# Using Satellite Links as Delivery Paths in the Multicast Backbone (MBone)*

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October 1, 1998

**Abstract**

The Multicast Backbone (MBone) is a virtual network that has been in operation since 1992. Through this experimental network, researchers have been learning how to deliver a scalable, one-to-many multicast service. While much of the focus on multicast research continues to be on addressing the challenges of the traditional Internet, other "non-traditional" infrastructures, like satellite, cable, and wireless networks are beginning to be recognized as important environments in which to provide and use multicast communication. The inherent broadcast nature of these networks suggests that multicast might be easier to provide as compared to the traditional Internet. In this paper, we examine how to deliver MBone sessions and MBone style applications over satellite links. We have already demonstrated the basic feasibility of delivering MBone sessions over a satellite network. The next step is to answer the question of whether a satellite network can offer performance and cost advantages. The focus of this paper is a quantitative analysis of three performance metrics: loss, jitter, and delay.

## 1 Introduction

The Multicast Backbone (MBone) is a virtual network that has been in operation since 1992. Through this experimental network, researchers have been learning how to deliver a scalable, one-to-many multicast service. The deployment of a truly scalable multicast service in the Internet has been one of the biggest challenges for researchers. The key reason can be found in the characteristics of the Internet itself. The bottom line is that the Internet provides a very limited delivery service; packets are carried best-effort across several administrative boundaries which are often congested and unstable, and can be subject to frequent routing pathologies. Packet loss rates, delays, and jitter can be high and conditions can vary for receivers in even small multicast groups.

*This work is supported in part by a research grant from HRL Labs, Malibu, California, USA.

While much of the focus on multicast research continues to be on addressing the challenges of the traditional Internet, other "non-traditional" infrastructures, like satellite, cable, and wireless networks are beginning to be recognized as important environments in which to investigate the provision of multicast communication. The inherent broadcast nature of these networks suggests that multicast might be easier to provide in these networks compared to the traditional Internet. As proof of this possibility, commercial vendors are finding they can offer some types of multicast services more efficiently over a customer's satellite networks. However, there are still a number of issues, especially relating to cost and service delivery, that remain unanswered.

There are a variety of applications that can be provided using multicast, including one-to-many software distribution, cache updates, database replication, streaming multimedia, multi-user games, interactive conferencing, etc. These classes of applications have different protocol requirements including real-time delivery constraints, jitter tolerances, and reliable data transfer requirements. The focus of this paper is on the delivery of multicast-based applications over satellite links. In particular, we examine how to deliver MBone sessions and MBone style applications over satellite links. The particular types of sessions we believe can be most efficiently delivered include those that: (1) cover a large geographic area; (2) include more than just a few receivers; (3) are of a broadcast nature with only a single transmitter; and (4) use streaming data types like audio/video/whiteboard/text. The prototypical MBone example that we use is the delivery of Internet Engineering Task Force (IETF) meetings which occur three times a year at locations around the world.

We have already demonstrated the basic feasibility of delivering MBone sessions over a satellite network in an experiment at the 40th IETF in Washington DC. The next step is to answer the question of whether a satellite network can offer performance and cost advantages, and for what types of sessions would satellites offer the most significant advantages. To a certain extent, researchers already have a qualitative understanding of the issues. However, the focus of this paper is to conduct a more quantitative analysis. The quantitative analysis is based on three metrics: loss, jitter, and delay.

This paper is organized as follows. Section 2 gives an overview of the Multicast Backbone. Section 3 details our first efforts to deliver MBone sessions over a satellite network. Section 4 describes our preliminary efforts to quantify the advantages and disadvantages of using satellites to deliver MBone content. Section 5 lists the characteristics of MBone sessions most suitable for delivery via satellite links. Future work is presented in Section 6.

## 2 Overview of the Multicast Backbone (MBone)

The main testing environment for global multicast communication has been the Multicast Backbone (MBone). The MBone[1] is an experimental virtual network created to provide the means for multicasting data to any number of connected hosts. In 1992, 20 sites connected together via a rudimentary multicast network and received audio transmissions from the March meeting of the Internet Engineering Task Force (IETF)[2]. That first audio conference, carried over the Internet and the MBone, allowed a few members spread all over the world to hear what was being said in San Diego, California.

As the MBone has evolved, new protocols have been deployed. In addition to original Distance Vector Multicast Routing Protocol (DVMRP)[3], Protocol Independent Multicasting (PIM)[4], Core Based Trees (CBT)[5] are being used. The eventual goal of multicast researchers is to make the MBone obsolete by making native multicast communication ubiquitous throughout the Internet. However, continuing to develop the Internet's multicast infrastructure is not simply a matter of turning on multicast at all the routers. For this reason, alternative network infrastructures like satellites are being considered. As the multicast infrastructure grows so does the problem of scalability and manageability. Furthermore, as the Internet's awareness of multicast grows so does the potential uses of multicast. Multicast is no longer a single function but a service with a widely varying set of characteristics.

As the MBone has evolved it has seen an increasingly diverse set of applications. Since the first audio conference in 1992 the MBone has seen the development of new applications using audio, video, whiteboard, and text as media. Even more recently developed applications using non-streaming media and require additional network services like multicast-based congestion control and reliability. Globally broadcast, streamed MBone *sessions* are a combination of the standard media types of audio, video, wb, and text. Information about these sessions are periodically transmitted across the MBone on a well-known multicast address. Using the Session DiRectory (sdr) tool[6], MBone users can obtain a list of advertised sessions. Through sdr, an MBone user can choose from this list and launch the MBone tools (including audio[7], video[8], whiteboard[9], or text[10]) required to receive the component streams of a session. For each of these tools there is a multicast group which the user *joins* when the tool is started. Once part of the group, members will receive group transmissions and they can actively participate or simply listen. Joining a group means that a user must be *grafted* into the multicast tree. The existing multicast routing protocols are capable of seamlessly providing both join (graft) and leave (prune) functions.

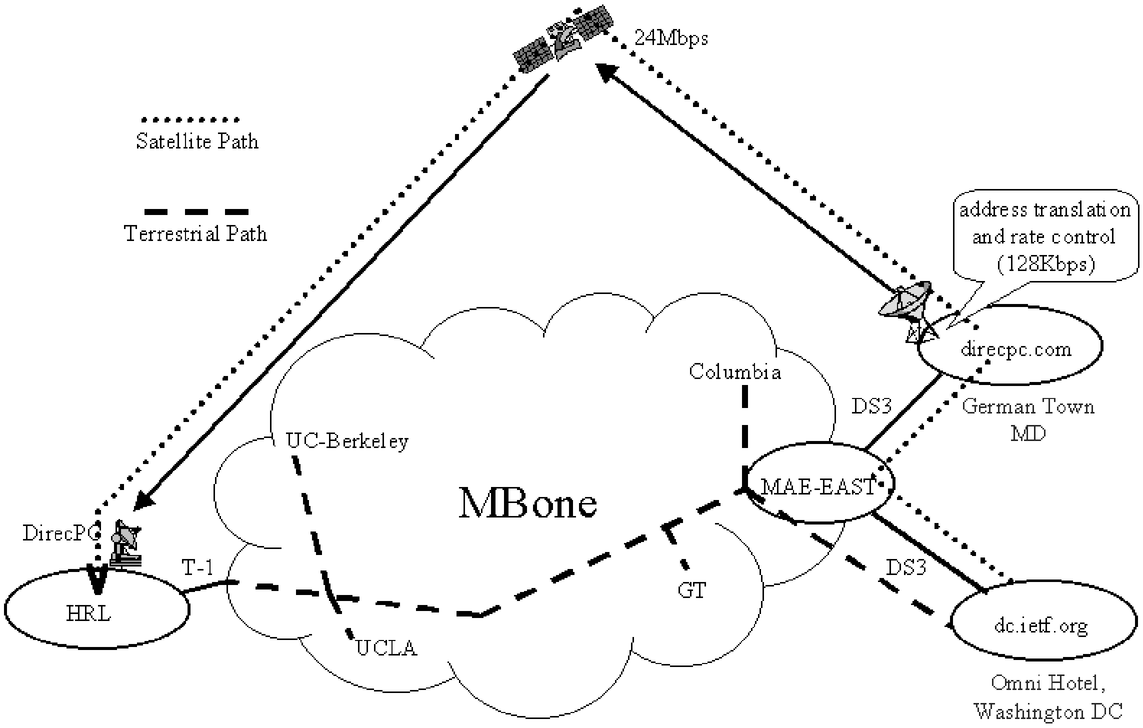


Figure 1: Logical architecture of the MBone-Over-Satellite experiment during the 40th IETF.

## 3 Satellite Delivery of MBone Sessions

We have already experimented with using satellite links to deliver MBone content[11]. For the first time at the 40th IETF in Washington DC, during the week of December 8-12, 1997, we delivered both IETF audio/video sessions. The primary lessons in the first attempts was how to bridge streaming multicast data onto a satellite network. We have continued to evolve this service including our most recent efforts for the 42nd IETF in Chicago, Illinois, USA from August 24, 1998 to August 28, 1998.

Figure 1 shows the topology of the MBone-over-satellite experiment. The first part of the experiment took advantage of the fact that IETF sessions are delivered over the MBone by the IETF staff. This satisfied our requirement for a control group with which to compare the satellite-based results. The two IETF channels were transmitted from the Omni Hotel in Washington DC and connected to the MBone via the Mae-East exchange point. We had several MBone receivers collecting quality data at their site and also one site collecting RTCP feedback from all receivers. The only disadvantage of using RTCP collected at the source is the potential loss of RTCP feedback reports from group members, especially those who are experiencing high loss. However, some percentage of reports will likely be received, even across congested links.

For the satellite component, we used the DirecPC[1] uplink center in German Town, Maryland, to (1) receive the MBone IETF channels; (2) perform address translation; and (3) transmit the sessions over DirecPC. The address translation was necessary to avoid address collision with the terrestrial MBone groups. On the down link side of the satellite there was a DirecPC receiver located at HRL in Malibu, California. It too was collecting data about the quality of the received stream.

# 4 Using Satellite Paths in the MBone

Quantitatively trying to prove that satellite paths in the MBone offers significant advantages depends on our ability to perform work in three areas. The first is to identify the key performance metrics; the second is to collect and analyze sufficient data to understand performance; and the third is to characterize the situations in which satellite links offer the most advantages. Our efforts in each of these three areas are described in the following sections.

## 4.1 Motivation and Metrics

There are a number of reasons why satellites seem a better choice for the delivery of streaming multimedia data. However, there are also some concerns which may limit the utility of satellite links. First, the potential benefits include:

- **Availability of Bandwidth**: Satellite networks offer a great deal of bandwidth with some systems capable of delivering data at rates of gigabits per second.
- **Lower Loss Characteristics**: In general, a satellite network has much lower loss rates than does the terrestrial Internet, especially when considering the growing congestion in Internet hot spots.
- **Infrastructure Support for Multicast**: When the signal from an orbiting satellite hits the Earth it has a large area of coverage. The broadcast nature of this signal makes the provision of multicast much easier. For example, a signal from a single satellite can span the entire continental United States. A signal intended for one user consumes as much bandwidth as a signal intended to reach thousands of receivers. On a related note, the common approach of providing an asymmetric, terrestrial back channel means traditional multicast protocols do not work the same way. This characteristic is both an advantage and a disadvantage. For

[1] DirecPC is a satellite network that delivers Internet traffic over a GEO satellite to anywhere in the United States. See http://www.direcpc.com for more information.

example, routing protocols may not be needed given that the satellite network is a one-hop broadcast-to-all medium.

- **Less Dependence on Wireline Infrastructure**: One of the common uses of multicast until now has been for the one-time delivery of conferences, workshops, and meetings. Providing a sufficiently fast Internet connection for these events can be both difficult and costly. One possible scenario is to use a satellite uplink to provide sufficient bandwidth, and then use permanent down links at strategic points to provide connectivity back into the Internet.

However, satellite links do have their limitations. The three that we have experienced in our work are:

- **Increased Delay**: Satellites obviously have an increased propagation delay. The question though is how much, and how do results for satellite delivery compare to terrestrial results.
- **Increased Jitter**: Qualitative results to date suggest that jitter values are also higher for satellite links. There may be a number of factors for this, but our best hypothesis is that the process of taking bits from the terrestrial network and putting them onto the satellite network is adding jitter.
- **Reaching an Uplink Point**: While injecting traffic into the satellite network can potentially be done from anywhere, we have been constrained to using a terrestrial path to get to DirecPC's main uplink site in Germantown, Maryland. This negatively affects performance though we have tried to compensate by removing the terrestrial-to-uplink component in our analysis.

Given our intuition that satellites may be better for certain types of applications, we need to develop a way to quantitatively compare the two. The two sets of metrics we consider are performance and cost. While the focus of this paper is on performance, we briefly discuss our preliminary efforts to study resource usage. Performance is measured in terms of the quality and timeliness of the transmission. These components are further refined to include packet loss, delay, and jitter.

The second metric, cost, is more difficult to evaluate. The first problem is there is no good common unit or basis for comparison. Trying to use a common unit like dollar costs is somewhat arbitrary because the process of converting resource usage to dollars is an inexact process. This conversion is straightforward for the satellite path because satellite operators typically charge for a specified amount of bandwidth for a specified duration. However, determining a dollar cost to charge an end user for a terrestrial multicast group is very difficult. Trying to determine the cost of unicast packets or streams is difficult enough without considering the added problem of dealing with multicast transmissions[12, 13, 14]. Our goal is to first study resource usage and then attempt to develop a suitable model for comparison.

## 4.2 Methodology

Data was collected for this research using two tools during the time in which the session was happening, and one additional tool for post-event processing. The types of data collected and the tools used for each include:

- **Group membership using *mlisten***: The mlisten tool[15] was used to collect group membership, join inter-arrival time, and membership duration information for each component of the two IETF channels. The *mlisten* tool works by joining each multicast group and noting the arrival of RTCP packets from each group receiver. This data is archived and can be used to reconstruct a group's membership over time. The *mlisten* tool does not look at data contained in RTCP packets and so does not collect information about packet loss and jitter.

- **Collecting packet loss, jitter, and delay**: All of the sessions transmitted over the MBone were recorded at the source using the rtpdump utility[16]. This tool collects both RTP and RTCP packets. These files can be processed and the RTCP feedback packets from all receivers can be used to determine loss, jitter, and an estimate of the round-trip time. The satellite receiver used a similar method, but statistics were gathered in real-time as the session was happening. Similar techniques have been used to study loss in other sessions[17]. The biggest challenge was trying to estimate one-way delay both for terrestrial- and satellite-based receivers. For terrestrial receivers we use RTP sequence times and timing information from RTCP feedback packets to estimate the round-trip time. Because of asymmetries in the satellite network we use a different approach for the DirecPC receiver. Using RTCP-style packets we compute the terrestrial round trip time and the terrestrial-plus-satellite round trip time. We can then estimate one-way delay over the satellite using these numbers.

- **Multicast tree construction**: In order to record the multicast routes used from the source to each receiver, the *mhealth* tool[18] was used. Mhealth is a management tool that captures RTCP data and performs an *mtrace*[19] to each receiver. This data was captured during the 42nd IETF and will allow us to generate a representation, over time, of the number of links used in the multicast tree for a particular group of receivers.

### 4.3 Results

In this section we show some of the results for data collected during the 42nd IETF held in Chicago, Illinois, USA, during the dates August 24-28, 1998. The results presented focus either on the entire week, in the case of group membership tracking, or on one particular day, Tuesday, August 25, in the case of loss, jitter, and delay. These results are a subset of the data collected but generally represent behavior commonly observed for other IETF meetings, and other MBone sessions. Finally, the satellite-specific results presented in this section were observed over a particular configuration using the DirecPC satellite network. While these results will likely be typical of other satellite networks, without results from other satellite networks we can only suggest that our hypothesis is that results will be similar.

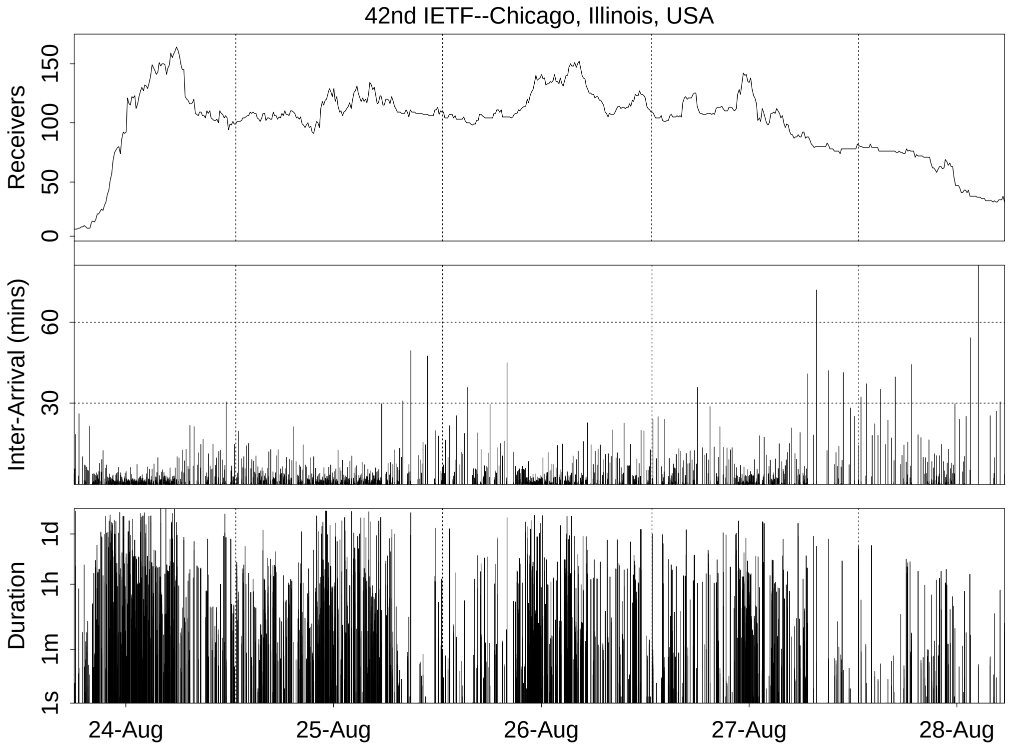


Figure 2: Group membership details for the 42nd IETF groups.

Figure 2 shows group size, inter-arrival time, and group membership duration for both IETF channels and all three media formats. The average values for each metric are shown in the graph. Again, results are consistent with past IETFs, i.e. membership and group join/leave activity increases during periods of active transmission. However, it might be worthwhile to note that there is a growing trend for smaller MBone audiences. One generally agreed upon conclusion is that the quality of MBone broadcasts is not increasing or is even decreasing. MBone receivers are becoming more dissatisfied with the current quality levels and are less likely to use the MBone. A second interesting observation is that for many multi-day sessions there is no activity at “night” and so membership dips dramatically. However, the IETF has a policy of retransmitting all of a day’s sessions at night so receivers on the opposite side of the world can see the sessions during their “daytime”. For this reason, the group membership does not decrease as much during the night.

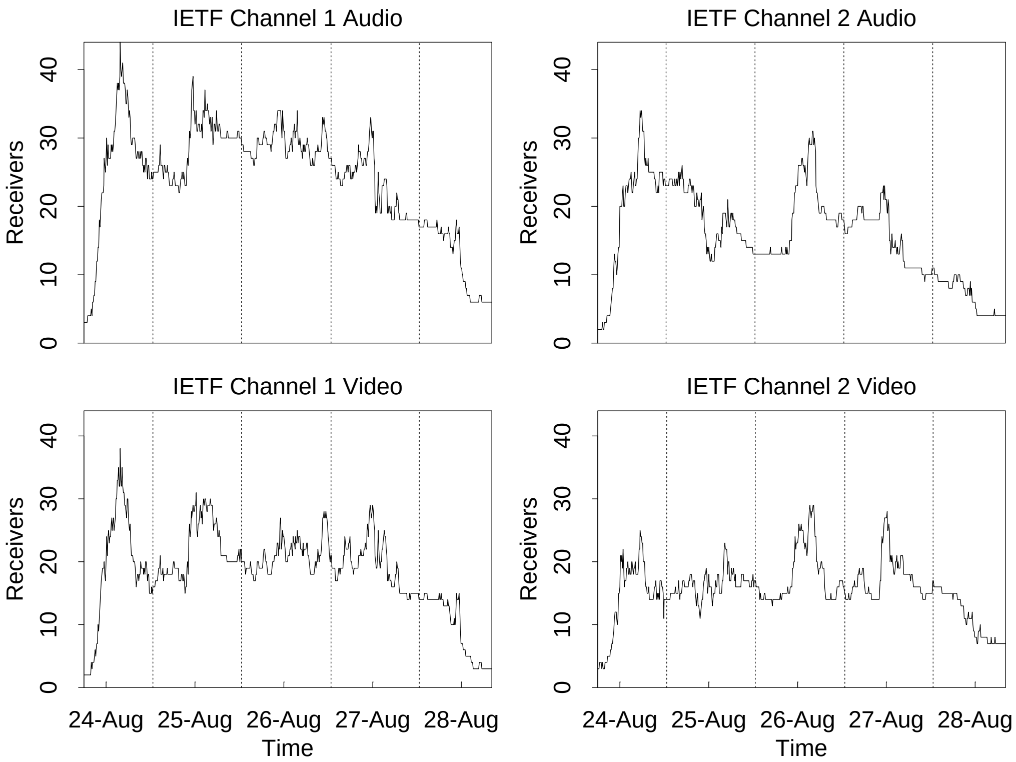


Figure 3: Breakdown of group membership for each IETF audio/video channel.

Figure 3 shows a breakdown of group size for each of the audio and video groups for both IETF channels. The results show typical behavior for moderately sized multicast groups[14, 20]. The data used in Figures 2 and 3 is important because it can be combined with topology information to re-construct the multicast tree over the course of the session. The data can also be correlated with active periods of transmission and loss patterns. For each group, multicast trees are built by using the minimum set of links to connect a source to all receivers at a particular point in time.

Figures 4 and 5 show the average loss for each receiver who participated in any of the four sessions on Tuesday, August 25, 1998. Figure 4 shows the average loss for the 110 audio receivers and Figure 5 shows the loss for the 140 receivers in the video group. The two horizontal lines in each graph represent the average for all terrestrial receivers, and the average for the DirecPC-based receiver (these lines are difficult to see because the average is nearly zero).

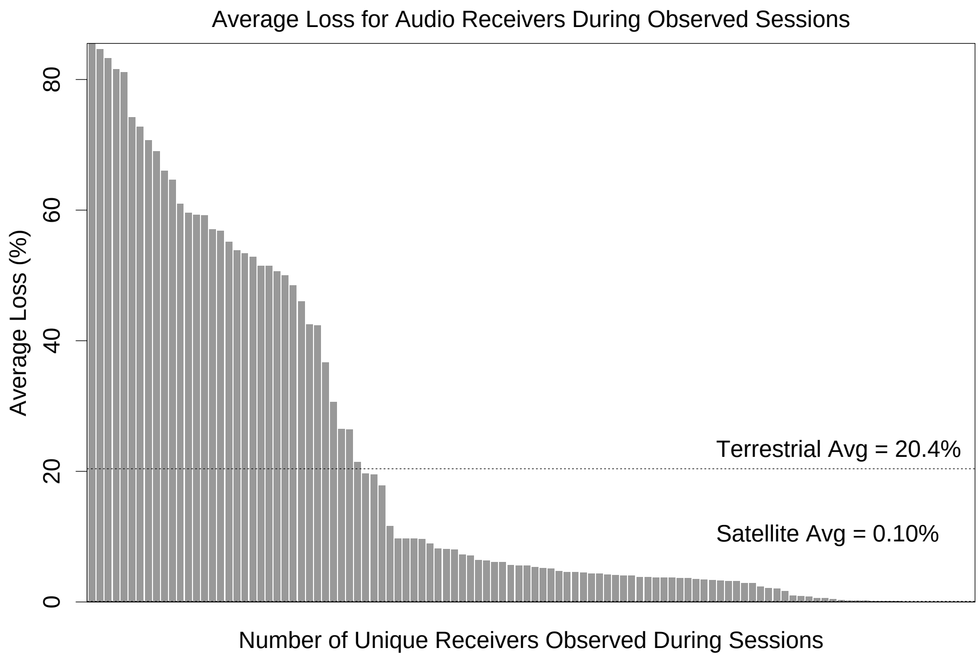


Figure 4: Packet loss for all Channel 1 audio receivers on Tuesday, August 25, 1998.

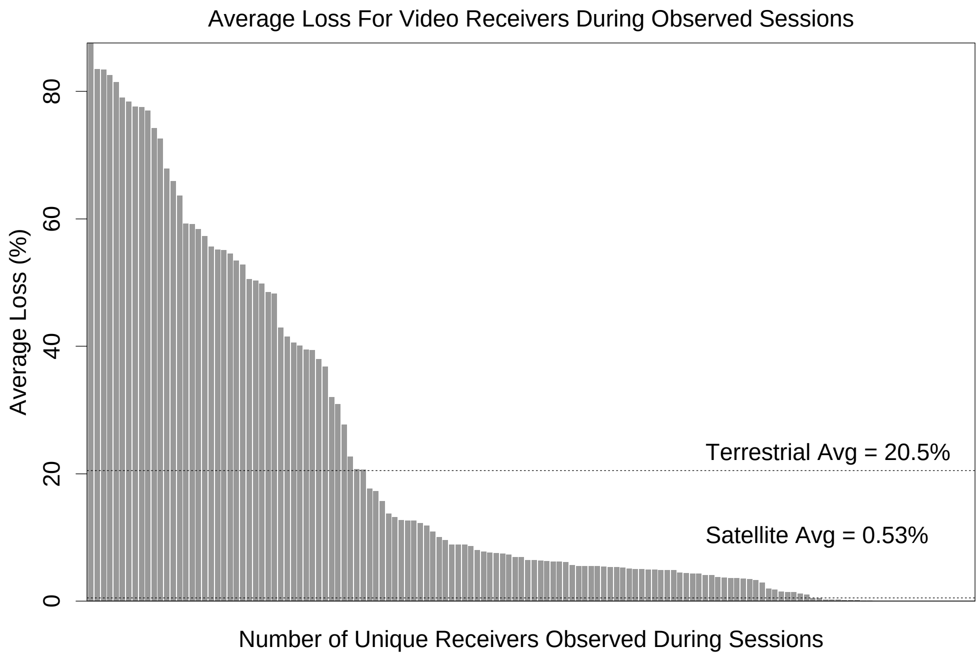


Figure 5: Packet loss for all Channel 1 video receivers on Tuesday, August 25, 1998.

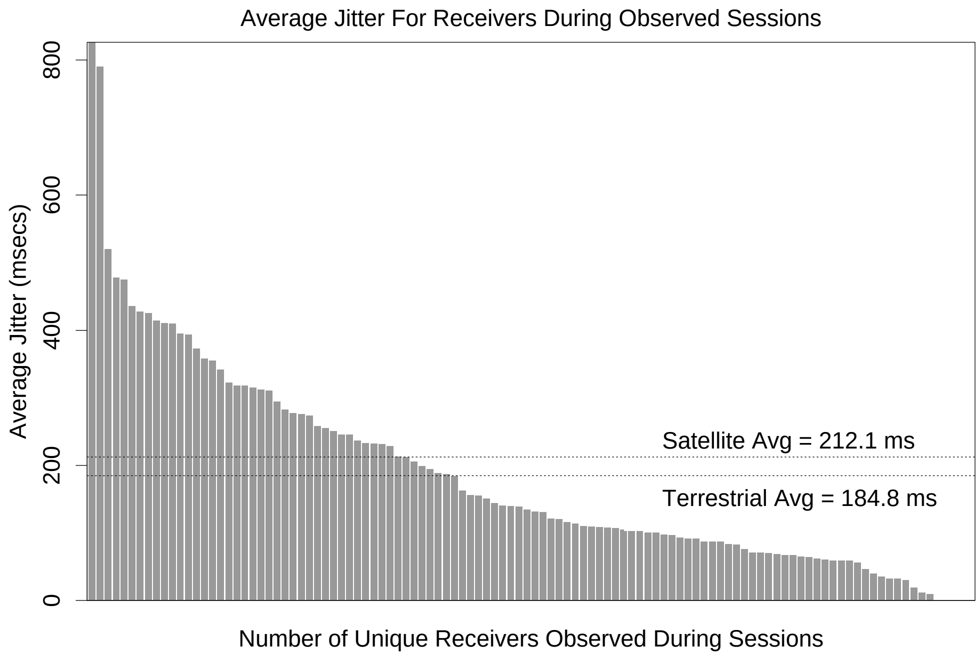


Figure 6: Jitter for selected terrestrial and DirecPC sites receiving IETF sessions.

These results were computed by averaging all of the RTCP packets received from each group member during the Tuesday IETF sessions broadcast on Channel 1. These results are aggregated and averaged over the entire period.

The results show that both audio and video have similar loss characteristics. The DirecPC-based transmission has almost no loss. This can be attributed to the fact that the satellite network can reserve bandwidth and typically has very little congestion. In the case of the terrestrial Internet, more than half of the receivers have less than 20% loss but the few receivers with very high loss arbitrarily increase the average dramatically. Trace results during the IETF suggest that the primary reason was that the multicast tree included several very heavily congested links, including trans-Atlantic and trans-Pacific links.

Figure 6 shows the jitter results for the same set of sessions and same set of receivers as was used for the audio loss results shown in Figure 4. The key result is that jitter via the DirecPC link is only slightly higher than the average for all the terrestrial-based receivers. This shows, at least for this set of experiments, that jitter is not significantly worse than for the terrestrial network. However, while jitter for the DirecPC receiver is not significantly different than the average, it is still worse than 65% of terrestrial receivers. This suggests there is still a need to investigate the

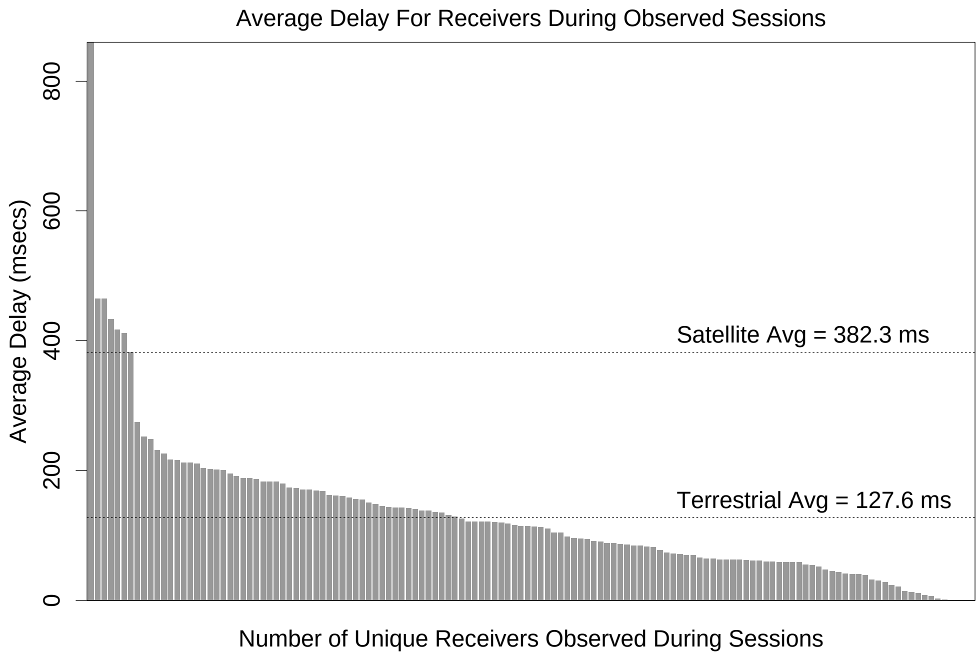


Figure 7: One-way delay for selected terrestrial and satellite sites receiving IETF sessions.

source of jitter in the DirecPC network and attempt to reduce it. In addition, techniques can be used to dampen the affect of the jitter. For example, a small amount of buffering and delay can be used at the receiver to wait for delayed packets. However, additional buffering adds additional delay, which for real-time, interactive sessions can be a drawback.

Figure 7 shows an estimate of the average one-way delay experienced by each video receiver to participate in the Tuesday IETF sessions transmitted on Channel 1. The general conclusion is that the delay for the DirecPC-based receiver is more than 2.5 times the average of the terrestrial-based receivers. This result was expected given the long propagation delay of satellite networks. The comparison would have been even worse if not for several terrestrial receivers who had very long delays. Further investigation into this set of receivers shows that all of them where located in Europe and had to cross very congested trans-Atlantic links. This set of hosts is also responsible for some of the highest audio and video losses, and some of the largest jitter measurements.

These results were computed using a combination of RTCP statistics and ping packets. For the terrestrial receivers, RTCP provides a mechanism to estimate round trip time because the source sends its timestamp in each RTP packet, and this is returned in the RTCP packet plus additional information about the elapsed time between when the receiver got the packet and when it sent the RTCP feedback packet[21]. Computing an estimate of one-way delay is a matter of computing the round trip time, subtracting the receiver's "hold" time and dividing by two. Computing the one-way delay for the DirecPC receiver was harder because of the asymmetric delay inherent in using the satellite network in one direction and a terrestrial path for the reverse direction. The method used was to send two RTCP-style packets from the DirecPC receiver to the DirecPC uplink site; one response was returned via the satellite link and the other was returned via the terrestrial Internet. By subtracting half of the terrestrial round trip time from the terrestrial/DirecPC round trip time we can estimate the DirecPC-only, one-way delay.

# 5 When to Use Satellites?

Investigation into the use of satellite links is ongoing, but results observed over DirecPC suggest quality can be significantly improved with only a slight increase in jitter and a fair increase in delay. These results suggest that using satellite links to deliver multicast transmissions makes the most sense for sessions with the following characteristics:

- **Large, disperse groups**: Terrestrial multicast is most efficient when groups are not widely scattered. Because of the inherent broadcast nature of satellites, each additional receiver can receive data for no additional cost, no matter how dispersed group members are. The issue of how to best provide inter-continental satellite connectivity is still an open issue.

- **Avoiding terrestrial hot spots**: Satellites offer performance gains for receivers whose terrestrial routing would carry them over links with high packet loss due to congestion. For example, the packet loss percentages to some sites makes the terrestrial MBone unusable but acceptable quality can be achieved using a satellite link. Furthermore, satellite down links do not necessarily need to terminate at a end host. A down link might be placed in a strategic location somewhere in the backbone allowing a transmission to bypass a congested network access or exchange point. The decision on where to put down links is an issue left for future work.

- **Pre-arranged broadcast sessions**: Because of the unidirectional nature of most satellite systems, the most effective use of satellite links is as a unidirectional broadcast. Other types of sessions, like truly interactive collaborations, will be more difficult because of the additional delay and jitter. However, VoD-style sessions or planned program broadcasts that do not have as strict timing requirements would be more suitable for delivery via satellite links.

And finally, a session that has well known start and stop times would make reservation and assignment of bandwidth in the satellite network easier.

## 6 Future Work

We have only begun to collect the data necessary to evaluate the trade offs of using satellite links to carry MBone sessions. The data sets we have to date are limited to IETF sessions. Our ongoing goal is to refine our data collection methods and, at future IETFs, collect more types of data for both satellite and terrestrial delivery. Once we have more complete data sets we can more accurately use the quantitative analysis techniques developed and presented in this paper. And finally, continued analysis and additional conclusions will give us a better understanding of the tradeoff of terrestrial- versus satellite-based multicast communication.

## 7 Acknowledgments

We thank Hughes Network Systems and its DirecPC division for providing satellite bandwidth and technology assistance. We would also like to express our gratitude to the DirecPC NOC personnel, especially Matt Kenyon, Richard Lodwig, and Bill Donnellan for their endless helps. Finally, we would like to thank David Makofske for assisting in the collection of data at the 42nd IETF.

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