high data rates delivered by the new networks. Current workstation architectures are severely limited in that they are able to handle very few continuous media connections before suffering CPU/bus overload. Initial efforts at overcoming the host system bottleneck took the approach of off-loading the processing and bandwidth requirements of multimedia applications from the computer's main CPU/bus on to a front end *multimedia enhancement unit*. Examples of such units are the Pandora Box [Hopper90] and the Multimedia Network Interface [Blair93] developed at Cambridge and Lancaster Universities respectively. These units are placed between the host computer and the network and directly generate and consume all continuous media streams coming from/arriving at the host. All multimedia peripherals supported by the host (e.g. video frame buffer, camera, audio hardware) are directly connected to the network interface so that continuous media data does not need to flow across the system bus. In the enhancement unit approach, the host computer's role is to *supervise* streams of data rather than directly handling the multimedia streams itself. More recently, a new approach has been investigated which can be viewed as extending the scope of the ATM network inside the end-system [Hayter91], [Scott92]. In this approach, the host computer is configured as a set of nodes (e.g. the main CPU(s), multimedia peripherals and external network interface) connected by an internal ATM switch; the various nodes then communicate with each other and with the outside world using ATM cells. This approach offers an elegant integration of network and end-system architectures, but has the disadvantage that it is not so easily applied to existing commercial workstations.

Mobile Networks Significant developments are also taking place in the field of mobile communications. In wide area mobile communications, *cellular* radio based systems [Walker90] are becoming prevalent. In these systems the geographical area covered by the network is divided into small areas (cells), each equipped with a base station. Each mobile station communicates with the nearest base station which subsequently relays the message, typically via a wire-based network, to another base station and hence to another mobile. The most important cellular based network at the present time is the second generation pan-European digital service commonly referred to as GSM (Groupe Special Mobile). This is intended to provide continent-wide mobile communications mainly for voice but also for data communications. GSM is based on digital time division multiplexing and has a raw data rate of 13.8 Kbps (with error checking this is reduced to 9.6 Kbps). Third generation mobile communications services are also envisaged now. For example, it is expected that Mobile Broadband Systems (or MBS) will be available by the year 2000. Such systems will provide a full range of multimedia services over radio networks. However, deployment will require substantial technological advances and the requirement to support multimedia services must be reconciled with the need to support an ever increasing number of regular subscribers. One way of addressing these concerns is to significantly reducing the cell size thus allowing more effective radio spectrum re-use (future radio networks may well include cells which occupy less space than a typical building). The negative aspects of small cell sizes are increases in deployment costs and increased complexity of call routers. The *practical* bandwidth of third generation radio networks will depend, at least in part, on the successful resolution of these issues.

Outstanding Issues

Although much progress has been made in deploying local and metropolitan multi-service networks, e.g. FDDI and DQDB are increasingly being used as metropolitan area backbone networks — little experience is yet available in the wide area. The major factor limiting ATM implementation is the inherent complexity involved in designing and administering a potentially global network handling millions of mixed media calls and bridging multiple organisational domains. To work towards this goal, international standards in the International Telecommunications Union (ITU) forum are being developed but are still far from complete. Although progress is slow in the wide area, steps are being taken towards the implementation of ATM in the local/metropolitan area (e.g. [Campbell93]). This deployment is motivated by relatively low cost of small scale switches, the increasing availability of ATM interface cards for workstations and PCs, and the development of standards for local ATM.

Many of the other issues in ATM networks relate to QoS guarantees and are discussed in detail in section 3.5.

3.3. Operating Systems and Transport Systems

Significant Developments

Operating Systems Design The most important requirement at the operating system level is to provide predictable real-time behaviour for the processing of a range of media types. Unfortunately, popular workstation operating systems such as UNIX are not able to provide such predictable performance because of their essentially non-deterministic nature [Nieh93]. For example, a UNIX process attempting to meet a particular real-time deadline can be blocked for arbitrary lengths of time in functions such as I/O operations, system calls or page faults. Most of the research on operating systems is attempting to extend UNIX-like systems to meet the demands of multimedia. Two main approaches can be identified:

i) modifying existing UNIX implementations, or

ii) completely re-engineer UNIX.

In the first approach, alterations are made to the existing UNIX kernel to provide more predictable behaviour. For example, work is currently underway at Sun MicroSystems in this area. The position adopted by SUN is that today's workstations have ample CPU power but their weaknesses lie in inappropriate resource management. The proposal is for *time driven resource management* [Hanko91] which allows applications to signal their likely forthcoming resource requirements in terms of parameters such as quantity, deadline and priority. The system will not attempt to guarantee performance, but will instead bias available resources in the requested directions and concentrate on graceful degradation of service, optionally accompanied by notification of degradation to the affected process. It is argued that this is an appropriate strategy in general purpose, multiprogrammed workstations.

The second approach is to preserve the standard UNIX interface, but re-implement the traditional kernel structures in terms of the *micro-kernel* model. Examples of micro-kernels capable of supporting UNIX interfaces are Chorus [Bricker91], Mach [Accetta86] and Amoeba [Tanenbaum88]. Work is being carried out at Lancaster University using Chorus as the basis of a distributed system with end-to-end continuous media support [Coulson93]. In addition, work has been carried out in a Mach environment to provide processor scheduling more appropriate to continuous media [Govindan91], [Tokuda93]. Finally, work has been undertaken at CWI, Amsterdam to support continuous media in an Amoeba based UNIX environment. The approach is to use co-processor based intelligent device controllers and to give applications controlled direct access to physical devices [Bulterman91]. Early evidence suggests to the authors that, at least in the long term, the strategy of re-engineering UNIX will be more successful.

Specific Issues There have also been significant developments in the specific operating system components discussed below:

i) scheduling policies

It is now recognised that currently used scheduling policies, primarily priority based algorithms, are too static and coarse grained for the support of multiple continuous media sessions in a dynamic environment. The emerging consensus in the scheduling community is that *earliest deadline first* scheduling [Liu73] is the right approach [Coulson93]. Deadline scheduling is particularly appropriate for continuous media QoS support as each information unit in a continuous media stream has an implicit deadline and, hence, it is natural to schedule the processes handling these units on the basis of such deadlines. More recent research has proposed the use of *split level scheduling* for the processing of continuous media [Govindan91]. In such schemes, the application programmer is presented with the abstraction of multiple user level threads of control (or simply threads) in a single address space (the use of user level threads has the advantage of minimising context switches in a concurrent application). Responsibility for the scheduling of user level threads is split between a user level scheduler and a kernel level scheduler. The two schedulers communicate, through an area of shared memory, to ensure that globally appropriate scheduling decisions are made.

ii) transport protocols

The present generation of communications protocols, i.e. the OSI protocols and the US Internet protocol family, are not suitable for the new environment of high speed networks and more demanding applications [Shepherd90]. Consequently, there has recently been considerable research activity directed towards the development of communication architectures for multimedia systems. Early work addressed the provision of new transport services designed to operate over high speed networks, e.g. XTP [Chesson88] and NetBlt [Clark87]. Such protocols are often referred to as 'rate based' because of their reliance on clock driven rather than window based flow control. More recently, protocols have emerged which are designed specifically to meet the needs of continuous media, e.g. TPX [Baguette92], CMTP [Wolfinger91] and HeiTS [Hehmann91]. These protocols are generally configurable in terms of quality of service specification for use by a range of different media types (the issue of quality of service management is revisited in section 3.5.1). The technique of *orchestration* has also been proposed to support continuous synchronisation in the communication architecture [Campbell92a]. Finally, a number of widely agreed implementation principles are beginning to emerge including the minimisation of data copying and the avoidance of multiplexing [Tennenhouse90].

iii) storage subsystems

Continuous media imposes severe demands which cannot be adequately met by conventional storage servers such as those used in UNIX systems. The main problem is lack of throughput. For example, most UNIX file systems can deliver only a very few continuous media streams simultaneously. However, bandwidth is not the only problem; the deterministic requirements of continuous media are also not well served by existing technology. For example, conventional disc caching strategies do not work well with continuous media files (whose access patterns are usually sequential) as they are optimised for access to data which exhibits temporal locality. Most of the work in continuous media storage servers has concentrated on disc layout and disc head scheduling. The aim is to optimise the layout of continuous media data on the disc to minimise disc head movements. Examples of research in this area are the Video-on-Demand service designed at the University of California at San Diego [Vin93], the Continuous Media File System developed at the University of California at Berkeley [Anderson92], and the Lancaster Continuous Media Storage Server [Lougher93]. In addition, the latter two systems use the technique of *disc striping* whereby successive segments of a continuous media stream are stored on separate discs arranged in an array. This technique enables N discs to provide a throughput approaching N times that of a single disc. Note, however, that these techniques have so far failed to produce fully scaleable solutions for the simultaneous retrieval of large numbers of continuous media streams.

iv) synchronisation schemes

A significant amount of work has been carried out on the topic of multimedia synchronisation. Much of the early work was targeted at the *specification* of temporal relationships in multimedia documents (e.g. [Postel88], [Poggio85]). More recent work has concentrated on synchronisation *mechanisms*. In general, there are two commonly advocated approaches. The first is based on the notion of *schedules* where each information unit (e.g. video frame or sound sample) is assigned a time stamp and the task of the synchronisation entity at the display site is simply to display each unit at the designated time. This is particularly suitable for pre- defined multimedia presentations where the full range of synchronisation requirements are known in advance. The drawback of this approach is that it is essentially *static* and problems arise when dynamic user interaction is required to change the course of an ongoing presentation. Static approaches to synchronisation are reported by Salmony [Salmony89], Little [Little90] and Escobar [Escobar92]. The second approach takes a more dynamic view of synchronisation. Researchers at CNET, France advocate the use of a real-time language known as Esterel [Berry88] to enable the specification of arbitrary and potentially dynamic real-time controllers. Nicolaou [Nicolaou90] also presents a dynamic scheme in which applications are notified of events corresponding to the arrival of information units in a continuous media presentation. Responsibility for dealing with such events is, however, left to the application programmer.

Outstanding Issues

There has been considerable progress in operating system support for multimedia with most progress having been made in the specific areas of communications and scheduling. There has been considerably less work on *integration* of the various components into an overall operating system design. Such integration is essential if requirements such as quality of service and real- time synchronisation are to be met on an end-to-end basis as required in section 2.1 [Campbell92b]. Most significantly, work is required to integrate techniques for communications and scheduling [Coulson93]. For example, to implement an audio connection with a given QoS, it is necessary to achieve the desired QoS in the transport protocol and to schedule processes at the rate required to deal with the arrival of audio data. Such integration should also eventually extend to areas such as device management and memory management.

One major protocol implementation issue is the decision as to where exactly protocol processing should be performed in future operating systems: some researchers still advocate traditional kernel implementations; others advocate the use of specialised hardware to implement protocol processing [Arnould89]; a third group suggest that protocols should be implemented in user space [Forin90] (this latter view is consistent with trends in micro-kernel design to move other functionality such as file systems out of the kernel and into user space). A further deficiency in the protocol area is the provision of transport services over ATM networks. Although the AAL protocols mentioned above perform many of the traditional transport functions (e.g. sequenced delivery, flow control and error control), 'lightweight' transport services are still needed for transparent communication across heterogeneous internetworks.

In the area of synchronisation support, there is a lack of concrete experience in support for real- time synchronisation. Indeed, some researchers now argue that synchronisation mechanisms are not required and that emerging networks will provide sufficient levels of synchronisation without the need for further mechanisms. Practical implementations are therefore essential to help understand the real-time synchronisation requirements of multimedia.

Finally, in the area of process scheduling, it is recognised that earliest deadline first policies do not operate well in overload situations. Some researchers therefore propose extensions to earliest deadline first policies, either by adding resource reservation or by aborting certain processes [Tokuda93]. It is clear that much more work is required in this area.

3.4. Distributed Systems Platforms

Significant Developments

The role of a distributed systems platform is to provide programmers with a set of abstractions to ease the development of distributed applications. In general, such platforms provide a level of distribution transparency, i.e. the programmer need not be aware of the distributed nature of the system. A number of distributed platforms have been developed, with most being designed to operate in a heterogeneous environment, masking out details of underlying hardware architectures, communications architectures and systems implementations. Examples of such systems include CORBA [CORBA91], ANSAware [ANSA89] and DCE [DCE92]. International activity is also under way to develop standards for Open Distributed Processing (ODP) [ISO92].

There is a general consensus that distributed systems platforms should offer an object-based environment where applications consist of a set of interacting objects. Object interaction is provided by an invocation mechanism which hides the location of objects from the programmer. Facilities are also provided to locate and manage objects in the distributed environment.

There is a clear need for such distributed systems platforms to support multimedia applications. However, most of the existing technologies were developed before the emergence of distributed multimedia computing. A number of projects have therefore looked at extending such platforms with multimedia facilities. Previous research at Lancaster developed extensions to the ANSAware architecture to support multimedia. The extensions include:

i) the introduction of a *stream* abstraction to allow users to interface QoS controlled transport services,

ii) the addition of quality of service annotations on object interfaces, and

iii) the introduction of synchronisation managers to implement real-time synchronisation constraints.

Similar work on extending ANSAware has been carried out by APM Ltd., Cambridge [Nicolaou91] and by France Telecom's CNET [Hazard91], [Stefani93]. A collaboration between Lancaster and CNET has also resulted in proposals for extensions to ODP to meet the requirements of multimedia. In addition, research in the Berkom Project in Berlin has developed the Y system, a distributed application platform layered on top of an ATM network. The Y system architecture consists of four planes: an internet plane, an interprocess communication plane, a support environment plane and a distributed application plane [Popescu-Zeletin91].

There has also been considerable work in the telecommunications community in providing platforms for the development of multimedia applications. Researchers at Bellcore have built a number of interactive distributed multimedia applications (e.g. Cruiser [Fish89] and Rendezvous [Patterson90]). Cruiser, for example, allows users to browse along a 'virtual corridor' in an office building and visit office occupants who leave their virtual door open. This results in an audio/visual conference connection being made between the browser and the occupant. The initial implementation of these applications was built directly on to the operating system and external hardware. This was later realised to be limiting from the point of view of extensibility and wider applicability, and therefore a generic platform architecture known as the Touring Machine [Bates90] was designed. The Touring Machine architecture consists of station objects, which encapsulate all the multimedia sources and sinks at a single multimedia workstation, and *call objects*, which represent a particular connection topology between stations. This architecture has been heavily influenced by the telecommunications background in which it was developed. In particular, a careful separation is maintained between resources owned by the network provider (call object) and resources owned by the customer (station object). This is a significant consideration in a wide area networking environment due to the necessity of tariffing structures and divisions of responsibility [Ruston91]. Work in this area is now continuing in the TINA Project (Telecommunications Information Networking Architecture) [TINA91]. This is a collaborative project to define a standard framework for telecommunications networking in the context of new multi-service networks, multimedia and real-time applications, telecommunications services and ISO standards. Telecommunications companies throughout Europe and the USA are represented. Support for multimedia services is one of the key concerns in this work.

Outstanding Issues

There are a number of outstanding issues in the provision of distributed systems platforms for multimedia. Firstly, there is not yet an agreement on the required abstractions for continuous media. There is therefore a clear need for further experience in developing applications with such platforms. Secondly, most existing platforms do not provide the required level of performance for multimedia applications. This is largely because they are layered on top of unsuitable operating systems (such as UNIX). Clearly, significant advances can be made by engineering distributed systems platforms using the new operating systems technologies discussed above. Finally, it is important to bring together the developments in the distributed systems and telecommunications communities. This is likely to be an extremely difficult task as the two communities have radically different views of the role of a multimedia platform. The TINA Project is taking a lead in this area by adopting many ODP concepts in their draft architecture.

3.5. Quality of Service Management

Significant Developments

Quality of Service is a recurring theme through all the architectural layers discussed above. However, individual researchers have tended to focus on the impact of QoS on particular layers in isolation rather than taking a global perspective. The key developments in the various layers are summarised below.

Parameter	*Description*
peak arrival rate of cells	The maximum resources required by the application at peak load.
peak duration	The average duration of the maximum load.
average cell arrival rate	The average amount of network resources requisted by the source. This is the number of cells measured during the duration of the connection divided by the duration.
burstiness	The ratio between the peak cell rate and the average cell rate.
cell loss ratio (CLR)	The ratio of number of lost cells to transmited cells. This type of error usually occurs because of congestion in the switches.
cell insertion ratio (CIR)	This type of error occurs when the address field in the header is corrupted to another valid network address.
bit error rate (BER)	Defined ad the number of bits which are delivered erroneously divided by the total number transmitted. These sorts of errors are mainly caused by the transmission system.

Fig. 3. CCITT QoS Parameters

QoS in the Network Layer Most of the work at this layer has assumed an ATM environment. One of the most important developments was the definition by CCITT of a set of QoS parameters for ATM virtual circuits [CCITT90] (see figure 3).

The first four parameters in figure 3 are intended to allow traffic to be characterised in advance so that the network can both allocate resources to support the desired traffic patterns and also police the traffic inserted at the network by the user to ensure that the user does not attempt to inject data into the network at a higher QoS than that agreed to. It is also intended that these parameters be used to support QoS renegotiation (known as in-call renegotiation). The remaining parameters control the degree of reliability expected by the user from the network.

Important research has also been carried out in the area of providing QoS guarantees in ATM switches. In [Lazar,90], an Asynchronous Time-Sharing network is proposed which provides sophisticated QoS support. The network supports four well-defined traffic classes which support circuit emulation, voice and video, file transfer and network management flows. Following on from this work [Hyman,92] describes a joint scheduling and admission control mechanism used to guarantee QoS of each traffic class. In [Clark,92] a distinction is made between three different service commitments:

i) guaranteed service for hard real-time applications; ii) predicted service, which utilises the measured performance of delays and is targeted towards continuous media applications; and iii) best effort service, where no QoS guarantees are provided. A unified traffic scheduling mechanism, based on a combination of weighted fair queuing and static priority algorithms, is also discussed.

The area of resource reservation is also fundamental in providing end-to-end QoS guarantees. There have been a number of significant contributions to resource allocation including ST-II [Topolcic90] which is designed specifically for point-to-multipoint packetised audio and video communications across the Internet, and RSVP [Zhang93] which provides multipoint-to- multipoint support. SRP [Anderson91] also supports end-system and networks resource allocation in an Internet environment.

QoS in the Operating System Most of the work in this area has centred on QoS in transport protocols. The emerging consensus is that connection-oriented protocols are required with the following QoS parameters:

i) throughput (measured in terms of transport data units per second),

ii) delay,

iii) delay jitter (i.e. variation in delay), and

iv) selection of error control policy.

It is also recognised that support is required for QoS management functions such as the monitoring of QoS levels, notification of QoS degradations to the transport service user, and user initiated re-negotiation of previously agreed

QoS on a live connection. The three protocols mentioned in section 3.3.1 (i.e. TPX, CMTP and HeiTS) all provide this level of QoS management.

Other areas of QoS support in operating systems are less developed. As mentioned in section 3.3.1, there is research into the provision of predictable levels of QoS (e.g. in CPU scheduling and end-system buffer management). However, little attention has yet been directed at QoS management issues. Important QoS management issues at the operating system level include admission tests for the controlled creation of new threads, notifying degraded QoS (e.g. missed deadlines) to application code, and dynamically adapting deadlines of periodically executing threads so as to correctly process a stream of continuous media. Some early work in this area is reported in [Tokuda93].

QoS in Distributed System Platforms There are as yet few reported results from work on quality of service support in distributed system platforms. As mentioned earlier, quality of service at this level is an end-to-end issue and hence QoS specification should apply to the complete flow of information from the remote service, across the network, to the point of application. QoS specification at this level should also be *user-oriented* rather than system oriented. In other words, the QoS specification provided should be meaningful to the end-user, and lower level considerations, such as the throughput and jitter of a transport connection, should be hidden. Finally, it is important that QoS specifications are *declarative*, i.e. users should be specifying what is required rather than how this is to be achieved.

Outstanding Issues

As seen above, there has been a significant amount of research at the network and transport layers. In contrast, the higher layers have received much less attention; there has been little work addressing the requirements of quality of service management in the operating system and almost none at the level of the distributed system platform. In addition, there has been very little research on techniques for *multiparty* multimedia communications. Most of the research discussed above assumes a point to point environment.. Multicasting raises a number of important issues, particularly when different sinks require different levels of quality of service.

More fundamentally, there is a strong need for a comprehensive quality of service architecture, managing quality of service across all layers of a distributed system. Such an architecture should provide mechanisms for: i) QoS specification at the platform layer and mapping of specifications on to lower layers of the architecture; ii) facilities for end-to-end negotiation and renegotiation of quality of service; iii) resource allocation and admission control; iv) policing to ensure that users are not violating negotiated QoS parameters; and v) monitoring to ensure that negotiated QoS levels are being maintained by the service provider.

4. Summary and Analysis

In general terms, the field of communications and distributed systems support for multimedia is extremely active and a number of interesting results are starting to emerge. However, many of the results are in specific areas and there is a lack of awareness of the field as a whole. This is a direct consequence of the lack of maturity of the field and the scale of the issues involved.

Communications is perhaps the most active area and a broad consensus is being reached on requirements at the lower levels of the protocol stack. Consensus also exists at the transport service level on the need for a greater degree of QoS configurability. The field of operating system support has been less active. Most work has concentrated on process scheduling with deadline-based scheduling emerging as the policy of choice. However, many important issues have hardly been examined, especially the need for integration with other systems components such as I/O and communications. A number of advances have been made in the area of continuous media storage servers, for example in the areas of disc layout and caching strategies. However, very few of the existing techniques are scaleable to large numbers of simultaneous continuous media streams. In the field of multimedia synchronisation, a reasonable amount of work has been carried out in the *specification* of synchronisation in multimedia documents, but less work has been applied to *mechanisms* for synchronisation.

Architectural issues in distributed multimedia systems are particularly important as they are concerned with the integration of narrower, more specialised, multimedia support mechanisms. Careful integration is crucial in distributed multimedia systems because of the real-time, end-to-end requirements of continuous media information. The work on distributed systems platforms and distributed systems architectures has a particularly important role to play in achieving this level of integration. There is also a strong need to take an architectural view of quality of service in order to integrate quality of service management into networks, operating systems and distributed systems platforms.

5. Research at Lancaster

Research at Lancaster University is focusing on the problems of developing a comprehensive and integrated architecture for continuous media applications. This research spans all the areas covered in this paper, from multi-service networks to distributed systems platforms. The main areas of activity (in the context of the architecture presented earlier in the paper) are illustrated in figure 4.

At the multi-service network level, work is currently underway to establish an experimental local area ATM network across the campus. This will be used as the main network infrastructure for ongoing multimedia research. Work is also underway to develop an appropriate AAL service on top of the ATM infrastructure to provide a general network service for multimedia communications [Campbell93]. A multimedia network interface is also being developed for this environment. This network interface, known as the LANC, is based on a high performance token ring network operating at 500Mpbs and is fully integrated into the host workstation [Scott92]. A minimal low cost version of this interface is also under development [Yeadon93].

At the operating system level, the SUMO project is exploiting and extending the real-time features of the Chorus micro-kernel to provide the necessary end-to-end quality of service support for continuous media applications [Coulson93], [Coulson,94]. New scheduling and communications services are currently being added to Chorus; the principal aim of this research is to achieve a high level of integration between these two components. Work is also underway to extend this framework with support for multicast services for continuous media over ATM. At the level of the distributed system platform, research is focusing on extensions to ODP to support multimedia and real-time applications. An experimental platform is being developed, on top of the adapted Chorus micro-kernel, providing an ODP-like platform extended with QoS specifications, QoS controlled stream bindings and reactive kernels. This work is in collaboration with CNET and is reported in [Coulson92b].

We feel it is important that the distributed system concepts emerging in our work can be applied to other multi-service networks, especially the emergent radio networks such as GSM and MBS. These networks have very different characteristics in terms of data throughput and error rates. We are therefore interested in distributed systems architectures which can handle

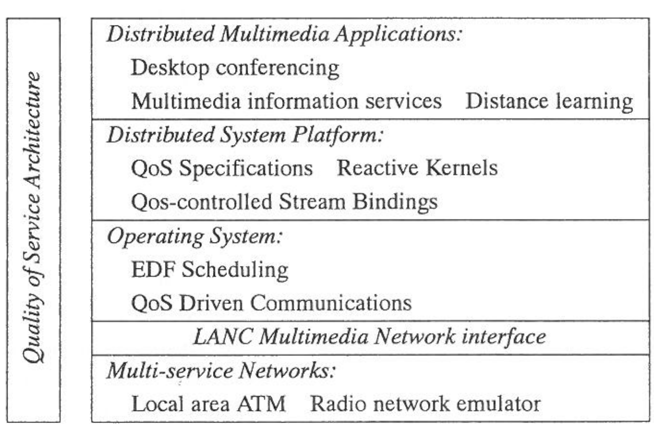

Fig. 4. Lancaster Architecture

such heterogeneity in the underlying networks [Davies93a]. To meet this objective, a project called MOST (Mobile Open Systems Technologies) has recently been established. This project is in collaboration with the electricity industry through a company called EA Technology and is examining the impact of mobile radio on open distributed systems architectures. The work is particularly concerned with the potential of mobile computing in the command and control of field engineers [Davies93b]. The experimental developments in MOST are based on an emulation of a radio network, running over conventional wired network; the second phase of the project will however be based on a live radio network.

Finally, the QoS-A project [Campbell92b] at Lancaster is looking at the development of an overall quality of service architecture for multiservice networks. This quality of service architecture is intended to span all the layers shown in figure 4, providing management and control at each of the layers. At each layer, facilities are offered for the key functions of QoS specification and mapping, end-to-end negotiation and re-negotiation, resource allocation and admission control, policing, and monitoring (see section 3.5).

6. Concluding Remarks

This paper has examined the area of communications and distributed systems support for multimedia applications. The key requirements for such applications are: i) quality of service management; ii) a range of real-time synchronisation mechanisms; and iii) support for interoperability in a heterogeneous distributed environment. It is also important that systems designers adopt a co-ordinated approach to meeting these requirements, i.e. it is important that all components of a distributed systems architecture work together to achieve the desired behaviour for multimedia applications.

Our view is that, at present, such a co-ordinated approach is missing. Most of the advances in the field have been in specific technologies such as transport protocols and scheduling algorithms. Ongoing research at Lancaster is addressing this deficiency in the state of the art. The overall aim of this research is to understand key principles behind the design and implementation of a distributed systems architecture featuring integrated support for multimedia applications. The work in the QoS-A project has a particularly important role in this research in providing an architectural view of quality of service management spanning all layers of the architecture from the underlying network to the application.

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