# An Experimental Study Of Video Traffic on an Ethernet Local Area Network*

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**Abstract**

Video applications and multimedia services will likely be the largest consumers of bandwidth on future high speed networks, such as B-ISDN/ATM.

This paper presents an empirical study of a continuous bit rate video application (VideoPix) on an existing (low speed) 10 Mbps Ethernet local area network. The performance of the application is found to be poor in terms of the quality (i.e., frame rate) of the video delivered to clients of the video server. However, a detailed analysis of the network traffic produced by the application shows that the network itself is not the performance bottleneck. Rather, the performance is limited by display technology, the X window system, and TCP/IP. If these performance limits could be overcome, a single uncompressed video application would easily consume all the available bandwidth on an Ethernet local area network.

Technical Subject Area: Multimedia and Broadband Services and Applications

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# 1 Introduction

Networks such as the Broadband Integrated Services Digital Network (B-ISDN) are the enabling technology for a new wave of video applications and multimedia services [1, 5, 6, 9]. Such networks will offer the raw bandwidth (e.g., 150 Mbps) necessary to support the wide scale deployment of such applications. Furthermore, such integrated networks will have mechanisms to guarantee the stringent quality of service requirements (e.g., delay, jitter, loss) characteristic of many multimedia applications.

Video applications will likely be the largest consumers of bandwidth on future high speed networks. Uncompressed video can easily consume large amounts of network bandwidth. For example, with 640x480-pixel NTSC-standard size images, and 8 bits of colour information per pixel, a display rate of 30 images per second would require over 70 Mbps. Even in compressed form, video applications typically require 1.5-10 Mbps, depending on the video compression algorithm used, and the characteristics of the video source used.

Understanding the performance impact of video applications on the network is thus a key to the successful design, deployment, and management of future high speed networks. Network traffic measurement is the first step in this process of understanding the impact of video traffic workloads. Such work is particularly important since, in many cases, video applications and multimedia services are available *now*, while the high speed networks necessary to adequately support them are not.

This paper presents an empirical study of a video application (VideoPix [7]) on an existing (low speed) Ethernet local area network. The application runs on standard Sun workstations and allows a video server to distribute NTSC standard video images to video client workstations elsewhere on the network. The video input can be selected from either a video camera or a VCR attached to the server. Clients can then view "video in a window" using the X window system [8]. Up to four video clients can be supported simultaneously, all watching the same video source.

In our environment, the video application is found to perform poorly. While the NTSC standard specifies a frame rate of 30 images per second, in practice we observe approximately 1 image per second for full size full colour images. Reducing the image size and changing to black and white instead of colour both improve the frame rate, but the performance of the video application is still nowhere near TV quality.

Our initial assumption was that the 10 Mbps Ethernet network was limiting the end-to-end performance of the video application. To verify this, we initiated an experimental study of the network traffic workload produced by the VideoPix application.

To our surprise, it turned out that the Ethernet was not the performance bottleneck at all. Rather, the performance limits come from current display technology and software overheads in the X window system and TCP/IP [2, 8].

The purpose of this paper, then, is to present the highlights of our experimental study of the VideoPix application. The paper focuses on the network traffic measurement and workload characterization aspects of the study.

The remainder of this paper is organized as follows. Section 2 presents the experimental methodology used for the study. A description of the measurements and results are presented in Section 3. Conclusions are outlined in Section 4.

# 2 Experimental Methodology

## 2.1 Experimental Setup

The experimental setup for the measurement study consisted on a video server workstation and a video client workstation, as shown in Figure 1. The video server workstation was a SPARCstation IPX with 16 Mbyte RAM. A VHS video cassette player was connected to the video server, providing NTSC-standard images from VCR-quality VHS videotape. The video client workstation was a SPARCstation IPC with 8 Mbyte RAM with GX-8 framebuffer and colour monitor. The video images were displayed on the client using the X window system.

The video images from VideoPix were transmitted over a 10 Mbps Ethernet local area network. The Ethernet segment used for the study was separated from the departmental and campus network by a router so that very little background traffic was present on the network during the study.

## 2.2 Measurement Tools

Two different network measurement tools were used for the study: a LAN analyzer [3] and *tcpdump* [4]. Both measurement facilities were directly connected to the Ethernet network used for the study, as shown in Figure 1.

The HP 4972A LAN Protocol Analyzer is a hardware-level network monitor. The LAN analyzer is a passive network monitor that employs the standard IEEE 802.3 Ethernet protocol to monitor all packet traffic on the network. The LAN analyzer provides aggregate network statistics such as network utilization, packet arrival rate, and packet size distribution. Traces can be collected using the LAN analyzer, and then transferred to another machine for later analysis. All packets traveling on the network are timestamped with a timestamp accurate to 32 microseconds.

*Tcpdump* is a software tool for network traffic monitoring. Tcpdump can be used at the user-level to specify kernel-level packet filtering by protocol, by host, or by application. All packet headers that match the specified filter are recorded into a packet trace file for later analysis. Each packet recorded by tcpdump contains a timestamp (accurate to 1 millisecond), source host, destination host, sequence number, packet size, protocol used, and other protocol dependent information. Again, tcpdump is a passive network monitor and is transparent to the participating hosts.

Tcpdump was used as the main trace collection facility for the experimental study, because of its flexibility. The LAN analyzer traces were used primarily for validation of the

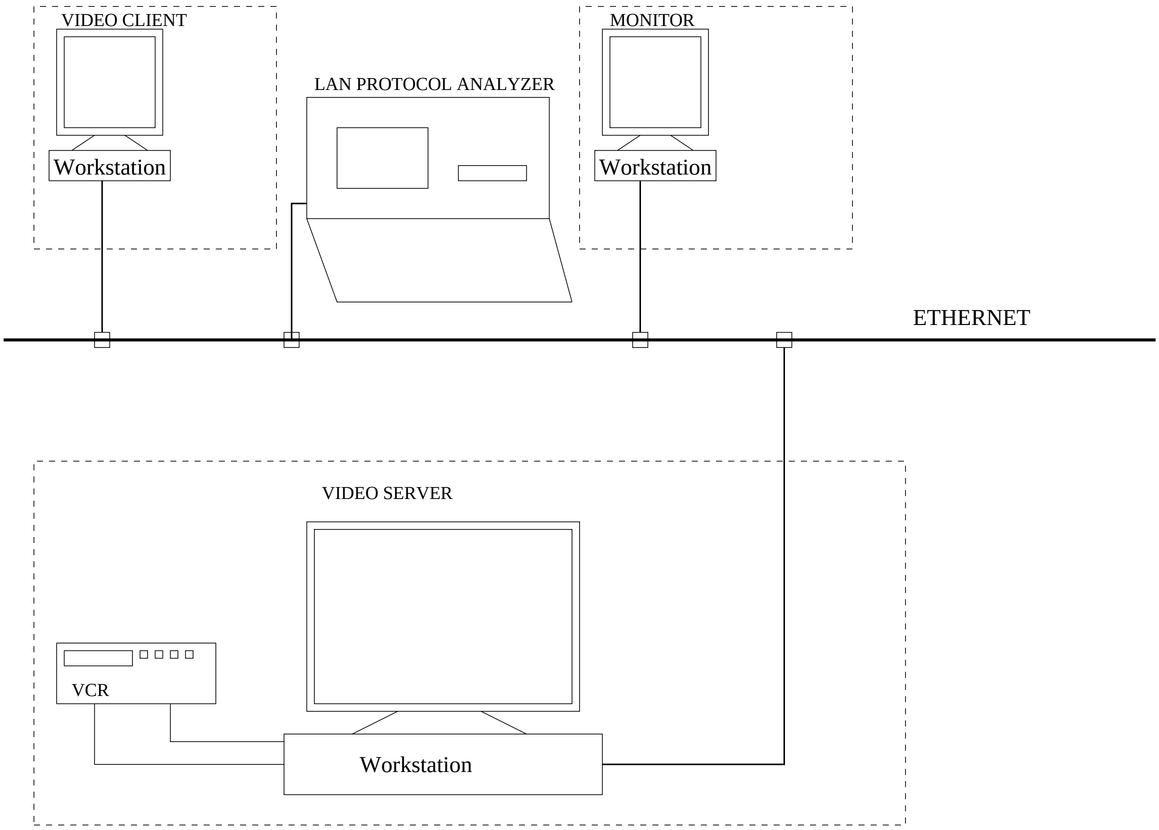


Figure 1: Experimental Setup

tcpdump data (e.g., to make sure that the software monitor was not missing too many packets).

### 2.3 The Measured Application: VideoPix

The video application used in the experimental study was VideoPix [7]. VideoPix is a Sun Microsystems package that provides NTSC-standard "video in a window" on Unix workstations. The application comes in two parts: a VideoPix hardware card that does the image digitization and storage, and the VideoPix software that provides the user interface.

The VideoPix user interface allows the user to specify the location, size, and other attributes of the displayed video images. Three sizes are available: full size (640x480 pixels), half size (320x240 pixels), and quarter size (160x120 pixels). The user can choose between black and white (B/W) and colour images. VideoPix also provides facilities for "frame grabbing" and storing images in different formats (e.g., RGB, JPEG, raster).

The images transferred across the network by VideoPix produce a continuous bit stream of raw uncompressed NTSC images. For black and white images, the images use 8-bit/pixel grayscale representation. For colour images, the images use 8-bit/pixel colour representation, suitable for the 256-colour displays used in the experiment. As soon as one image has been received, displayed, and acknowledged by the video client, the video server sends the next image.

## 3 Video Traffic Measurements

Traces were collected using *tcpdump* for periods of 5 minutes for each image size and type allowed by VideoPix. Longer traces were not possible because of the large storage requirements for each trace. However, longer traces are not required since VideoPix is a continuous bit rate source. That is, studying several seconds worth of network traffic tells you all there is to know about the application's workload characteristics.

### 3.1 Trace Characteristics

Table 1 displays a summary of the traces obtained. All traces were 300 seconds in duration. The average number of packets per second on the network produced by VideoPix ranges from a low of 78 packets per second for quarter size colour images, to a high of 722 packets per second for full size black and white images. In all cases, the data transfer is unidirectional. That is, packets from the video server to the video client carry lots of data bytes (in the TCP data segment). Packets from the client to the video server are simply acknowledgement packets (zero data bytes beyond the minimum Ethernet plus TCP header size).

Table 1: Summary of Trace Information

| VideoPix Image Type | Duration (sec) | Client-to-Server | | Server-to-Client | | Total Pkts/sec |
|---|---|---|---|---|---|---|
| | | Packets | Data Bytes | Packets | Data Bytes | |
| Full Size Colour | 300 | 31081 | 0 | 53137 | 60173644 | 281 |
| Half Size Colour | 300 | 18387 | 0 | 31602 | 36070252 | 167 |
| Quarter Size Colour | 300 | 8570 | 0 | 14826 | 14298432 | 78 |
| Full Size B/W | 300 | 74911 | 0 | 141830 | 152422244 | 722 |
| Half Size B/W | 300 | 44165 | 0 | 81820 | 89413752 | 420 |
| Quarter Size B/W | 300 | 18057 | 0 | 33802 | 38830724 | 173 |

## 3.2 Video Frame Rate

A simple calculation can be performed on the data in Table 1 to determine the frame delivery rate for the video client for each image size and type. For example, with full size colour images (640x480 pixels, with 8 bits of colour information per pixel), VideoPix achieves a frame display rate of $\frac{60173644\ bytes}{300\ sec} \div 307200\ bytes/frame = 0.65$ frames per second at the video client. This calculated value is consistent with the perceived video quality. The video is jerky, and the display rate is definitely less than one frame per second.

A summary of the (calculated) frame display rate for the other image sizes and types is shown in Table 2. Smaller image sizes result in faster frame rates, as expected. Black and white images also result in faster frame rates, as might be expected. In all cases, however, the perceived video is still noticably jerky. The highest display rate achieved is 6.74 frames per second for quarter size black and white images.

The results in Table 2 suggest a strong dependence of the frame display rate on the display technology. For example, the display rate for quarter size images is roughly four times the display rate of full size images. The display rate for black and white images is about 2.6 times faster than the display rate for colour images of the same size. Thus the display rates achieved seem to be a function of the frame buffer technology used for image display.

Table 2: Summary of Video Frame Display Rate Achieved

| VideoPix Image Type | Frame Rate (images/sec) |
|---|---|
| Full Size Colour | 0.65 |
| Half Size Colour | 1.56 |
| Quarter Size Colour | 2.48 |
| Full Size B/W | 1.65 |
| Half Size B/W | 3.88 |
| Quarter Size B/W | 6.74 |

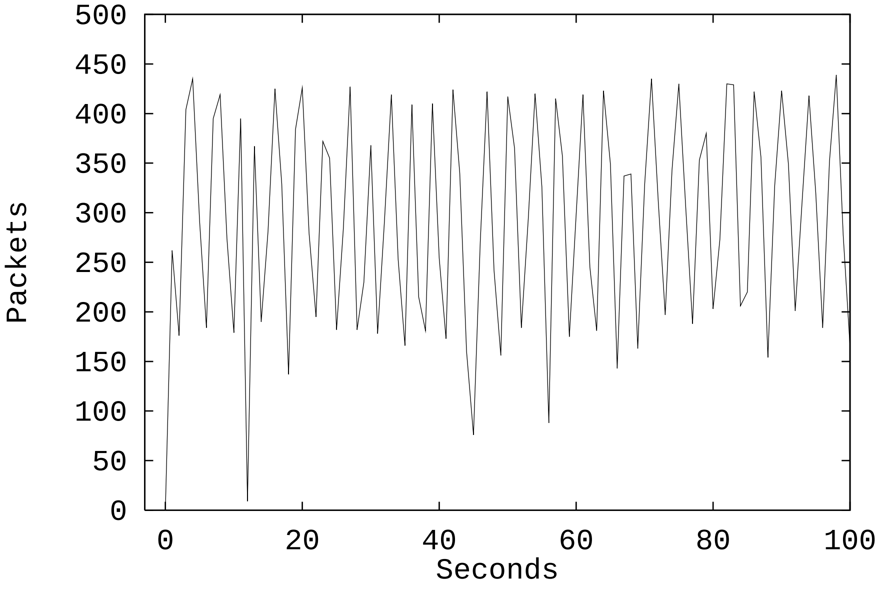


Figure 2: Total Packet Arrival Rate for Full Size Colour Images

The remaining subsections focus on the network traffic workload characteristics for two particular examples of the VideoPix application: full size colour images (the most visually desirable, but slowest to display), and quarter size black and white images (the fastest to display). The workload characteristics considered include packet arrival rate, packet interarrival time distribution, packet size distribution, and network utilization.

## 3.3 Packet Arrival Rate

The total number of packets transferred by VideoPix for full size colour images is shown in Figure 2. The packet arrival rate is calculated by counting the number of packets seen in each one second period of the tcpdump trace.

The average packet arrival rate for the trace is approximately 280 packets per second, but the actual packet arrival rate fluctuates significantly. The jaggedness in the graph is an artifact of the one second interval used for plotting the data. Since VideoPix transmits images consecutively, and the time required to transmit one full size colour image exceeds one second, some one second intervals see a full blast of video packets, and some intervals see the slight pause between successive images. Thus while VideoPix is conceptually a continuous bit rate video source, it does produce bursty network traffic when viewed at the granularity of one second intervals.

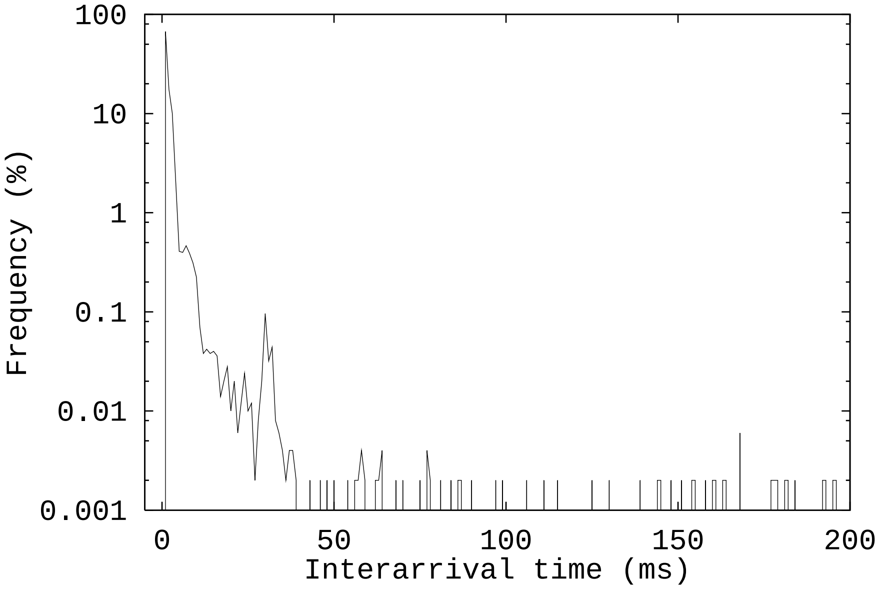


Figure 3: Packet Interarrival Time Distribution for Full Size Colour Images

## 3.4 Interarrival Time Distribution

The same packet trace data was analyzed to study the packet interarrival time distribution. Packet interarrival times are calculated by subtracting the timestamps on successive packets in the trace. The resulting differences are then plotted as a frequency distribution, as shown in Figure 3.

Most of the packet interarrival times are short, as expected. Over 95 percent of the packets had interarrival times less than 7 milliseconds. The mean packet interarrival time is 3.57 milliseconds.

## 3.5 Packet Size Distribution

The results for packet size distribution are shown in Figures 4 to 6. Figure 4 shows the aggregate packet size distribution for full size colour images. Approximately 37% of the packets are maximally sized Ethernet packets (1460 data bytes). Approximately 33% of the packets are minimally sized acknowledgement packets (zero data bytes). The remaining packets have intermediate sizes, primarily of 1176, 1024, and 588 bytes.

The remaining two figures (Figures 5 and 6) show the packet size distribution for unidirectional traffic from the video server to the video client. These plots focus only on the packets transmitted by the video server; all the acknowledgement packets transmitted by the client are ignored. Figure 5 shows the packet size distribution for full size colour images,

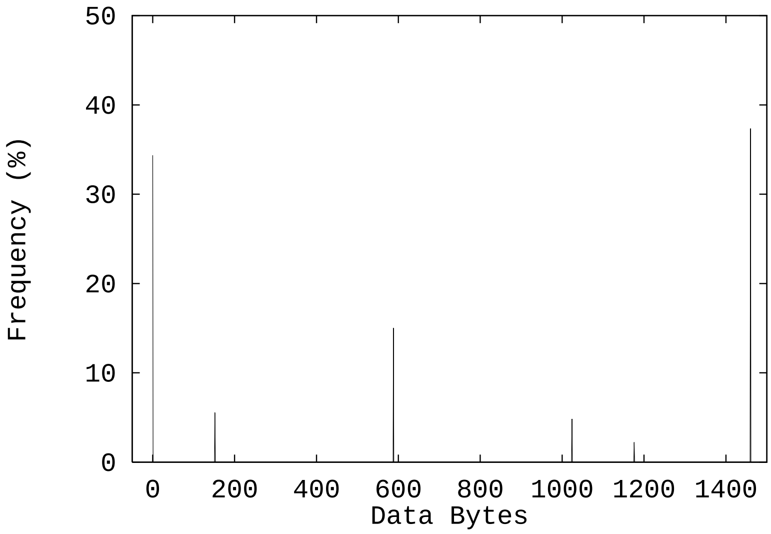


Figure 4: Total Packet Size Distribution for Full Size Colour Image

and Figure 6 shows the distribution for quarter size black and white images.

The figures show that data traffic is dominated by maximally sized Ethernet packets (e.g., over 60% are 1460 bytes), plus a sprinkling of smaller packet sizes. The presence of spikes at packet sizes of 1460, 1176, 1024, and so on can be attributed to the flow control mechanism in TCP. At the server, TCP uses a default flow control window size of 4096 bytes. Thus the server can construct two maximally sized Ethernet packets of 1460 data bytes each, and has 1176 bytes left over to send before the send window is exhausted. Thus the common and recurring pattern in the network traffic is as follows: three data packets of sizes 1460, 1460, and 1176, respectively, followed by one or two acknowledgement packets from the client to advance the send window, followed by another burst of data packets. Occassionally, the 1176 byte packet is broken into other packet sizes (e.g., 1024 plus 152, or 588 plus 588), for unknown reasons.

This flow control window size is another factor that limits the performance of the VideoPix application. The server must often block and wait for the send window to be advanced before sending any more image data. Increasing the flow control window size would somewhat improve the end-to-end performance of the VideoPix application.

## 3.6 Network Utilization

Measurements were taken using the LAN Protocol Analyzer to determine the network utilization for the various image types. The average and peak network utilization observed for the various image types are shown in Table 3. The network utilization includes the

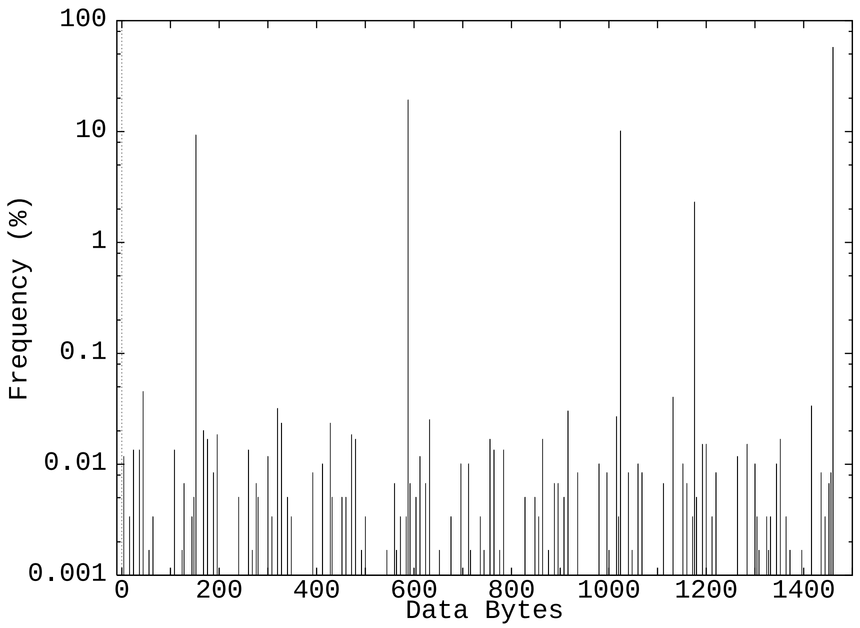


Figure 5: Packet Size Distribution for Full Size Colour Image (Server–Client)

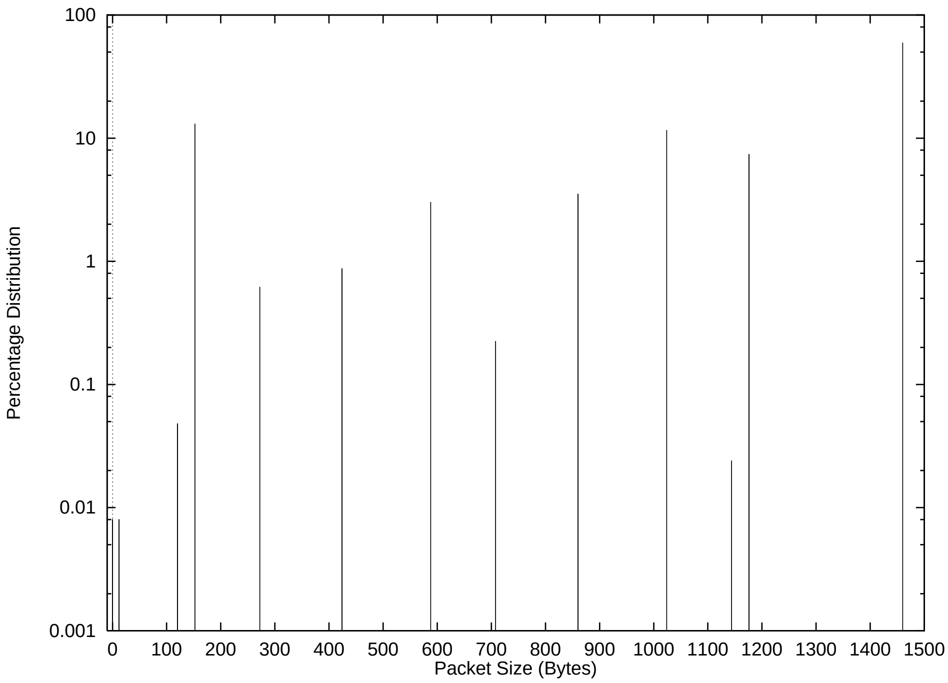


Figure 6: Packet Size Distribution for Quarter Size Black and White Image (Server–Client)

Table 3: Utilization of the Network

| Image Type | Utilization Percentage | |
|---|---|---|
| | Average | Peak |
| Full Size Colour | 21.69 | 30.00 |
| Half Size Colour | 11.47 | 16.95 |
| Quarter Size Colour | 5.67 | 11.95 |
| Full Size B/W | 39.57 | 44.68 |
| Half Size B/W | 26.14 | 31.03 |
| Quarter Size B/W | 11.72 | 13.14 |

transmission of packet headers (Ethernet, TCP, and IP) as well as data bytes. With this consideration in mind, the network utilization results presented here are consistent with the results presented for the tcpdump measurements in the preceding subsections.

The utilization results show that the Ethernet itself is not the performance bottleneck for the VideoPix application. The average utilization is barely over 20% for full size colour images. The highest network utilization observed is approximately 40% for full size black and white images.

A separate experiment provides further confirmation for the observation that the Ethernet is not the bottleneck. The VideoPix application can be run and viewed directly on the server itself, which has the same frame buffer and display technology as the client. In this configuration, VideoPix produces no packet traffic on the Ethernet network. However, the frame display rate for full size colour images is still only 0.80 frames per second. Thus the frame buffer seems to be the main performance bottleneck. The software overheads (e.g., packetization) for network communication do slow VideoPix down somewhat, but the network itself is not the bottleneck.

## 3.7 Summary of Results

The end-to-end performance of the VideoPix application is found to be poor in our environment, in terms of the frame display rate at the video client. The maximum frame rate that was observed was approximately 8 images/sec (for quarter size B/W images).

This low frame display rate is most likely due to the low speed of the frame buffer at the client. Smaller images result in a significant speedup in the frame display rate. Black and white images also result in speedup. These observations are consistent with the hypothesis that the frame buffer is the performance bottleneck for the VideoPix application.

A study of the utilization of the network revealed that the network itself is not the performance bottleneck for the VideoPix application. The highest average utilization of the network was a maximum of only 40 percent, for full size B/W images. Nevertheless, VideoPix represents a significant load for a single client-server pair of workstations on the network. With this average load per VideoPix session, an Ethernet would be unable to support more than three or four simultaneous VideoPix users. Furthermore, as workstation and display technology improve, video applications will be able to consume more and more of the bandwidth available in local area networks.

# 4 Conclusions

This paper presents an empirical study of an uncompressed video application on an Ethernet local area network. The performance of the application is found to be poor in terms of the quality (i.e., frame rate) of the video delivered to clients of the video server. However, a detailed analysis of the network traffic produced by the application shows that the network itself is not the performance bottleneck. Rather, the performance is limited by display technology, the X window system, and TCP/IP. If these performance limits could be overcome, a single uncompressed video application would easily consume all the available bandwidth on an Ethernet local area network.

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