TRAFFIC MEASUREMENTS ON A TOKEN RING NETWORK

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Abstract

Data traffic measurements on a local area network are important for understanding the operation of current networks, and for the future design of networks and related equipment such as gateways. Data traffic measurements were made on a ten megabit token ring at the Massachusetts Institute of Technology and during the week of observation, 6.9 million packets transported 1.2 billion bytes. This paper presents and analyzes the week of network measurements. These measurements are compared with measurements by Shoch and Hupp of traffic on an Ethernet at Xerox PARC. Some of the findings in this paper confirm measurements made at Xerox.

1. Introduction

This paper reports the network traffic measurements made on a token ring at the Massachusetts Institute of Technology, Laboratory for Computer Science. The data in this paper were originally presented in an undergraduate thesis at the Massachusetts Institute of Technology[1].

1.1. Why Take Network Measurements?

Measurements of the token ring were originally motivated by the desire for ring performance analysis and a comparison of the performance of the ring with other local area networking strategies, such as the Ethernet. The network measurement system was also supposed to help with network management. Network management requires measurements of the network to determine the current state of the network. The current network state is compared with the expected network state. If the network is not behaving normally, then the network monitor can be used for fault detection and isolation. Determining the expected or normal network state also requires network measurements.

Another reason for network measurements is to validate or refute the assumptions made in analytical and simulation analyses of networks, because an analysis cannot be accurate if its underlying assumptions do not reflect reality. A better understanding of data traffic will lead to improved network analysis and simulation, and improved designs for networks and protocols.

1.2. Experimental Environment

The Laboratory for Computer Science ring network is a ten megabit, star topology ring with token passing channel allocation and decentralized control[2]. The ring has a thousand meters of cable that connects thirty-three computers spread across the second, fifth and ninth floors of the lab. Most of the hosts on the ring are timesharing VAX 11/750s running Berkeley Unix; other hosts include two timesharing PDP 11s and an IBM PC. Three gateways connect the ring to a ten megabit Ethernet, a three megabit Ethernet and the ARPANET. The Internet Protocol (IP) is used above the ring protocol.

Applications on the ring include remote login, file transfer and mail. An important service on the ring is a Remote Virtual Disk (RVD) service, which allows disk drives attached to two VAX 11/750s to be accessed remotely via the network by any host. Most of the VAX computers on the ring have only a small local disk and access a shared file system on the Remote Virtual Disk.

The network monitoring system is two cooperating computers: a passive monitor collects data from the ring, and an analysis machine analyzes and stores data from the passive monitor. The passive monitor is a PDP 11/10 which receives packets, extracts the desired data from the packets and sends this data to the analysis machine via the ring. The passive monitor generates 1.5% of the packets and 7% of the bytes on the ring, but these packets are excluded from the reported results. The passive monitor has two singly-buffered network interfaces to minimize undetected packets: the first interface receives most packets and the second interface receives packets while the first is busy. The analysis machine is a timesharing VAX 11/750 running Berkeley Unix that further reduces the network data into the graphs and tables in this paper.

2. Experimental Results

The data in this section were collected during a one week period beginning November 30th, 1983 at 00:07 and ending December 6, 1983 at 23:54. The analysis machine logged 6,934,030 packets and 1,230,324,945 bytes that week although it failed to receive data about 374,798 packets (5.4%) from the passive monitor station.

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2.1. Interpacket Arrival Time

Analytical and simulation analyses of computer networks often use a Poisson arrival process to model packet arrivals, but measurements on the ring suggest that a different model may be more appropriate. The passive monitor timestamps arriving packets and the analysis machine produces an interpacket arrival time histogram with these timestamps. The interpacket arrival time histogram for one second, in one millisecond intervals, is shown in figure 2-1. Not all interpacket gaps were recorded; interpacket gaps were discarded when the token was lost during the interarrival period, and when an interpacket gap could not be determined because of missed packets.

For a Poisson arrival process, the probability of an arriving packet is independent of previous arrivals, and the probability density function of packet interarrival times is: $p(t) = \lambda e^{-\lambda t}$, where λ is the average packet arrival rate. The histogram in figure 2-1 has the *percentage of packets* axis plotted on a logarithmic scale so that a Poisson arrival process would produce a straight line of: $\ln[p(t)] = \ln[\lambda] - \lambda t$. However, the plotted data does not fit a line because the probability of a packet arrival in the short period following a packet is greater than if packet generation were Poisson. This implies that the probability of packet arrival is dependent on the history of the network and therefore cannot be Poisson. In any case, it is not expected that packets would be independent; for example, a file transfer generates packets periodically.

The graph of interpacket arrivals appears to be a combination of three Poisson arrival processes, in which case the total arrival function would be:

$$p(t) = k_1\lambda_1 e^{-\lambda_1 t} + k_2\lambda_2 e^{-\lambda_2 t} + k_3\lambda_3 e^{-\lambda_3 t}$$

More research is needed to determine if a combination of three exponential interarrival processes fit the measured data well.

Several distinct spikes occur on the curve, the largest of which are at 1, 6, 16, 19, and 38 milliseconds. These spikes are probably caused by popular transactions on the ring, such as the time between a packet and its acknowledgment in a virtual circuit protocol. In addition, there are spikes around 240 milliseconds, 462 milliseconds, 690 milliseconds, and 990 milliseconds. This suggests some periodic process on the ring that occurs at multiples of 240 milliseconds.

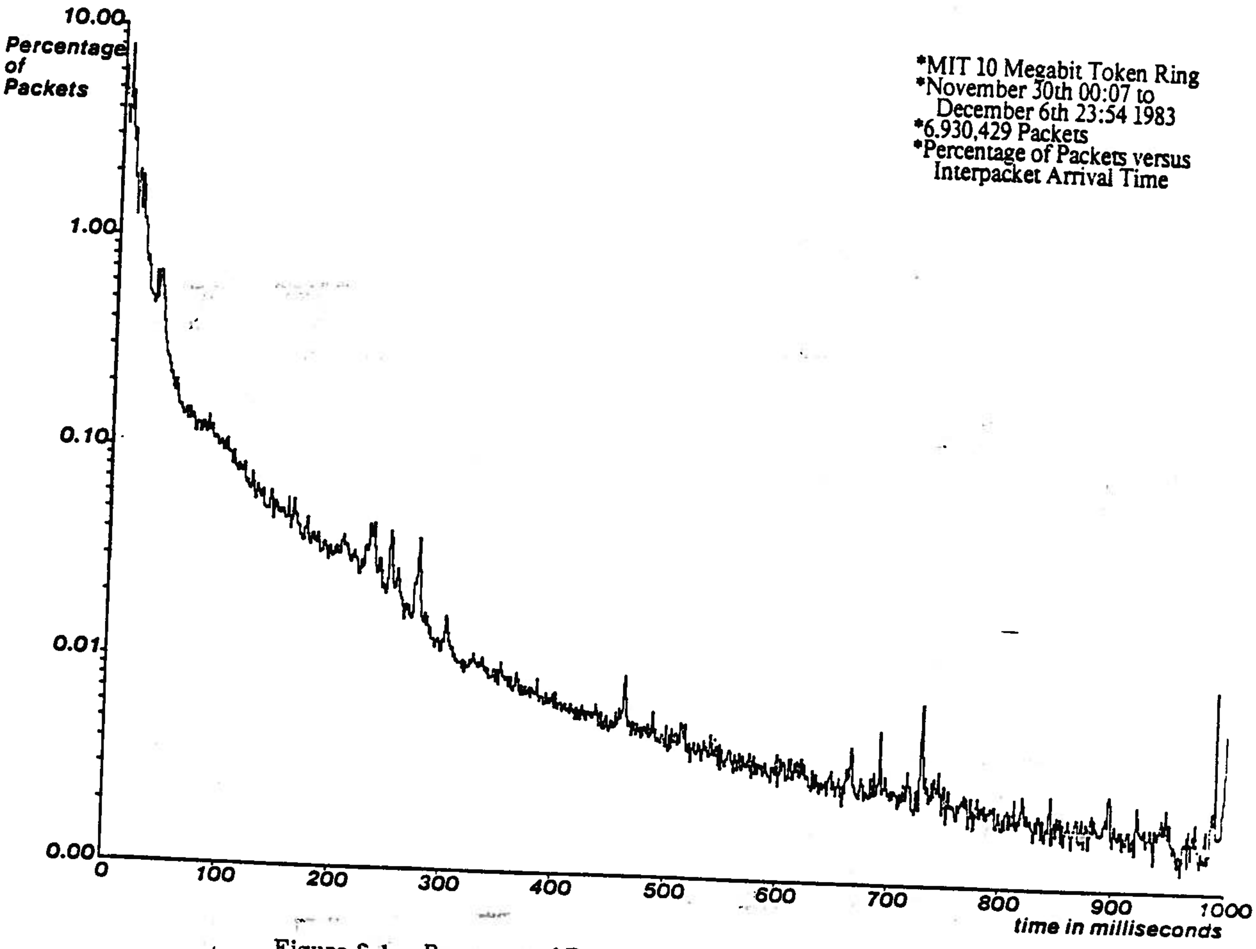

Figure 2-1: Percentage of Packets versus Interpacket Arrival Time

A model of packet arrivals that accounts for the relationship between packets is the *packet train* model proposed by Jain[3]. The packet train model is based on the concept that packets between a source-destination pair are related. For the purposes of train measurements, a train is defined as a group of packets between a source-destination pair with no two packets separated by more than 500 milliseconds. Measurements by Jain on the ring show that the average train is 18 packet long, the mean interpacket time within a train is 51 milliseconds and the mean intertrain time is 24 seconds. Because the number of trains occurring simultaneously is low, back-to-back packets are often from the same train. The measurements show that on the ring, if a packet has just been transmitted from host A to host B, there is a 29% chance that the next packet will also be from A to B. There is also a 31% chance that the next packet will be from B to A.

The ring interpacket arrival time histogram is presented in figure 2-2 for comparison with that in figure 2-3 obtained by Shoch and Hupp[4]. Both histograms are plotted on linear axes and cover 200 milliseconds. Since the ring is 3.4 times faster than the Ethernet, many packets could arrive within less than a millisecond of one another because even full size (2048 byte) packets take less than two milliseconds to transmit on the ring. However, the histograms are similar, which suggests that network software or applications, rather than network speed, determines interpacket arrival time.

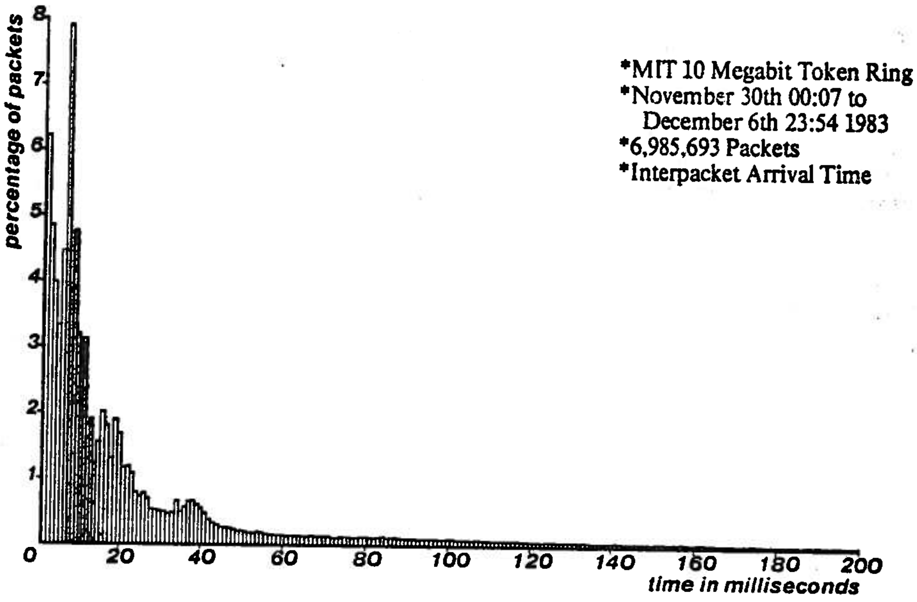

Figure 2-2: Ring Histogram of Interpacket Arrival Time

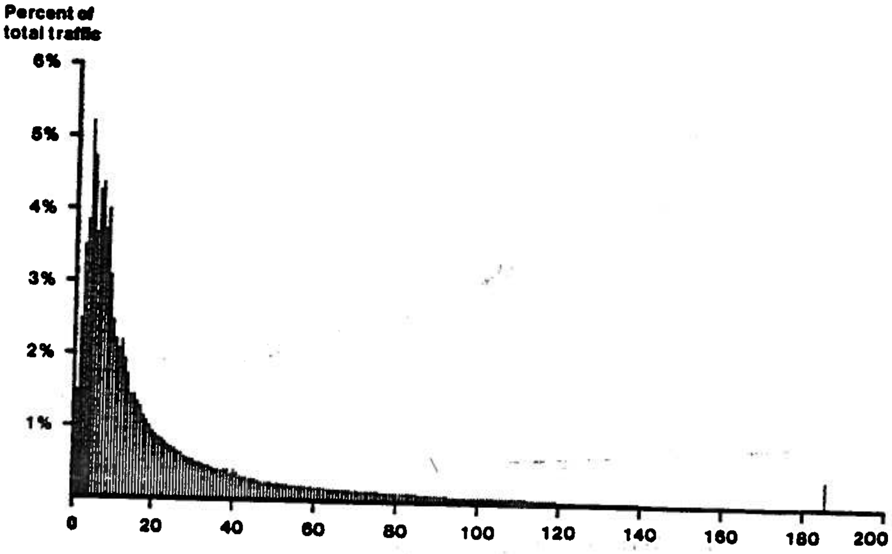

Figure 2-3: Ethernet Histogram of Interpacket Arrival Time (from reference 4)

This also suggests that the Ethernet traffic is not Poisson. Measurements on a ten megabit Ethernet at the University of Delaware also show that packet arrival is not Poisson[5].

2.2. Packet Length Distribution

A knowledge of packet length distribution can influence host buffer design and management. Packet length distribution on the ring is bimodal - most packets are either small (less than 100 bytes) or large (530 to 570 bytes). This implies that hosts need have only two packet buffer sizes (100 bytes and 570 bytes) for efficient handling of network data.

Figure 2-4 is a histogram of the percentage of packets at each length. Telnet (remote login) data packets cause the large spike at 48 bytes and telnet acknowledgment packets form the spike at 46 bytes; these two spikes alone account for 43.40% of all packets. Remote Virtual Disk single block transfers form a spike at 570 bytes. The histogram displays only packets of 600 bytes or less, which account for 99.07% of all packets and no single packet length outside the histogram accounts for more than 0.69% of all packets.

The histogram in figure 2-6 is similar to figure 2-4, except that each slot has been weighted by packet length. The largest spike is at 570 bytes, which suggests that most of the bytes on the network are transported by Remote Virtual Disk packets - the actual figure is 43% of all bytes. The histogram contains 94.36% of all bytes; beyond the 600 byte limit of the histogram, there are two packet lengths with more than 0.13% of the bytes. One is 1.2% of the total bytes at 1070 bytes, the cause of which is unknown. The other is 4.2% of the total bytes at 1082 bytes, which is an RVD packet with two disk blocks instead of one. This leaves only 0.3% of all bytes unaccounted for.

Shoch and Hupp reported similar findings on the Ethernet[4]. Both the ring and the Ethernet show that most packets are small, but most bytes are sent in large packets - see figures 2-4 through 2-7. The packet length distribution is bimodal for both the ring and the Ethernet. Terry and Andler also make the observation that packets are either small (under 128 bytes) or large (a 2K disk block)[6].

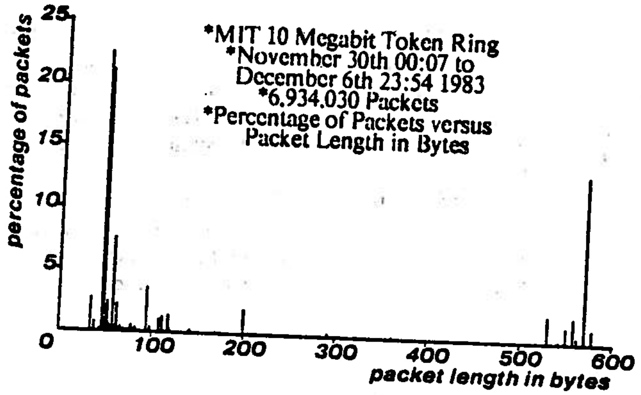

Figure 2-4: Ring Percentage of Packets versus Packet Length

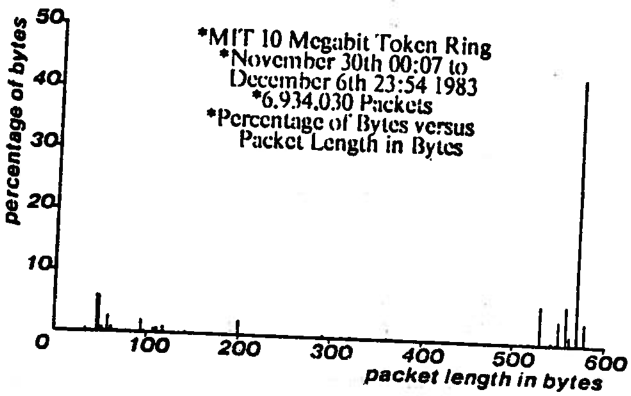

Figure 2-6: Ring Percentage of Bytes versus Packet Length

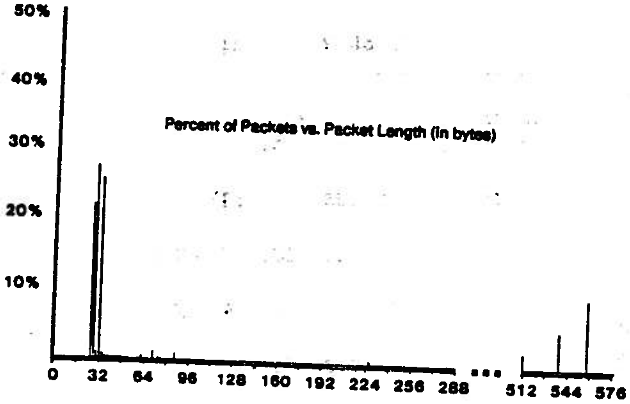

Figure 2-5: Ethernet Percentage of Packets versus Packet Length (from reference 4)

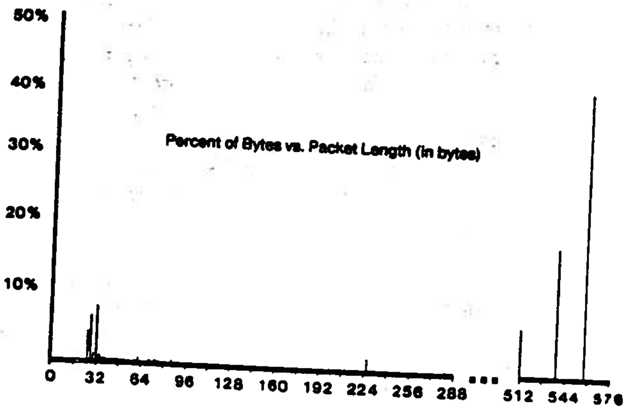

Figure 2-7: Ethernet Percentage of Bytes versus Packet Length (from reference 4)

2.3. Network Utilization

Network utilization is measured by either the number of packets per unit time, or the network load as a percentage of network capacity. Network utilization statistics can be used to decide if the network load is at the correct level for acceptable network performance. If the load is too high, the network can be divided and the pieces joined by gateways. If utilization is low, networks can be combined for more efficient interhost communication or more hosts can be added. Network maintenance should be scheduled when network usage is low, to minimize inconvenience to network users. Likewise, low-priority file transfers should be done at times when little other traffic occurs. On the other hand, network congestion is best measured during high network usage.

By either measure, ring network utilization is low. For the week of November 30 to December 6, the busiest day had 1,448,542 packets and a 0.26% load, but utilization is higher for shorter periods. The busiest hour had 261,447 packets and a 1.4% load; the busiest minute had 30,003 packets and a 5.6% load; the busiest second had 1184 packets and a 66% load. The 66% load figure may be exaggerated by token loss; if the token is lost, packets will queue until the token is replaced, and these packets will be transmitted in a burst when the new token arrives.

The traffic on the Xerox PARC Ethernet is also bursty[4]. The busiest day had a 0.84% load, the busiest hour an 3.6% load, the busiest minute a 17% load and the busiest second, a 37% load. Because the ring capacity is 3.4 times that of the Ethernet, the ring and the Ethernet carry about the same number of bytes per day.

The variation in utilization throughout the day is shown in figure 2-8. The number of packets transmitted per second, averaged over 10 minute intervals, has been averaged over a week. Because of an error in the monitoring program, only 9 of the 10 minutes were recorded for each interval; each bar in the graph has been multiplied by 10/9 to adjust for this error.

Network usage rises in the morning, is up sharply between 9:00 and 10:30 and begins to fluctuate around noon. Network usage is highest in the afternoon and drops at 6:00 PM, after which usage remains around 10 packets per second until 3:00 AM because of late workers. Remote Virtual Disk packets cause a noticeable amount of traffic on the ring, and removing RVD from service for system maintenance at 3:00 AM reduces ring traffic. The RVD service is in use again at 5:00 AM and file system checks of the remote disks cause the traffic spike then.

Figure 2-9 shows the network load versus time of day for an Ethernet system. The measurements in this paper averaged network traffic over 10 minute periods, but network load was averaged over 6 minute periods for the Ethernet. The results can be compared because both 6 and 10 minutes are long enough to eliminate short term events, but short enough to show network traffic changes throughout the day. Because packets per second were measured on the ring and network load was measured on the Ethernet, a direct comparison is difficult but general trends are visible.

Xerox PARC is a different working environment from the MIT Laboratory for Computer Science because Xerox is a business and runs on a 9:00 to 5:00 schedule, as can be seen in the network traffic in figure 2-9. Notice that the Ethernet shows spikes in network load at noon and 6:00 PM, probably caused by people saving files on a fileserver before lunch and before leaving in the evening. The Laboratory for Computer Science is an academic environment and although most staff and faculty work during the normal business day, many students have classes during the business day. These students do computer work later in the evening, which accounts for the network load not dropping until 3:00 AM.

2.4. Protocol Usage

An understanding of the applications that are run on the network can be used to improve software and network design. The protocols in use on a network imply what applications are running on the network and table 2-1 shows the protocol usage on the ring.

The network layer protocol used on the ring is the Internet Protocol (IP), a datagram-based protocol that supports several transport layer protocols. One is the Transmission Control Protocol (TCP), a host-to-host protocol for reliable communication in internet environments. Almost 60% of the packets on the ring are TCP packets, used for remote login, mail, and file transfer (FTP). Most TCP packets are small, so TCP accounts for only 27% of the bytes on the ring. As was noted above, 46 and 48 byte packets are TCP telnet remote login packets. Since these two packet lengths alone account for 43.40% of the packet on the ring, most TCP packets are remote login packets.

More than 25% of the packets on the ring are Remote Virtual Disk (RVD) packets that are used to request and deliver disk blocks of data from servers on the network. Most RVD packets are long, so RVD accounts for 60% of the bytes.

Table 2-1: Ring Protocol Usage

Internet Protocol	Number of Packets		Number of Bytes	
TCP	4,130,055	(59.56%)	336,504,735	(27 35%)
RVD	1,742,713	(25.13%)	733,872,083	(59 65%)
UDP	925,846	(13.35%)	207,369,315	(16 85%)
ICMP	235,590	(3.40%)	10,244,901	(0 83%)
others	3,219	(0.05%)	1,945,879	(0 :6%)

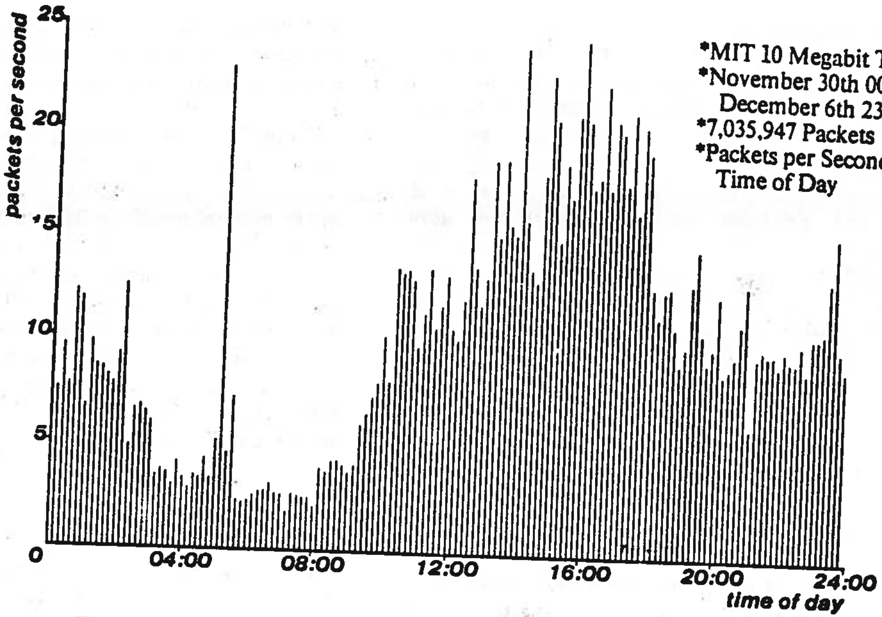

Figure 2-8: Ring Packets (Ten Minute Average) versus Time of Day

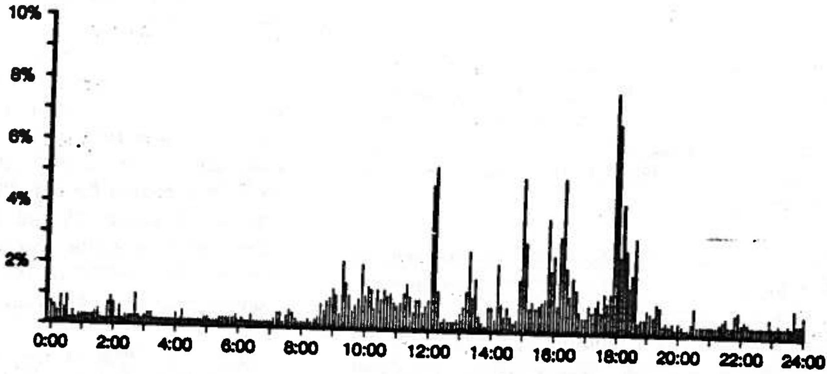

Figure 2-9: Ethernet Load (Six Minute Average) versus Time of Day (from reference 4)

The User Datagram Protocol (UDP) is a transport level protocol for unreliable datagram service. The major uses for UDP are transaction-oriented applications, such as communication with servers, and file transfer (TFTP). UDP packets account for 13% of the packets and 17% of the bytes on the ring.

The Internet Control Message Protocol (ICMP) is a transport level protocol for communicating with a source host from a gateway or a destination host. The purpose of ICMP is to provide feedback about problems in the network. ICMP packet account for 3% of the packet and less than 1% of the bytes on the ring.

2.5. Intranet, Internet, and Transit Packets

In general, it is desirable to have machines-pairs with heavy traffic on the same network to maximize throughput and minimize gateway traffic. One might expect that most of the traffic on a local area network would be among hosts on the same network, but this was not so on the ring. Traffic divides into three classes: *intranet* (both source and destination on the ring), *internet* (source or destination, but not both on the ring) and *transit* packets (neither source nor destination on the ring). Since the network monitor only records the local ring addresses of each packet, a problem with these measurements is that it is impossible to determine whether packets going to a gateway are destined to the gateway itself or some machine past the gateway on another network.

For the purposes of determining the percentage of intranet, internet and transit packets, it is assumed that no packets are destined for gateways. This is a legitimate assumption for the top three transport protocols (TCP, RVD, UDP) which account for 98.04% of all packets. For ICMP packets, some could be destined to a local gateway, but it is impossible to tell how many without examining the IP destination addresses.

Internet traffic accounts for 50% of the traffic on the ring, while intranet traffic accounts for only 46% of the traffic. The large amount of internet traffic is caused by remote login packets between the ten megabit Ethernet and the ring, and mail packets from the ARPANET. Transit traffic accounts for 4% of the ring traffic. See table 2-2 for a breakdown by protocol.

Table 2-2: Intranet, Internet, and Transit Traffic

Internet Protocol	Intranet Packets	Internet Packets	Transit Packets
TCP	33.91%	61.10%	4.99%
RVD	99.76%	0.16%	0.08%
UDP	15.21%	76.09%	8.70%
ICMP	0.33%	95.27%	4.40%
combined	45.87%	49.83%	4.30%

The ring has 50% internet traffic, more than the 28% on the Ethernet. The Xerox PARC Ethernet has almost no transit traffic, while the ring has 4% transit traffic[4]. Differences in the network environment account for the larger number of internet packets on the ring.

Many computers at the Laboratory for Computer Science connect to the ring, but most of the personal computers used for remote login are on the two Ethernets in the building, which explains why many of the remote login packets (TCP) are internet packets. Both RVD servers and all machines that regularly use RVD are on the ring for optimal performance, thus most of the RVD packets are intranet packets. The few packets that are not internet packets were generated by experiments with RVD on machines off the ring. Many UDP packet are internet packets because many servers, such as the name server and the printer server, are on other networks.

2.6. The Most Active Hosts

Hosts that communicate extensively should be on the same network for the most efficient communication. Also, to improve the performance of the network, it is essential to improve the performance of the most active hosts. These hosts should be monitored and analyzed in more detail. Table 2-3 presents the most active packet sources on the ring - the corresponding table for packet destinations is similar. The most active transmitters on the ring are the ARPANET gateway and a Remote Virtual Disk server - each contributes over 12% of the ring traffic. A timesharing system also contributed largely to the traffic because it is heavily used - most users login remotely over the network and use Remote Virtual Disk storage. The development machine is for developing and testing networking programs, which explains its many transmissions. Servers on the ring, specifically gateways and Remote Virtual Disk servers, transmitted 49% and received 47% of all packets on the ring.

Table 2-3: Hosts generating at least 5% of the packets

Host Name	Primary Function	Packets Transmitted	Percentage of Packets
Gateway	gateway	851,053	12.27%
Milo	RVD server	850,305	12.26%
Borax	timesharing	730,179	10.53%
Bridge	gateway	541,608	7.81%
Opus	RVD server	532,091	7.67%
Dutch	development	391,976	5.65%
CLS	timesharing	383,502	5.53%
	total	4,280,714	61.73%

On the Xerox PARC Ethernet, servers transmit 69% and receive 71% of the packets[4]. The difference in the two cases is partly due to a difference in interpretation. Servers on the ring are the Remote Virtual Disk servers and the gateways, but servers on the Ethernet are these types of servers and also two timesharing machines. Most Ethernet hosts are personal workstations that communicate with the timesharing machines and servers rather with than each other. The ring connects almost entirely timesharing machines that communicate with one another and are not considered servers. Ring hosts are also more autonomous and have less need for servers. The difference in server traffic is thus caused by both the different types of hosts and the definition of server on the two networks.

3. Conclusion

Traffic measurements on the ring show that traffic was similar to that found on the Ethernet, suggesting that the token ring has adequate performance and that network applications, rather than the physical network, determine the data traffic. The network monitor is also used to determine whether the network is operating properly; if not, it is also used for fault isolation. The network monitor has also been used during the debugging and testing of networking software and hardware.

The primary conclusions from the measurements are:

1. Interpacket arrival time is not Poisson because packet arrival is not memoryless - packets are most likely to occur just after a packet has passed. A better model of packet arrival is needed to fit the observed data. Measurements of the University of Delaware Ethernet also show that packet arrival is not Poisson.

2. Packet length distribution is bimodal - packets are either small (less than 100 bytes) or large (530-570 bytes). The Xerox PARC Ethernet also demonstrates bimodal packet length distribution.

3. Traffic on a local area network is bursty by nature and network utilization is a small fraction of capacity. The average over the busiest day was 0.3%, the busiest hour 1.4%, the busiest minute 6%, and the busiest second 66%. Data network traffic varies with the time of day. The network is busiest from noon to 6 PM, and least busy from 3 AM to 8 AM. Traffic on the Xerox PARC Ethernet was also bursty.

4. 60% of the packets on the ring are TCP packets (most of which are for remote login applications), but 60% of the bytes are transported by RVD packets (which are for file transfer applications).

5. Internet traffic on the ring accounts for 50%, intranet traffic for 46%, and transit packets for 4% of all packets. The Xerox PARC Ethernet had 28% internet traffic and almost no transit traffic.

6. Four of the five most active hosts are the two Remote Virtual Disk servers and two of the three gateways

Future network and protocol designs should take these measurements into account to provide for the best performance of systems on a local area network.

Acknowledgments

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