Real Time Audio and Video Transmission of IEEE GLOBECOM'96 over the Internet

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Abstract

The paper describes the experience of transmitting of proceedings of the IEEE Globecom'96 conference in London, England, over the Internet, using the Mbone and SoftwareVision systems. We discuss the configuration issues involved, and problems encountered, together with techniques by which such problems may be identified and solved. This event showed that, whilst Internet broadcasting is clearly still an evolving technology, it is usable today, and has considerable potential for growth in the future.

Introduction

This paper is about the experiences that we had in transmitting the proceedings of some events at the IEEE Globecom '96 in London, England, over the Internet in the week of 17-22 November, 1996.

Initially, staff from the Department of Computer Science, UCL were asked to organize a mini-conference within Globecom, on the subject of the Internet. It was then decided to add a technical exhibition, and to consider transmitting the event over the Internet, at the request of NTT laboratories and some other research institutions in Japan and the USA.

We quickly formed a list of the technical staff to be involved from BT, MCI, NTT, UCL and UKERNA, and set up an E-mail list, shared computer accounts, and established basic Internet service provider relations and connectivity.

Live Video and Audio of all of the events in the Churchill Auditorium of the Queen Elizabeth II Conference Center were captured and transmitted, in real time, as well as stored and transmitted later, for remote participants in 3 continents, over the Internet.

Two independent systems were used simultaneously, one supplied by researchers from NTT laboratories in Japan, and the other by researchers from UCL. The former system is based on a server model of distribution[1], whilst the latter is based on the use of network level IP packet multicast.

Both systems employ compression algorithms[2] so that the network capacity requirement in each case was of the order of 100 kbps to 200 kbps total, thus enabling remote participants without very high end network connectivity to take part. Receivers need only software for a PC running most popular versions of Windows or a Unix workstation to be able to receive either type of transmission, or to retrieve the recorded sessions from NTT laboratories' servers.

The multimedia transmission was carried over carefully engineered links that traversed many different subnet technologies, including point-to-point circuits, SMDS networks, ATM networks, and fast ethernet switches. This was both to give a high level of assurance that the traffic would not experience too much interference from other traffic at the site and elsewhere, and to ensure very low packet store and forward delays.

The system ran for 4 days continuously, and was generally very successful. In the future, it should be possible to have remote paying attendees, although reliability would become an important question in such instances. It has been suggested that receivers could *lease* a key to decrypt an encrypted video stream, much along the lines used for satellite and cable TV pay-per-view systems. Reselling of the material would not be prevented, but at least live virtual attendance would be limited, and by changing encryption keys regularly, the growth of the community able to "spy" on the event could be constrained. This will have to be investigated by the

[1] In some senses this is analogous to the use of an MCU In the ISDN/H.320 video-conferencing world, except that here we are packet based, not circuit based. Another system like this is the CU-SeeMe reflector based multi-party video conferencing tool

[2] Both systems use the ITU H.261 algorithm for video compression, which is designed for digital video-telephony, and is suited to typical Internet capacity, as well as being reasonably amenable to implementation at the sender side in software. As regards the receiver side, it is very straightforward to implement. The main difference between Internet implementations of H.261 and ISDN based ones is that Internet ones are typically in software, and do not employ the expensive H.221 framing protocol.

IEEE, and any other organizations interested in using this technology in anger.

Configuration

In this section, we provide an overview of the network and audio/visual configuration necessary to “broadcast” the GLOBECOM conference over the Internet. The focus of this is, necessarily, from the point to view of an Mbone session, since the authors were more heavily involved in that aspect of the broadcast.

Network

There were three networked areas in the conference centre: exhibits, cyber-cafe and the main auditorium. Each of these areas was served by a separate ethernet, and these are linked via a Cisco router in the basement. Access to the Mbone is via an external link from the Cisco. This is illustrated in figure 1. Originally, the Cisco router was going to terminate tunnels from the BTnet machine, `news-feed2.bt.net`, but due to interworking problems between DVMRP and PIM, the two multicast routing protocols in use, we ended up setting up an Mbone tunnel from the Mbone1 machine to the mbone machine within BTnet.

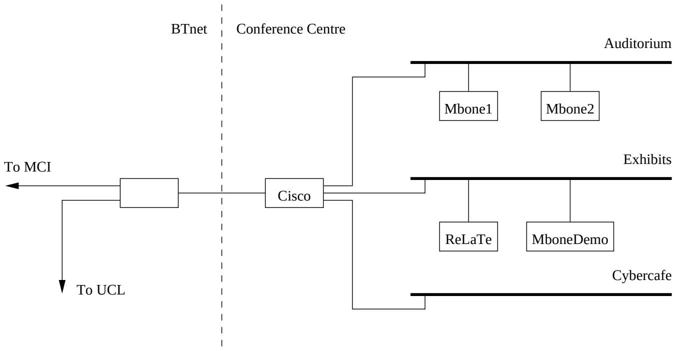

Figure 1: Planned Network Layout

UCL provided four machines: two for the multicast of the conference sessions, and two to provide a demo and multicast routing for the exhibit/cafe areas. Two systems were be provided by NTT to broadcast the conference sessions using the SoftwareVision system.

The machines provided by UCL functioned as follows:

Mbone1 Main mrouted and first video feed.

Mbone2 Second video feed and audio.

ReLaTe ReLaTe (Remote Language Teaching) demo.

MboneDemo Mbone display machine for main exhibition area

The ReLaTe and MboneDemo machines were situated in the exhibit area, adjacent to the cafe. Originally, we planned to have two ethernet interfaces, and connect to both networks. In normal use it received multicast traffic destined for the exhibit/cafe networks via a tunnel from Mbone1. In the end we reverted to using the Cisco to carry out local copying.

The Mbone1 and Mbone2 machines were situated in a translator booth, overlooking the main auditorium, with good audio/visual cabling access, next to a riser from the basement, where the cable plant and router arrived. They connected logically to the Mbone by a tunnel through the Cisco to BTnet, BT’s commercial Internet service. From BTnet, we implemented two multicast tunnels to MCI and UCL.

Audio/Visual

UCL and NTT provided two video cameras each, overlooking the main auditorium. Cables were provided by the conference center to connect these cameras to the Mbone machines, and to provide audio line level from the auditorium microphones via a mixer, and from the mbone workstations back to the auditorium PA system. In the end, we provided a PAL/NTSC scan-line converter so that we could share input from the slide camera that UCL had. There was a lack of communication between the Mbone booth, and the location of the camera operators and the audio engineer’s booth, which caused some problems. Wireless communication tools (radio/phone/IR links) would have made things far more efficient.

Other requirements

A telephone which accepts incoming calls, and can make international calls for use by the Mbone team was essential. Not only could we reach WAN operational staff, but we could dial out to IP dialup sites, and thence test what was wrong when our network connectivity was down. Later, it transpired that we could even dial in to the NTT site with a laptop equipped with a 28.8kbps modem, and retrieve live video from there, and gain some idea of the quality being received at the remote site!

The Conference

A captured screen-dump of the Mbone session is shown in figure 2. It is seen that this session comprises two separate video streams (slide camera, and speaker camera), with a single audio stream. The capability to feed audio *into* the auditorium, such that remote participants could ask questions of the speaker was present, but was not used.

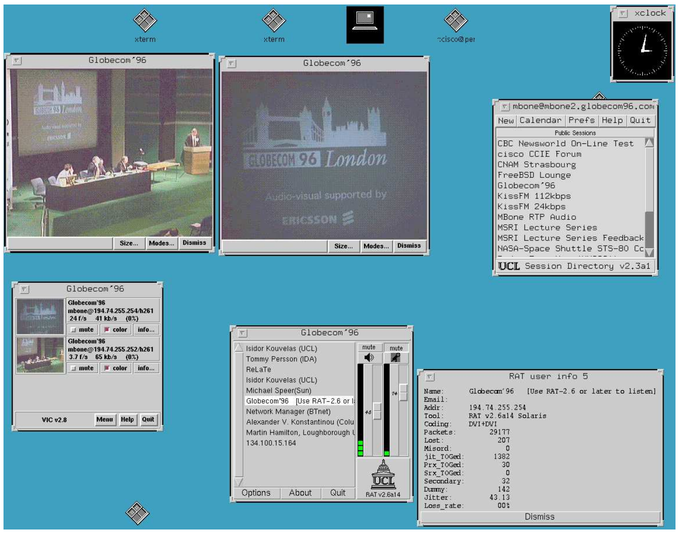

Figure 2: A Captured screen of a session

The size of the remote audience varied somewhat, but peaked at over a hundred simultaneous viewers. During the live conference sessions, the audience was mainly European, listening on the Mbone; the SoftwareVision system attracted larger audiences during the European night, with a repeat broadcast which was view by many people in the far east.

Lessons

There were a number of lessons learnt during this operation, and we outline them in the following subsections, in a bottom up manner, starting with the link level, and going on up, approximately through the ISO/OSI 7 layer model, as it were, until we reach the human factors levels.

Link Level

The first thing we learnt was that Local Area Network technology is very flexible and reliable. Despite changing our network design within the QEII centre several times,

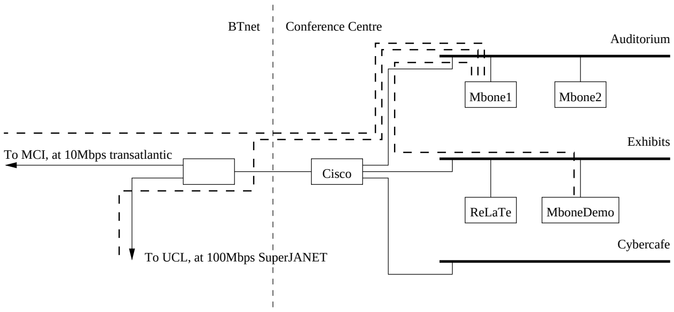

Figure 3: Actual Network Layout

the use of Ethernets, and particularly of mini-hubs, was highly successful, and flexible. The final network layout, showing logical multicast routing tunnels is shown in figure 3.

In the lesson for the wide area, we had the opposite lessons. Both for the links to and from the center, which were "Megastream" (E1, 2Mbps links), and for cross connectivity between the UK BTnet commercial service, and the UK academic networks which operate on SMDS switched networks, we encountered a variety of installation and configuration problems. The key problem in both cases was that we had configured IP routes to use these, before establishing that the link-layer connectivity was indeed in place. This should be avoided whenever possible!

Onwards connectivity from the UK academic network, SuperJANET, was provided over the pan-European ATM research network, JAMES, as part of access that UCL has for the Prospect and MERCI projects, which involve multimedia conferencing for distance education. Since these had already been configured and tested as part of those projects, IP level connectivity for unicast and multicast was assured.

IP Level Routing, Unicast and Multicast

For mbone topological and loss network debugging, we used `mrinfo` for finding out which multicast tunnel routes were configured and `mtrace` for discovering the current topology: these tools are essential. But before this comes into play, `traceroute` and `ping` are vital for tracking throughput/loss and connectivity problems, as well as access to routers. `tcpdump` or a similar packet sniffer are also all very useful. Better integration and more accurate mbone statistics would always be an improvement: it is not easy to trace out a multicast distribution tree to find a lossy link, for example. Telnet and E-mail are both also essential.

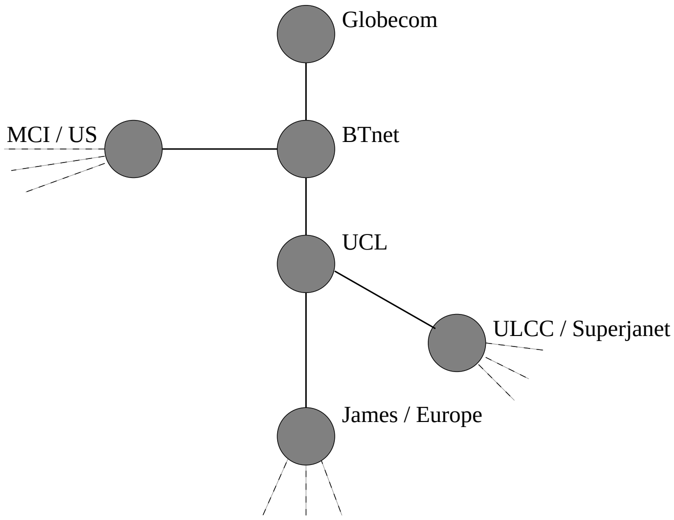

Figure 4: International Access

In the following, the output of a number of network monitoring tools is shown. This output was produced during the conference broadcast, and shows the range of network conditions encountered.

```
traceroute nms.expo96.ad.jp
traceroute to nms.expo96.ad.jp (133.246.192.11) 30 hops max, 40 byte packets
 1  * cisco (128.16.6.150)  2 ms  3 ms
 2  128.40.14.245 (128.40.14.245)  2 ms  3 ms  3 ms
 3  cisco-c.ucl.ac.uk (128.40.20.253)  4 ms  53 ms  8 ms
 4  cisco-e.ucl.ac.uk (128.40.20.254)  4 ms 6 ms 6 ms
 5  194.83.100.62 (194.83.100.62)  6 ms 5 ms 5 ms
 6  128.86.1.9 (128.86.1.9)  5 ms 6 ms 8 ms
 7  s1-4.c36-11.New-York2.t3.ans.net (204.151.184.25)  174 ms 171 ms
 8  f2.t36-0.New-York2.t3.ans.net (140.223.36.221)  200 ms * *
 9  h12.t32-0.New-York.t3.ans.net (140.223.33.25)  167 ms 206 ms
10  enss219.t3.ans.net (140.223.33.130)  180 ms *  224 ms
11  mci.sprintnap.net (192.157.69.11)  269 ms *  242 ms
```

```
ping -vs nms.expo96.ad.jp
PING nms.expo96.ad.jp: 56 data bytes
64 bytes from nms.expo96.ad.jp (133.246.192.11): icmp_seq=0. time=426ms
64 bytes from nms.expo96.ad.jp (133.246.192.11): icmp_seq=1. time=558ms
64 bytes from nms.expo96.ad.jp (133.246.192.11): icmp_seq=2. time=326ms
64 bytes from nms.expo96.ad.jp (133.246.192.11): icmp_seq=3. time=336ms
^C
----nms.expo96.ad.jp PING Statistics----
5 packets transmitted, 4 packets received, 20% packet loss
round-trip (ms)  min/avg/max = 326/411/558
```

```
Mtrace from 194.74.255.252 to 128.40.64.6 via group 224.2.133.213
Querying full reverse path...
  0  jammu.avc.ucl.ac.uk (128.40.64.6)
 -1  kashmir.avc.ucl.ac.uk (128.40.64.5)  DVMRP  thresh^ 1
 -2  mrouter.ucl.ac.uk (128.40.22.218)  DVMRP  thresh^ 8
 -3  noc2.ulcc.ja.net (193.63.94.26)  DVMRP  thresh^ 24
 -4  noc.ulcc.ja.net (193.63.94.25)  DVMRP  thresh^ 1
 -5  lea.cs.ucl.ac.uk (128.16.64.24)  DVMRP  thresh^ 24
 -6  sauce-atm.uio.no (129.240.202.82)  DVMRP  thresh^ 32
 -7  stockholm.mbone.ebone.net (192.36.148.206)  DVMRP  thresh^ 40
 -8  schnell.ebone.net (198.67.134.250)  DVMRP  thresh^ 64
 -9  dec3800-1-fddi-0.WestOrange.mci.net (204.70.64.29)  DVMRP  thresh^ 32
-10  dec3800-2-fddi-1.WestOrange.mci.net (204.70.64.77)  DVMRP  thresh^ 1
-11  news-feed2.bt.net (194.72.7.122)  DVMRP  thresh^ 64
-12  ? (194.74.255.254)  DVMRP  thresh^ 24
-13  ? (194.74.255.252)
Round trip time 274 ms

Waiting to accumulate statistics... Results after 10 seconds:

  Source        Response Dest    Packet Statistics For     Only For Traffic
194.74.255.252  128.40.64.6      All Multicast Traffic     From 194.74.255.252
     v       __/  rtt  253 ms    Lost/Sent = Pct  Rate       To 224.2.133.213
194.74.255.254  ?
     v      ^      ttl   24        5/418  =  1%  41 pps     0/95   =  0%   9 pps
194.72.7.122    news-feed2.bt.net
     v      ^      ttl   64        1/309  =  0%  30 pps     0/95   =  0%   9 pps
204.70.64.77    dec3800-2-fddi-1.WestOrange.mci.net
     v      ^      ttl   65        1/1154 =  0%   0 pps     0/95   =  0%   0 pps
204.70.64.45
204.70.64.29    dec3800-1-fddi-0.WestOrange.mci.net
     v      ^      ttl   66        1/352  =  0%   0 pps     0/95   =  0%   0 pps
198.67.134.250  schnell.ebone.net
     v      ^      ttl   67       -3/1175 =  0% 117 pps     0/95   =  0%   9 pps
192.36.148.206  stockholm.mbone.ebone.net
     v      ^      ttl   68      116/1442 =  8% 144 pps     7/95   =  7%   9 pps
129.240.202.42
129.240.202.82  sauce-atm.uio.no
     v      ^      ttl   69       -3/1487 =  0% 148 pps     0/88   =  0%   8 pps
128.16.48.10
128.16.64.24    lea.cs.ucl.ac.uk
     v      ^      ttl   70      758/1729 = 44% 172 pps    25/88   = 28%   8 pps
193.63.94.25    noc.ulcc.ja.net
     v      ^      ttl   71      -29/973  = -2%  97 pps     0/63   =  0%   6 pps
193.63.94.26    noc2.ulcc.ja.net
     v      ^      ttl   72       -1/277  =  0%  27 pps     0/63   =  0%   6
pps128.40.22.218   mrouter.ucl.ac.uk
     v      ^      ttl   73        0/229  =  0%  22 pps     0/63   =  0%   6 pps
128.40.64.5     kashmir.avc.ucl.ac.uk
     v      __    ttl   74          230         23 pps       63          6 pps
128.40.64.6     128.40.64.6
  Receiver      Query Source
```

```
Mtrace from 194.74.255.254 to 128.40.64.6 via group 224.2.133.213
Querying full reverse path...
  0  jammu.avc.ucl.ac.uk (128.40.64.6)
 -1  kashmir.avc.ucl.ac.uk (128.40.64.5)  DVMRP  thresh^ 1
 -2  mrouter.ucl.ac.uk (128.40.22.218)  DVMRP  thresh^ 8
 -3  noc2.ulcc.ja.net (193.63.94.26)  DVMRP  thresh^ 24
 -4  noc.ulcc.ja.net (193.63.94.25)  DVMRP  thresh^ 1
 -5  lea.cs.ucl.ac.uk (128.16.64.24)  DVMRP  thresh^ 24
 -6  laphroaig.cs.ucl.ac.uk (128.16.64.4)  DVMRP  thresh^ 1
 -7  news-feed2.bt.net (194.72.7.122)  DVMRP  thresh^ 24
 -8  ? (194.74.255.254)  DVMRP  thresh^ 24
 -9  ? (194.74.255.254)
Round trip time 106 ms

Waiting to accumulate statistics... Results after 10 seconds:

  Source        Response Dest    Packet Statistics For     Only For Traffic
194.74.255.254  128.40.64.6      All Multicast Traffic     From 194.74.255.254
     v       __/  rtt   87 ms    Lost/Sent = Pct  Rate       To 224.2.133.213
194.74.255.254  ?
     v      ^      ttl   24       12/661  =  2%  66 pps     4/81   =  5%   8 pps
194.72.7.122    news-feed2.bt.net
     v      ^      ttl   25        2/1806 =  0% 180 pps     0/77   =  0%   7 pps
193.63.58.2
128.16.64.4     laphroaig.cs.ucl.ac.uk
     v      ^      ttl   26     -208/1814 =-10% 181 pps     0/77   =  0%   7 pps
128.16.64.24    lea.cs.ucl.ac.uk
     v      ^      ttl   27     1608/2721 = 59% 272 pps    34/77   = 44%   7 pps
193.63.94.25    noc.ulcc.ja.net
     v      ^      ttl   28     -312/1113 =-27% 111 pps     0/43   =  0%   4 pps
193.63.94.26    noc2.ulcc.ja.net
     v      ^      ttl   29        0/251  =  0%  25 pps     0/43   =  0%   4 pps
128.40.22.218   mrouter.ucl.ac.uk
     v      ^      ttl   30        0/185  =  0%  18 pps     0/43   =  0%   4 pps
128.40.64.5     kashmir.avc.ucl.ac.uk
     v      \__   ttl   31          179         17 pps       43          4 pps
128.40.64.6     128.40.64.6
  Receiver      Query Source
```

```
/usr/multicast/mtrace 194.74.255.254 224.2.199.104
Mtrace from 194.74.255.254 to 132.146.196.31 via group 224.2.199.104
Querying full reverse path...
  0  gideon (132.146.196.31)
 -1  host254.bt-sys.bt.co.uk (132.146.196.254)  PIM  thresh^ 0
 -2  pitt.futures.bt.co.uk (132.146.111.251)  DVMRP  thresh^ 0
 -3  noc.thouse.ja.net (193.62.157.234)  DVMRP  thresh^ 24
 -4  mbone.ulcc.ja.net (193.63.94.99)  DVMRP  thresh^ 24
 -5  noc.ulcc.ja.net (193.63.94.25)  DVMRP  thresh^ 1
 -6  lea.cs.ucl.ac.uk (128.16.64.24)  DVMRP  thresh^ 24
 -7  sauce-atm.uio.no (129.240.202.82)  DVMRP  thresh^ 32
 -8  stockholm.mbone.ebone.net (192.36.148.206)  DVMRP  thresh^ 40
 -9  schnell.ebone.net (198.67.134.250)  DVMRP  thresh^ 64
-10  dec3800-1-fddi-0.WestOrange.mci.net (204.70.64.29)  DVMRP  thresh^ 32
-11  dec3800-2-fddi-1.WestOrange.mci.net (204.70.64.77)  DVMRP  thresh^ 1
-12  news-feed2.bt.net (194.72.7.122)  DVMRP  thresh^ 64
-13  ? (194.74.255.254)  DVMRP  thresh^ 24
-14  ? (194.74.255.254)
Round trip time 328 ms

* Results after 52 seconds:

  Source        Response Dest    Packet Statistics For     Only For
Traffic
194.74.255.254  132.146.196.31   All Multicast Traffic     From
194.74.255.254
     v       __/  rtt  224 ms    Lost/Sent = Pct  Rate       To
224.2.199.104
194.74.255.254  ?
     v      ^      ttl   24        0/2041 =  0%  39 pps     0/621  =  0%
11 pps
194.72.7.122    news-feed2.bt.net
     v      ^      ttl   64       -2/2048 =  0%  39 pps    -1/621  =  0%
```

```
11 pps
204.70.64.77    dec3800-2-fddi-1.WestOrange.mci.net
     v     ^      ttl   65        9/6813 =  0%   6 pps     2/622  =  0%
0 pps
204.70.64.45
204.70.64.29    dec3800-1-fddi-0.WestOrange.mci.net
     v     ^      ttl   66       11/2279 =  0%   2 pps     1/620  =  0%
0 pps
198.67.134.250  schnell.ebone.net
     v     ^      ttl   67       11/8473 =  0% 162 pps     0/619  =  0%
11 pps
192.36.148.206  stockholm.mbone.ebone.net
     v     ^      ttl   68     1027/10457= 10% 201 pps    56/619  =  9%
11 pps
129.240.202.42
129.240.202.82  sauce-atm.uio.no
     v     ^      ttl   69      976/9501 = 10% 182 pps    41/563  =  7%
10 pps
128.16.48.10
128.16.64.24    lea.cs.ucl.ac.uk
     v     ^      ttl   70     6917/12726= 54% 244 pps   230/522  = 44%
10 pps
193.63.94.25    noc.ulcc.ja.net
     v     ^      ttl   71      259/5809 =  4% 111 pps     0/292  =  0%
5 pps
193.63.94.99    mbone.ulcc.ja.net
      v     ^      ttl   72        1/4678 =  0%  89 pps     0/292  =  0%
5 pps
193.62.157.234  noc.thouse.ja.net
     v     ^      ttl   73     1096/3165 = 35%  60 pps     2/292  =  1%
5 pps
132.146.110.222
132.146.111.251 pitt.futures.bt.co.uk
     v     ^      ttl   74     1708/3371 = 51%  64 pps     0/290  =  0%
5 pps
132.146.111.254
132.146.196.254 host254.bt-sys.bt.co.uk
     v     \__    ttl   75          1634        31 pps       290
5 pps
132.146.196.31  132.146.196.31
  Receiver      Query Source
```

Transport Level - RTP and TCP Performance

The transport layer protocol used for traditional Internet applications is TCP. However, for multimedia conferencing, the appropriate protocols are RTP/RTCP over UDP. Since UDP is connection-less, and does not attempt to recover from lost packets by any hop-by-hop or end-to-end means, unlike TCP. This avoids the non-deterministic delays and *stalling* effects due to retransmissions after loss and timeout in TCP. It does so at the expense of degradation of picture or speech quality, but given loss is constrained to a reasonable level (less than 50% typically), audio and video coding schemes, and receiver tools can be designed to accommodate this without too much perceived loss of quality by the user.

The Realtime Transport Protocol, RTP, is simply a framing protocol for the media, while RTCP (Realtime Transport Control Protocol) is a statistics reporting protocol used to coordinate membership and traffic conditions within a multi-party conference. It is important to note how useful RTCP is for debugging quality problems at the network and link layers.

The Applications

The applications that we used were the Mbone tools from UCL and LBL, namely Sdr, the Session Directory tool, which lists all Mbone events; Rat, the UCL Robust-Audio Tool; Vic, the LBL Video Conferencing program, and Wb the LBL White-board, which is heavily used to provide feedback between participants.

The NTT tools were the SoftwareVision packages, with hardware assist for coding, but pure software reception. These tools are available from the network, from the sites are given in the references at the end.

Audio/Visual

We were very fortunate in having direct assistance from the audio-visual company at the QEII (the appropriately named "Interface") They ensured that we had a direct line-level studio quality audio feed to and from the PA and microphones in the main auditorium, as well as providing remote cabling for access between our cameras in the auditorium, and our computer equipment in the booth.

It is worth noting that a lot of computing audio equipment has "less than professional quality" analog audio input/output, so that typically, injecting audio output from a computer system (even a Sun or SGI workstation) to a large PA sometimes generates unexpected levels of background noise. We were fairly lucky in this respect in that the systems we happened to use were, purely by chance, not too noisy.

An important aspect of "Mboning" a large event is the choice of cameras - you need to be able to zoom in on speakers. We had one studio quality camera for capturing slides, but the other cameras we used were domestic camcorder variety - these were adequate. but only just.

Human level Staffing

Good knowledge of IP, Ethernet, Unix and Windows, as well as router configuration, and good contact information is essential. Phones (even Cell phones) and personal organizers are useful to trouble shoot things quickly.

Acknowledgments

May thanks are due to Peter Ingram and David Pratt of BT for help with coordination and router configuration. The staff at UCL's Information Systems Division, and the University of London Computer Center at the Networks Operations Center, and UCL CS helped to debug Internet multicast routing and SMDS interworking problems. Nigel Titley at BTnet helped coordinate the QEII/BT/MCI connectivity.

Further information on the SoftwareVision and Mbone tools is available from:

- http://www.hil.ntt.jp/SoftwareVision/index-e.html
- http://ugwww.ucs.ed.ac.uk/mice/archive/

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