Report on WWW-traffic measurements

Tapani Nieminen

Helsinki University of Technology
Communications Laboratory
OTAKAARI 5A, FIN-02150
ESPOO, email: Tapani.Nieminen@hut.fi

1. THE GOAL OF MEASUREMENTS

The basic idea of these measurements has been to get a better understanding of the TCP/IP traffic caused by a single WWW-user. The measured statistics are aimed to be used in planning of mobile user interface for Internet. In literature we have found plenty of statistics of WWW-traffic, but they have been collected from the WWW-servers or main trunks and intended to optimize their capacity by using a cache, etc.

2. WHAT WAS MEASURED

The measurements have been made during 5.8.-23.9. 1996 in Helsinki University of Technology from the Communications Laboratory internal Ethernet LAN. The LAN was divided into three segments and there were about 40 PC's and 5 HP 700-series workstations. The measurement point was in the middle segment, from where we could see all the data coming in or going out from the LAN. From the same segment the laboratory LAN was connected to the department LAN and farther to Internet, through a PC-based KarlBridge.

2.1 The Measurement setup

The data has been collected by a public domain program called GOBBLER. It has been listening the LAN Traffic the whole measurement period except for about 20 interrupts of 5-20 minutes to transfer the data. The measurements on 26.8. were lost, when the next file was saved by a mistake on the same name. Since 2.9. the measurement period has been a whole week and measurements were started on Monday mornings.

To limit the amount of data to be handled, the GOBBLER was set up to filter MAC-packets by two rules. The protocol used was IP and one of the six consecutive words starting from byte 34 was 0050H, which is the TCP-port number used for WWW-servers. Normally an IP-header is 20 bytes and a MAC-header is 14, so the TCP-port addresses are in the bytes 34-35 for the source and 36-37 for the destination. The TCP-initialization packets have an IP-header of 24 bytes, so then the TCP-port addresses are in the bytes 38-41. The last option (bytes 42-45) was added just to be sure, and no WWW-packets were found with a 28 bytes long IP-header.

2.2 The setup used with WWW

The way, how the PCs and HP-workstations were setup during measurements was as follows. The PCs were using Trumpet Winsocket as TCP/IP-stack. In the initialization file set mtu (maximum transfer unit = the size of largest IP-packet) to be 1024 and rwin (receive window size) to be 4096. Netscape was used as WWW-browser. During measurements many persons updated the version from 2.0 to 3.0. The options of Netscape limit typically the number of (simultaneous TCP-) connections to four, network buffer size to 6 kB, memory cache to 600 kB and disk cache to 5000 kB. If the same page is viewed several times, it is read from the cache. The novelty of the page is verified once during (WWW-)session and always, when the user selects to reload the page.

The HP-workstations (WS) were using HP-UX operating system with it normal TCP/IP-stack and settings. One WS named tiltuy had version 10.01 and the rest had HP-UX 9.0x. Command “netstat -i” showed mtu to be 1500, but the receive window size could not to be read. The measured data showed it to be 32768 for tiltuy and 8192 for the others. The WWW-browser used was Netscape. After measurements it was updated to the version 3.0. The options of Netscape limit the number of connections to four, network buffer size to 32 kB, memory cache to 3000 kB and disk cache to 5000 kB. The browser verifies novelty of the page once during (WWW-)session.

2.3 Data Preprocessing

The data was preprocessed in a HP workstation by two C-language programs “tnfi2mac” and “tnwwwmat”. In the first one the 4-5 consecutive data files covering 1 - 3 days each were concatenated to form a week long period. All non-WWW packets were filtered out and data parts were cut off leaving only timing information, and MAC-, IP- and TCP-headers, that included all the information needed for the statistics. Then the data of each packet was saved in one of 56 files on the basis of the terminal side MAC address. The WWW-terminal side was chosen on the base of TCP-port numbers. The WWW-server is assumed always to use TCP-port number 80 (0050H) and the other end is assumed to be a terminal.

The terminals were compared by the MAC- and IP-addresses to the known addresses of the PCs and HP-workstations in the LAN to guarantee, that all the terminals processed really belonged to the Communications Laboratory LAN. To confirm the processing all the exceptions were collected to a file and identified to correspond known terminals, like the ISDN-router. They were excluded from the measuring data, because their usage was small and statistics were assumed to differ in some respect, like delay, from the analyzed groups (PCs and WSs). As result from “tnfi2mac” we got 56 files, each holding the headers of all WWW-packets coming from (labeled as Uplink) or going to (Downlink) a specified terminal during a week.

In the next phase this raw material was collected and changed to MATLAB files by program “tnwwwmat”. The data was handled in two batches first 46 PC-files and then 5 WS-files, because their statistics were assumed to differ in some respects. The non-zero files are analyzed one at a time so, that the statistics of a week actually form a queue of N times one week terminal sessions. For the MATLAB processing “tnwwwmat” calculates 33 matrices, that can be divided into four groups. They are divided into “All”, “Uplink” and “Downlink” statistics represent by the second letter “a”, “u” or “d” in the name of the data file.

1. Packet level statistics are saved in large 9 matrices, which include

- length of every (IP-)packet as got from the IP-header (“pubyte.mat" and "pdbyte.mat")
- length of every (IP-)packets (IP- & TCP-)headers in bytes ("puhede.mat" and "pdhede.mat")
- delay from previous packets in either link ("putime.mat" and "pdtime.mat")
- delay from previous packets in the same link ("putimu.mat" and "pdtimd.mat")

2. TCP-session level statistics are saved in 8 matrices, which include
- number of packets in a TCP-session ("tupac.mat" and "tdpac.mat")
- sum of bytes in a TCP-session (“tubyt.mat" and "tdbyt.mat")
- sum of bytes in the (IP- & TCP-)headers in a TCP-session (“tuhed.mat" and "tdhed.mat")
- duration of a TCP-session ("tatim.mat")
- starting time of a TCP-session ("tastr.mat").

Because of the HTML-protocol opens a separate TCP-session for each WWW-page, -picture or other such element, it is quite usual, that there is several TCP-session open simultaneously. So I didn’t see any sense to try measure the delay between TCP-sessions, when their mutual relations were not determined.

3. Burst level statistics are saved in 8 matrices, which include
- number of packets in a Burst ("bupac.mat" and "bdpac.mat")
- sum of bytes in a Burst (“bubyt.mat" and "bdbyt.mat")
- sum of bytes in the (IP- & TCP-)headers in a Burst (“buhed.mat" and "bdhed.mat")
- duration of a Burst ("batim.mat")
- delay from the previous Burst ("badel.mat").

A Burst was defined as a period of activity on the connection, during which the maximum delay between two consecutive packets does not exceed two seconds.

4. WWW-session level statistics are saved in 8 matrices, which include
- number of packets in a WWW-session ("supac.mat" and "sdpac.mat")
- sum of bytes in a WWW-session (“subyt.mat" and "sdbyt.mat")
- sum of bytes in the (IP- & TCP-)headers in a WWW-session (“suhed.mat" and "sdhed.mat")
- duration of a WWW-session ("satim.mat")
- delay from the previous WWW-session ("sadel.mat").

A WWW-session was defined as a period of activity on the connection, during which the maximum delay between two consecutive packets does not exceed five minutes. It was estimated to represent the period, when the user is actively using WWW. When there is no traffic in five minutes the user can be assumed to have either closed, put to background or simply forgotten the WWW-session at least for a while. When the length of active WWW-sessions was analyzed in one reference, the differences caused by selecting time limit to 5, 10 or 20 minutes were noticed negligible.

2.4 MATLAB-processing

MATLAB was used to calculate histograms and unite the statistics from different weeks and plot the pictures and graphs. The limitations in available memory and processing capacity forced to calculate the histograms and other statistics for one week at the time. The data for the whole period was created by combining these results. This makes it also possible to compare the results between different weeks.

Each histogram was calculated separately from each weekly data and saved in a file with histogram name and suffix ".mvt" to separate the from input MATLAB-files, that use suffix ".mat". To be able to calculate the mean and the standard deviation jointly over seven variable size data matrices, three variables, yn, ys and y2, were counted and saved in the same file with corresponding histograms. They include the number of items (yn), sum of items (ys) and sum of squares of items (y2). Calculating data for PCs was done by a program "tn2sump" and for workstations by "tn2sumt" with help of about fifteen help programs. The 95 figures are drawn by program "tn2epsp" and saved to postscript files with suffix ".eps". With the same program can produce similar figures also directly from a weekly data file.

3. EVALUATION OF THE RESULTS

The measured data covers WWW-traffic from the Communications Laboratory for a period of 7 weeks. The measurement data covers 48 days. Thirty-two PC-terminals used WWW during the measurement. Fourteen of them were active during each week and totally 173 weekly terminal files were recorded, which makes the average 5,37 out of seven per active PC-terminal. From the five HP workstations was recorded 25 weekly terminal files, which makes the average 5 out of seven per workstation.

The gathered data amount is rather large. Still this over 1 gigabytes of data from seven weeks' periods would flow through an Ethernet at maximum (10 Mbit/s) speed in 15 minutes. Here are the main numbers describing it and more detailed statistics are presented by 95 figures.

	Packets	Megabytes	TCP-sessions	Bursts	WWW-sessions
PC	2569000	837,1	112267	65053	3132
Workstations	557200	172,2	14281	5629	424
Total	3126200	1009,3	126548	70682	3556

Table I. The data measured during 5.8.-23.9.1996 Packets, IP-bytes and Data-bytes.

The whole analysis except the packet starting time, that was recorded by GOBBLER-program, is based on the information included in the headers of IP- and TCP-headers of each packet. So in the figures bytes marked IP-bytes means the bytes included in the IP-packets (headers and data). The size of MAC-packets is with Ethernet 14 bytes more or 64 byte at the minimum. In ATM using LAN Emulation, the MAC-header is 16 bytes, AAL5-header is 8 bytes and padding 0 ... 47 bytes. The ATM headers use five bytes for every 48 byte cell. So the bytes for IP-packet length N bytes will become $N_A = 53 * (\text{int} ((N + 71) / 48))$, where int( ) means taking integer part.

The times are counted as differences between events. In the original GOBBLER files the time passed from the beginning of the measurement is saved into four bytes. Since the time resolution is one microsecond, the counter goes around about 20 times per day. In the preprocessing the fifth byte was calculated on the basis, that records are in FIFO-order. So every time, when the four LSBs had a value, that was smaller than the previous one, the timer was assumed to have gone around and the MSB was increased. With this method from the long quiet periods we would get only the dividend from the period divided by 1 hour 12 minutes counter period. Because this cannot happen very often, its influence on actual results is negligible. Also the times for last events in weekly files are only once under 575 000 seconds, when a week is 604 800 seconds.

The analyzed period in each file starts from the first WWW-event and stops to the last. So the analyzed time is only 5.3567e+7 seconds terminal time from the 1.046e+8 seconds in 173 weeks. The explanation is simple. In many files there is plenty of silent period in the beginning and probably even more at the end, since week was usually changed on Monday morning, and most persons did not work on weekends.

The results have been analyzed on four logical levels (Packet, TCP-connection, Burst and WWW-session). The numerical data has been presented in two sets of 95 figures, one for PCs and the second for HP-workstations (WS). The figures show many distributions calculated from the data. Each figure (fig.) is drawn by MATLAB to fixed size (210 mm x 160 mm) to A4 page and are saved in encapsulated postscript files. Here are short descriptions, what they include.

3.1 Packet statistics

The documented material includes 33 figures, where in the first five (fig. 1-5) “Distributions of Packet by their IP-Sizes” all IP-packets are analyzed. Every packet includes IP- and TCP-headers, and in most cases also the data part. The next five (fig. 6-10) “Distribution of Packet Data-Sizes” present the same statistics for only those packets, that carry a non-zero data part, and the headers are deduced from the packet sizes. In both series there are first normalized cumulative distributions of packets and bytes to give an overview about the statistics. The three histograms give more detailed picture about the packet size distributions overall and on Up- and Downlink separately. In all these distributions the resolution is one byte.

	min.	10%	50 %	90%	max.
All/PC	40	41	44	1.02e+03	1.5e+03
Down/PC	40	44	552	1.02e+03	1.5e+03
Up/PC	40	41	42	173	1.02e+03
All/WS	40	41	283	576	1.5e+03
Down/WS	40	44	576	577	1.5e+03
Up/WS	40	41	42	43	552

Table II. The packet sizes, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured IP-Packets were reached.

	min.	10%	50 %	90%	max.
All/PC	40	257	994	1.02e+03	1.5e+03
Down/PC	40	512	1.02e+03	1.03e+03	1.5e+03
Up/PC	40	41	44	344	1.02e+03
All/WS	40	290	576	577	1.5e+03
Down/WS	40	512	576	577	1.5e+03
Up/WS	40	41	42	360	552

Table III. The packet sizes, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured IP-Bytes were reached.

Numerical values from the cumulative distributions in figures 1, 2, 6 and 7 are given in tables II - V. They tell the packet size, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured value is reached.

From the packet size distributions (fig. 1 - 5) we can see, that the Uplink and Downlink differ quite significantly from each other. The Uplink carries 47 % of packets, but only 10 % of the total bytes. Ninety percents of all Uplink packets contains just the header of 40 bytes (79,6 %) or 44 bytes (10,1 %) without any data. From fig. 6 and 7 we found out, that from data carrying packets only 10 % and bytes only 4,4 % come from Uplink. The packets carrying data are rather small (average 255 bytes and variance 66 bytes) and their distribution resembles mostly Gaussian and Poisson distributions.

In the workstations the difference is even larger, when Uplink carries only 38,7 % of IP-packets, 7,5 % of IP-bytes, 5,2 % of Data-packets and 3,1 % of Data-bytes. Of all Uplink packets 92,4 % contains just the header of 40 bytes (91,8 %) or 44 bytes (0,6 %) without any data. The packets carrying data are a little larger (average 286 bytes and variance 45 bytes) than in PCs.

The Downlink transfers 53 % of packets and over 90 % of the total bytes. Of all Downlink packets 83 % contains data and most of them concentrate to few particular byte sizes namely 1024 (with 28,9 %), 552 (23,6 %), 512 (5,9 %) and 576 (3.5 %) bytes. These are clearly the maximum packet sizes set by the transport mechanism. We checked the initialization files for Winsocket-program from six PCs. The window size was found to be 4096 bytes and the maximum data unit 984 bytes. This makes with a 40 byte header a 1024 byte IP-packet. From fig. 7 we notice, that this packet size transmits 50 % of whole WWW- payload and packet size 576 22 %. So they together cover 3/4 from the payload at Downlink, which is 95,6 % from the total payload.

Usually the transferred WWW-item (for PCs average 6617 bytes and variance 49010 bytes from fig. 51) is much larger than the maximum packet size. So the distribution has few high spikes caused by the preferences of the transport mechanism like at packet lengths 552, 1024 and some others. The rest of area is covered with rather flat distribution. I understood it to be caused by the last packets with a size of the dividend left over, when WWW-items are divided by the used maximum packet size.

	min.	10%	50 %	90%	max.
All/PC	1	2	3	984	1.46e+03
Down/PC	1	2	512	984	1.46e+03
Up/PC	1	2	3	133	984
All/WS	1	2	243	536	1.46e+03
Down/WS	1	2	536	537	1.46e+03
Up/WS	1	2	3	4	512

Table IV. The packet sizes, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured Data-Packets were reached.

In the workstations the Downlink carries only 61,3 % of IP-packets, 92,5 % of IP-bytes, 94,8 % of Data-packets and 96,9 % of Data-bytes. Of all Downlink packets 88 % contains data and they concentrate to sizes 552 (17,1 %) and 576 (53,4 %) bytes. It is interesting, that the main packet size in workstations is half smaller even the maximum transfer unit mtu is larger (1500 for WS and 1024 for PC). Either there is problems in the negotiation mechanism, or the most servers consider 1500 too large. So they use instead "default" 576 bytes, which size transmits 67 % of whole WWW-payload and packet size 512 21 %. The size of the transferred WWW-item for WS with average 10540 bytes and variance 256500 bytes is clearly larger compared to a PC.

	min.	10%	50 %	90%	max.
All/PC	1	462	984	985	1.46e+03
Down/PC	1	472	984	985	1.46e+03
Up/PC	1	193	258	349	984
All/WS	1	448	536	537	1.46e+03
Down/WS	1	512	536	537	1.46e+03
Up/WS	1	236	287	355	512

Table V. The packet sizes, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured Data-Bytes were reached.

The next 15 figures (fig 11 - 25) show the "Distribution of Packet Interarrival Times" from different angles. There is actually 5 cases: All packets, Downlink measured from last packet on Downlink or on either, and Uplink measured from last packet on Uplink or on either. By comparing these we can get some ideas from phenomena embedded into TCP/IP-transport mechanism. Because most of the events concentrate very close to each other, there are three series using different time scales.

The first series (1/3) covers the first 10 seconds with the resolution of 50 ms. The problem is just, that 77,8 % (84 % for WS) from the up packets and 67 % (80 % WS) from the down packets concentrate to the first 50 ms bar. The second series covers first 0,32 s with the resolution of 1 ms. Its picture is much sharper, but still 18.3 % (37,5 % WS) of down and 11,1 % (33,4 % WS) up packets pass during the first millisecond. The third series covers logarithmic x-axis from 1e-5 to 1e+5 seconds with resolution 20 bars per decade. So alone it covers the whole interesting area, but the used log-log scale makes exact evaluation of details more difficult.

Numerical values from the cumulative distributions in figures 27 and 29 are given in tables VI - VIII. They tell the packet interarrival times, when the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured value were reached.

About the packet interarrival time distributions we can notice, that the distribution on average behaves on linear scale close to the exponential distribution. On the Uplink there is a clear local peak in the figures 11, 14 and 15 at 5 seconds. This might correspond some timer period, after which the terminal sends a new request, if no response was received. This looks very probable due the fact, that it is so similar in all the figures. It must be caused by two Uplink packets separated with a period of five seconds and no packets received from Downlink. The three smaller peaks at 3, 3,5 and 6 seconds might be same type mechanisms, although at figure 15 they are almost buried under more dense random distribution.

From the Downlink I find couple peaks, that seemed to have a little shift. The value was smaller, when I compared them to the last packet on either links instead of the last packet on Downlink (like fig. 17 at 65 ms to fig 18 at 70 ms). It presents probably about 65 ms response to an acknowledgment send by a terminal about 5 ms after the previous down packet. In Figures 19 we can find out between 40 to 60 ms a slight “shelf”, that cannot be found from others. It can be presenting the terminal delay, before it can empty its buffer and give promise to send more. In Uplink (fig. 20) there are clear peaks for example at 54, 162, 215 and 270 ms. If they would be interpreted as standard round trip delays to some used WWW-servers, they should come up with the same size from the Downlink. There they are much weaker and during actual data transmission the situation is not symmetric. They could present the round trip delay in three-way handshaking procedure from establishing connections or some standard acknowledgment rhythms in transmission at particular packet sizes.

In the workstations there is clear local peak in the figures 11, 14 and 15 is at 4 seconds on the Uplink. In figure 20 there is a very strong (a decade over neighbors) peak at 200 ms. A similar shelf, than with PCs was noticed from 40 to 60 ms in figure 19, reaches in workstations also to 200 ms. So strong and equipment dependent phenomenon can not be caused by round trip delays to WWW-servers, which have variable distances. It could be caused by buffer delays. The workstations have both larger buffers and longer measured period.

When looking log-log figures, it should be noticed, that there are three systems (log10 y-axis, log10 y-axis and the resolution that is kept relative to the x-value) affecting to the curve. They all do smoothen the curve growth, while moving to the left on x-axis. From the logarithmic distributions (fig. 21-25) we can see how densely the packets really do come. Even the relatively flat stage from 0.5 ... 200 ms means, that during the measurements there was as many packets got in 60 microsecond window around 0.5 ms than in 24 ms window around 200 ms. So the density is 400 times higher at 0.5 ms.

In Downlink we see clear peaks at 1, 0,5 and 200 ms. The first two figures correspond roughly the delay caused by 1024 or 576 bytes long packets over 10 Mbit/s Ethernet. The minimum delay 80 microsecond must be related to 64 bytes minimum packet size. The peak at 200 ms seems to be caused by some transport mechanism. A class 25 ms transfer between figures 22 and 23 reveals, that there has been a Uplink packet (like acknowledgment increasing the transmission window) little after last packet in the Downlink. The delays over one second seem to be mostly preceding an up packet (new request or repeat caused by timer).

In the Uplink delays seem to concentrate to 1 ... 50 ms from previous (down) packet and about 200 ms from last up packet. Also at 5 and 60 seconds there are clear local peaks.

The logarithmic distributions (fig. 21-25) for the workstations show hints, where and how the increased speed is divided. The relatively stable area stage from 3 ... 200 ms is shadowed by 5-10 dB higher peaks between 0,3 ... 3 ms.

In Downlink we see clear peaks at 0,3, 0,6 ... 0,75 and 2 and a lower at 200 ms. The second is strongest and it corresponds roughly the delay caused by 576 bytes long packets over 10 Mbit/s Ethernet. The peak at 200 ms has a class 20 ms transfer between figures 22 and 23 revealing an Uplink packet, like acknowledgment, little after last packet on the Downlink.

In the Uplink delays seem to concentrate between (0,08 ...) 0,3 ... 2,5 (... 200) ms from previous (down) packet and 125 ... 200 ms from last up packet. The peak in both at 80 microseconds can be caused by fast request following handshaking acknowledgment. The rest seems to be mostly acknowledgments repeating at 150 ... 200 ms period, but just under 2,5 ms delay from last down packet.

Cumulative Distributions of Packet Interarrival Times (fig 26 and 27) were made to get a better understanding of delay intervals and where do the bulk of packets really concentrate. From table VI we get, that the first 10% of packets comes to the workstation twice (PC 0,6 / WS 0,3 ms), 50 % four times (8 / 2 ms) and still 90% almost twice (224 /126 ms) as fast than to PCs. If we consider the directions separately, only the first 10% seems to have unbalance when the Downlink is mere 10-40 % faster and the Uplink 2-3 times faster. When we compare delays inside links they are clearly larger on the Uplink than on the Downlink. This is mainly due to the much smaller message fragmentation on the Uplink, that sets larger protocol delays to the main role.

	min.	10%	50 %	90%	max.
All (from PC)	1e-05	0.000631	0.00794	0.224	1e+05
Down	1e-05	0.000562	0.00794	0.251	1e+05
Down/DownL	7.94e-05	0.000631	0.0224	0.447	1e+05
Up	1e-05	0.000891	0.00794	0.158	1e+05
Up/Uplink	7.94e-05	0.00141	0.0562	0.562	1e+05
All (from WS)	1e-05	0.000316	0.002	0.126	1e+05
Down	7.94e-05	0.000398	0.002	0.141	4.47e+03
Down/DownL	7.94e-05	0.000562	0.00251	0.2	1e+05
Up	1e-05	0.000282	0.00178	0.1	1e+05
Up/Uplink	7.94e-05	0.000708	0.0316	0.251	1e+05

Table VI. The packet interarrival times [s], when the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured IP-Packets were reached.

	min.	10%	50 %	90%	max.
All (from PC)	7.94e-05	0.001	0.0224	0.316	1e+05
Down/DownL	7.94e-05	0.000891	0.0224	0.316	1e+05
Up/Uplink	7.94e-05	0.00141	0.02	0.355	1e+05
All (from WS)	7.94e-05	0.000631	0.00224	0.158	1e+05
Down/DownL	7.94e-05	0.000631	0.002	0.141	1e+05
Up/Uplink	7.94e-05	0.00112	0.0178	0.282	1e+05

Table VII. The packet interarrival times [s], when the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured IP-Bytes were reached.

	min.	10%	50 %	90%	max.
All (from PC)	7.94e-05	0.001	0.02	0.282	1e+05
Down/DownL	7.94e-05	0.001	0.02	0.282	1e+05
Up/Uplink	7.94e-05	0.00141	0.00708	0.1	3.16e+03
All (from WS)	7.94e-05	0.000631	0.002	0.141	2.51e+04
Down/DownL	7.94e-05	0.000631	0.002	0.126	1.12e+03
Up/Uplink	7.94e-05	0.00158	0.00562	0.355	2.51e+04

Table VIII. The packet interarrival times [s], when the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured Data-Bytes were reached.

From figures 26 and 27 we can also notice, that the two time distributions for Downlink are almost equal under 1 ms area. It means, that the previous packet has also come from the Downlink. The area includes 23 % (WS 40 %) of all Downlink packets and means, that the majority of these short delays are caused by successive packets flowing from the server to the client. A logical explanation is, that they are caused by the dense “packet trains” transferring large files. They stop just to wait for either a next disk access in the server, an acknowledgment from the client, or when the request has become fulfilled. The packets implementing the actual file transfer use the maximum allowable size like 1024 (576 for WS) bytes. So the delay seems actually be caused only by the time each packet is occupying the Ethernet.

The Cumulative Distributions of Bytes by Packet Interarrival Times (fig 28 and 29) and their distributions (fig. 30 and 31) were made to estimate how long the links are occupied by packets. They present both all IP-bytes (incl. IP- and TCP-headers) and just Data (exc. IP- and TCP-headers). The statistics from figures 27 and 29 are shown in tables VI-VII .

We can compare the relative amount of packets (fig. 27) and bytes (fig. 29) on the logarithmic time scale. We find these “train wagon” packets at the Downlink to be rather small, when the delay is under 0,5 ms. They cover only 2,1 % (WS 4,7 %) of all bytes, but 9,3 % (8,8 %) of packets. Then the packet size increases very sharply. So “train wagons” 0.5 ... 1 ms carry 10.8 % (WS 33,5 %) of bytes and 10.7 % (28 %) of packets. And from 1 ... 2 ms they carry 14.3 % (13,6 %) of bytes and 11.8% (11,3 %) of packets. In 10 ms after previous packet there comes about 44.5 % of Downlink bytes and 52.4 % of packets. We must remember, that the first packet of such a sequence, “ the engine of the train” is not included in these figures. This is due to the way these statistics are calculated.

From the figure 31 we get the interesting result, that the Uplink carries only 4.3 % (WS 3,1 %) from all data bytes used by HTML to offer the WWW-service. By comparing figures 30 and 33 we can note, that the portion of TCP/IP-headers is clearly larger, when the time from last packet is under 0.26 ms or when it is over 4.3 seconds. This means, that then the most of packets are headers, although some data packets have been recorded even after 1.5 hours delay.

3.2 Statistics of packet sequences

The other three groups handle statistics for higher level logical structures formed of sequences of packets. All of them include 21 figures, which are numbered in the same order. TCP-sessions have figures 33-53, Bursts have figures 54-74 and WWW-sessions have figures 75-95. The first three figures show the Distributions of session size in packets cumulatively and on both links. In these distributions the resolution is partly linear. After 25 bars the resolution is doubled so, that in the part 0...50 it is one packet, from 50...100 two packets, from 100...200 four packets, etc. With this structure, that resembles the A-law for PCM by ITU-T, I managed to find some balance between the needed accuracy and dynamics. The next four figures show the Distributions of delays between sessions and session Length. In the last three the presentation is similar to time distributions of packet interarrival times shown in first section (fig. 11, 16 and 21) and the first is similar to fig. 21.

Then there are six figures from the Cumulative Distributions of IP- and Data-Bytes and bitrates as the function of session length. They present totals to Down- and Uplink, means to Down- and Uplink, and for comparisons total bytes and mean bitrates for both links. They all have the same logarithmic scale and resolution than fig 21. The four next figures show distributions of the Average Bitrate for the session. In bitrate1 the length of the last packet in the session is assumed to be 1 ms and in bitrate2 it is assumed to be 1 s. They are calculated by dividing the sum of bytes transferred during the sessions by the duration of the session and presented with the resolution of 100 bytes/s.

Since time is recorded only in the beginning of each packet, the length of a session actually reaches only for beginning of the first packet to the beginning of the last packet. The beginning of next session is not practical because of its uncertainty. Using the actual resolution with short sessions can cause unrealistic results to bitrate calculations. A session with a single 1500 byte packet will get the minimum time resolution 1 microsecond as its length and shows the admirable 1,5 Gbytes/s bitrate.

To avoid this and still get reasonable results I determined to add one second to the counted time. It seemed practical compared to the two second time period separating bursts by definition. Later this assumption felt to be too "loose" and so I changed the added time to 1 ms, which corresponds the duration of a large packet in Ethernet. If also the bitrate scale would be changed to logarithmic, the figures would be improved to have both a reasonable resolution and enough dynamics to show also all occasional peaks. All single packet sessions were filtered out to get rid off unrealistic anomalies. The filtering rule was to remove sessions, whose duration was under 20 microseconds. The minimum size Ethernet packet takes over 50 microseconds to be transferred.

The last four figures present the distributions of IP- and Data-Bytes and bitrates as function of the session length. Their Cumulative Distributions were collected to the previous group of six figures. To packet statistics distributions of IP-bytes (incl. IP- and TCP-headers) and Data (exc. IP- and TCP-headers) like figures 30 and 31 is added two more showing the average bitrates for the sessions in same way. Its idea is to show, how the capacity needs are divided among sessions by their length.

The numerical statistics from the cumulating of session sizes, and bytes and bitrates as function of session length are shown in three tables for each group.

3.3 TCP-session statistics

With TCP-sessions there is one extra figure (fig 32) showing to us the packet interarrival time distribution viewed over TCP-sessions. The difference to fig. 21, is, that during the analysis the packets have been divided into groups of separate TCP-connections instead of terminal sessions, which allow four simultaneous TCP-connections. This gives a sharper look to the mechanisms, which actually rule these statistics. In the PCs the whole area from the peak around 200 ms to the peak at 5 s gets higher and the rest, particularly at high delays decreases. Even there it can be noticed, that the local maxims tend to decrease less than their surroundings. The strong peaks in fig. 32 can be assumed to be the results from the basic mechanisms, which are fragmented, when several TCP-connections are multiplexed in the physical network.

In workstations the same is repeated with the exception, that instead of a clear peak at 5 s, there are peaks at 10, 12,5, 60 and 300 seconds. Also the main point at 0,6 ... 0,75 ms is unchanged. This fits very well to the explanation, that it is caused on the Downlink by dense "packet trains", where there are in between no Uplink packets. The mean delay decreases with PCs from 20,8 s to 3,7 s and with WSs from 13,8 s to 0,46 s. This is mainly caused by removing of the long packet interarrival times, which do separate active TCP-connections from each other.

The distributions of TCP-session size in packets (fig. 33-35) make at the first glimpse the Uplink and the Downlink look very similar. The average amount of packets is 10,8 (WS 15,1) up and 12,1 (23,9) down and variances are 49,5 (237) and 66,2 (518) packets. In more careful comparison person can notice, that in fig 34 the peak is closer y-axis than in fig. 35. Figure 33 shows also, that although on larger sessions there is a clear 10 to 25 % majority of down packets, in short sessions the number of up packets is larger. The actual histogram numbers reveal, that the highest probability on the Uplink is with five packets 28,8% (WS 26,6 %). On the Downlink most probable are three packets for PC (22,5 %) and four for WS (25,7 %). Under these values is only 5.3 % / 4 % of sessions in up and 6,8 % / 4,8 % in down direction. The median size for a session is 6 (WS 7) up and 5 (WS 6) down packets and 90 % limits are 16 (18) up and 21 (27) down packets.

	min.	10%	50 %	90%	max.
All (from PC)	0	3	6	18	9.73e+03
Down	0	3	5	21	8.45e+03
Up	0	5	6	16	9.73e+03
All/Packets	1	5	18	416	9.73e+03
Down/Packets	1	4	27	720	8.45e+03
Up/Packets	1	5	12	208	9.73e+03
All from(WS)	0	4	7	22	5.12e+04
Down	0	4	6	27	5.12e+04
Up	0	5	7	18	2.36e+04
All/Packets	1	6	70	2.36e+04	5.12e+04
Down/Packets	1	7	144	5.12e+04	5.32e+04
Up/Packets	1	6	25	2.36e+04	2.41e+04

Table IX. The TCP-session sizes in packets, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured TCP-sessions, and the packets in TCP-sessions were reached.

This becomes quite understandable, when they are considered against the model of a TCP-connection, that WWW-browser uses to get all the items from the server. For each item, like a text page or a picture, the procedure is roughly as follows. In the Uplink on about ten (PC 9,67 /WS 13,95 from fig. 6 and 33) packets (headers) without any data are used to establish (min. 2), acknowledge and maintain (min. 1) and close (min. 1) the TCP-session. Usually only one (PC 1,12 /WS 1,15) packet is needed to send the actual request for the wanted WWW-item.

In the Downlink the situation is different, since the transferred WWW-items (average for PC 6617 bytes with variance 49010 bytes and for WS average 10540 bytes and variance 256500 bytes from fig 51) are much larger. The transport protocol limits the packet size to 576, 1024 and some others. Since over 80 % of packets carry data, there is about ten (PC 10,06 / WS 21) data and only two (PC 2,03 / WS 2,8) header packets per session. This is possible when acknowledgments and other information needed to maintain the TCP-connection are carried in the headers of data packets. So we can interpret the Downlink behavior for a TCP-session roughly as follows. Two (WS probably three) packets are used to establish (min. 1) and close (min. 1) the TCP-session. The amount of packets needed to carry wanted WWW-item varies from one to hundreds, with the average of 10-20.

Although most of the sessions are very short, the situation will change, when the actual traffic loads are considered. When weighted by the amount of packets, the median is 2 ... 20 times and the 90 % limit is 20 ... 2000 times higher. This behavior is stronger on the Downlink and with the workstations.

With this model the 5 - 7 % TCP-sessions, that has less than 5 up and/or 3 down packets, can be considered faulty. Some of them have just hung and WWW may open an other session to get the item it wants. Some of them might just miss for example the close packet, but fulfill the basic task. And some might be just statistical anomalies caused by the fact, that analyses program assumes the TCP-session to be ended, if there is no traffic during 10 minutes. The 23 % probability for just three down packets includes WWW items, which stay under the maximum packet size, and the verifications of WWW cache hits.

When the WWW-browser finds the requested page from cache it can either believe, that it is valid data, or it can verify this from the server. In our setup the WWW-browser checks all the items requested from the cache once during the WWW-session. So on the first request it opens a normal TCP-connection to the server and tells in the message the necessary information about the item, which it already has on its hard disk. If the item has not been changed, the server responds only “item is OK”, and the data can be read from the WWW-browsers cache.

	min.	10%	50 %	90%	max.
TCP-sessions (PC)	1e-05	0.282	1.41	12.6	1e+05
IPs/Down	1e-05	1.26	8.91	178	1e+05
Bytes/Down	1e-05	1.26	8.91	178	1e+05
IPs/Up	1e-05	0.447	2.82	50.1	1e+05
Bytes/Up	1e-05	0.355	1.78	20	1e+05
TCP-sessions (WS)	1e-05	0.631	2.24	14.1	1e+05
IPs/Down	1e-05	2.24	79.4	794	2.51e+04
Bytes/Down	7.94e-05	2.24	79.4	794	2.51e+04
IPs/Up	1e-05	1	5.01	398	2.51e+04
Bytes/Up	0.00282	0.794	2.51	25.1	2.51e+04

Table X. The TCP-session lengths [s], where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured TCP-sessions, IP- and Data-Bytes were reached.

Fig. 36 is labeled “The distribution of Delay between TCP-sessions”, but presents actually the time measured from the beginning of the previous TCP-session. Delay between TCP-sessions was not possible to define, because there can be up to four simultaneous TCP-connections. The two peak structure between 100 ms ... 200 s looks quite natural. We can assume, that roughly half of TCP-connections is responses to user actions, and the rest are more or less opened automatically directed by the links in requested WWW-item.

Figures 37-39 show, that the length of TCP-session varies in very large area with the highest probability around 0,5 ... 1 seconds. The low end starting 1 ms can include some unsuccessful sessions and possibly some fragments due measuring program. Their part is only 0,89 % of sessions. Also sessions taking hours or days look very suspicious, but only 0,23 % of sessions exceed thousand seconds (~17 minutes). Still they manage for PCs to increase the mean up to 84 seconds and variance up to 2920 seconds, when they are just 17,8 and 293 seconds for the workstations.

For TCP-sessions the average bitrates have been calculated to give some ideas of how much a mobile WWW-user would demand capacity from the network he is using. With the harder limit (T+ 1 ms) the mean and variance for PC/WS are 766 / 427 and 1869 / 1157 bytes/s in Uplink and 2243 / 1843 and 4411 / 3429 bytes/s in Downlink. With the softer limit (T + 1 s) they are about half of those. In practical systems the capacity must be able to keep response times acceptable and there can be on several simultaneous TCP-sessions. But it looks promising that for workstations only 1% of Downlink sessions need over 13,7 Kbytes/s capacity (= 109,6 kbytes/s). In Uplink the situation is much better and less than 1 % needs over 2 Kbytes/s (= 16 kbit/s). Figures 40-43 show, that most of the bitrate demands are caused by quite short sessions, while most of traffic happens in the longer ones. So in practice, cutting off the top bitrates would probably cause only slight increase to the absolute response times.

	min.	10%	50 %	90%	max.
Bitrate1/Down (PC)	0.000631	0.2	1.12	6.31	1e+05
Bitrate2/Down	0.000631	0.501	2	8.91	1e+05
Bitrate1/Up	0.000631	0.0447	0.355	1.78	1e+05
Bitrate2/Up	0.000631	0.2	0.794	3.98	1e+05
Bitrate1/Down (WS)	7.94e-05	0.398	1.78	6.31	2.51e+04
Bitrate2/Down	7.94e-05	0.794	2.51	8.91	2.51e+04
Bitrate1/Up	7.94e-05	0.0708	0.891	3.55	2.51e+04
Bitrate2/Up	7.94e-05	0.501	1.58	5.01	2.51e+04

Table XI. The TCP-session lengths, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the calculated Bitrate1 [byte/(T+ 1 ms)] and Bitrate2 [byte /(T+ 1m)], were reached.

From figures 50-53 we can see, that the session with duration under 150 ms transfer actually more bytes up than down. Most of the traffic happens in long sessions, under 1s long are 41 % of sessions, but they cover only 28,6 % Uplink and 8 % Downlink bytes. The median is a little under 10 s, when 88,6 % of sessions have passed 74,5 % from bytes up and 54,8 % from bytes down.

3.4 Burst statistics

A Burst was defined as a period of activity on the connection, during which the maximum delay between two consecutive packets stays under two seconds.

	min.	10%	50 %	90%	max.
All (from PC)	0	1	6	50	6.91e+03
Down	0	1	6	52	5.89e+03
Up	0	1	6	47	6.91e+03
All/Packets	1	9	70	384	6.91e+03
Down/Packets	1	10	78	496	5.89e+03
Up/Packets	1	8	62	288	6.91e+03
All from(WS)	0	1	9	84	5.12e+04
Down	0	1	9	96	5.12e+04
Up	0	1	8	72	2.3e+04
All/Packets	1	28	224	3.07e+04	5.12e+04
Down/Packets	1	35	400	5.12e+04	5.32e+04
Up/Packets	1	20	132	2.3e+04	2.36e+04

Table XII. The Burst sizes in packets, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured Bursts, and the packets in Bursts were reached.

From the distributions of Burst size in packets (fig. 54-56) at the first glance Uplink and Downlink look very similar, and here it’s much more true than with TCP-sessions. The average amount of packets is 18,6 / 38,3 up and 20,9 / 60,7 down and variances are 57,9 / 400 and 70,8 / 873. In careful comparison we notice, that the highest probability, on the Uplink 18,3 / 18,8% is with packet size one, and Downlink 12,2 / 12 %, of bursts have no and 13,3 / 10,3 % only one packet. The median size for a burst is 6 packets and 90 % limits are reached around 50 / 80 packets. When compared to TCP-connections, the small bursts seem to smaller and the median is about the same. Since there is in PC 1,73 and in WS 2.54 TCP-sessions toward a burst, the number must be significantly higher in the larger ones.

The average bitrate for Bursts has with the harder limit of bitrate1 the mean 1490 / 3156 and variance 4473 /11980 bytes/s in Uplink and the mean 9082 / 9020 and variance 30000 /31700 bytes/s in Downlink. With the softer limit of bitrate2 are the mean 324 / 354 and variance 381 / 273 bytes/s in Uplink and the mean 2226 / 2620 and variance 3241 / 3997 bytes/s in Downlink. It is very interesting, that they are so a like between PC and WS with do differ much more in many other respects.
Can this be more or less due to the limitations of the WWW-servers and the network.

In practical systems, this might be the main measure for their quality, since all the traffic is concentrated to bursts. There are some burst that require almost 80 Kbytes/s bitrate. But over 20 Kbytes/s (= 160 kbits/s) needs only 0,42 % of Uplink bursts with bitrate1 and 3,9 % of Downlink bursts calculated with bitrate1 and 0,21 % calculated with bitrate2.

	min.	10%	50 %	90%	max.
Bursts (PC)	1e-05	1.12e-05	1	7.08	1e+05
IPs/Down	1e-05	1.58	7.94	50.1	398
Bytes/Down	1e-05	1.58	8.91	56.2	398
IPs/Up	1e-05	0.891	5.62	22.4	398
Bytes/Up	1e-05	0.794	4.47	15.8	398
Bursts (WS)	1e-05	1.12e-05	1.41	8.91	1e+05
IPs/Down	1e-05	3.16	35.5	794	891
Bytes/Down	7.94e-05	3.55	39.8	794	891
IPs/Up	1e-05	2	11.2	251	794
Bytes/Up	1e-05	1.58	7.94	22.4	251

Table XIII. The Burst lengths [s], where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured Bursts, IP- and Data-Bytes were reached.

	min.	10%	50 %	90%	max.
Bitrate1/Down (PC)	7.94e-05	0.000891	0.00794	3.98	398
Bitrate2/Down	7.94e-05	0.562	2.82	11.2	398
Bitrate1/Up	7.94e-05	0.00126	0.0158	2.51	398
Bitrate2/Up	7.94e-05	0.355	1.78	7.94	398
Bitrate1/Down (WS)	7.94e-05	0.000631	0.002	6.31	794
Bitrate2/Down	7.94e-05	0.794	3.55	14.1	794
Bitrate1/Up	7.94e-05	0.0002	0.000794	1.41	794
Bitrate2/Up	7.94e-05	0.501	3.16	12.6	794

Table XIV. The Burst lengths, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the calculated Bitrate1 [byte/(T+ 1 ms)] and Bitrate2 [byte /(T+ 1m)], were reached.

Fig. 57 presents the delays between the bursts. By the definition it should be same as fig 21. above 2 second, and I could not visually find any differences. Figures 58-60 show, that the length of Bursts varies in very large area with the highest probability around 0,5 ... 1 seconds. The peak at 0 s (means only one packet) covers 14,9 % (WS 11,7 %) of all bursts. The mean burst duration is 2,74 (3,77) seconds and variance 6,28 (13,86) seconds, but the low end starts 0,1 ms and the longest reach to 400 seconds (6,5 minutes). The median is one second and 95 % is under 10 seconds. By comparing fig. 39 and 60 we see, that bursts under 100 ms are much more common than TCP-sessions. From 100 ms to 10 s their relation is close to the average and over 10 s the amount of bursts decreases faster.

From figures 71-72 we can see, that the byte distribution of bursts fits quite well together with TCP-session (fig. 50-51), when the duration is between 100 ms and 100 s. This clear relation of length between TCP-sessions and bursts hints, that although there is twice as many TCP-sessions than bursts, many reasonable size TCP-sessions might form a burst of their own. And when bursts are formed from TCP-sessions, fragmentation and consolidation are in balance at this area. The shorter bursts transferring more data than same size TCP-sessions are probably caused by the fragmentation of TCP-sessions with long delays. The relation between bytes coming down and going up stays much more stabile than in TCP-sessions, although it still about doubles above 1 s bursts. It seems like short, mostly up bytes carrying, TCP-sessions are combined to bursts with longer TCP-sessions or their fragments, which as bigger dominate this relation. Most of traffic flows in long sessions, under 1s long are 41 of sessions, but they cover only 28,6 % Uplink and 8 % Downlink bytes. The medians for bytes transferred to PCs are 6 s up and 8 s down, but for WSs 11 s up and 36 s down reflecting the larger WWW-items. A significant part of the down bytes concentrate to few long bursts like the 90 % limits 50 s for PCs and 794 s for workstations show. Fig. 60 and 61 show, that the later is probably cause of a single 794 second and 25 Mbytes burst. It alone includes roughly 17 % of all the bytes transferred to five workstations during the seven weeks.

3.5 WWW-session statistics

A WWW-session was defined as a period of activity on the connection, during which the maximum delay between two consecutive packets stays under fife minutes. It was estimated to represent the period, when the user is actively using WWW.

	min.	10%	50 %	90%	max.
All (from PC)	0	20	164	1.02e+03	1.43e+04
Down	0	19	164	1.09e+03	1.38e+04
Up	0	21	168	960	1.43e+04
All/Packets	1	196	1.06e+03	4.86e+03	1.43e+04
Down/Packets	1	208	1.18e+03	6.14e+03	1.38e+04
Up/Packets	1	184	928	4.1e+03	1.43e+04
All from(WS)	0	4	160	1.22e+03	8.81e+04
Down	0	4	172	1.44e+03	8.81e+04
Up	0	5	152	1.06e+03	3.99e+04
All/Packets	1	304	2.82e+03	8.81e+04	9.01e+04
Down/Packets	1	376	3.33e+03	8.81e+04	9.01e+04
Up/Packets	1	232	1.86e+03	3.99e+04	4.1e+04

Table XV. The WWW-session sizes in packets, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured WWW-sessions, and the packets in WWW-sessions were reached.

The distributions of WWW-session size in packets (fig. 75-77) are very similar on Uplink and Downlink. The average amount of packets is 387 / 509 up and 434 / 806 down and variances are 702 / 2140 and 856 / 4626. Somewhat annoying is the notice, that a little over 3 % of WWW-sessions have fewer packets than a minimum TCP-session (one page) needs. Question is again about some kinds of anomalies either in the TCP-sessions (long delays) or the data processing. One logical solution would be to base the definition of WWW-session to systematically verified (anomalies removed) TCP-sessions instead of packets. The chance would improve the quality of information in all levels, but it would need more work. The 10 % limit corresponds to PC 3-4 WWW-items with 21 packets up and 19 down, but for WS only one short item. The median size for a WWW-session is around 170 packets for both PCs and WSs and the 90 % limit is 10 - 35 % larger. The greater number of down packets for workstations corresponds roughly the smaller packet size used. When the comparison is done by the number of transferred bytes, the few really large WWW-sessions in the workstations seem to increase all the limits remarkably. It is no wonder, since the two largest up and down sessions are responsible of about 30 % of all bytes.

	min.	10%	50 %	90%	max.
WWW-sessions (PC)	1e-05	3.55	200	1.12e+03	1e+05
IPs/Down	1e-05	178	891	2.82e+03	3.55e+03
Bytes/Down	1e-05	178	891	2.82e+03	3.55e+03
IPs/Up	1e-05	100	794	2.51e+03	3.55e+03
Bytes/Up	0.0112	70.8	708	2.24e+03	3.55e+03
WWW-sessions (WS)	1e-05	2.24	112	708	1e+05
IPs/Down	1e-05	178	1e+03	1.78e+03	2.82e+03
Bytes/Down	0.000794	178	1e+03	1.78e+03	2.82e+03
IPs/Up	0.000794	100	708	1.78e+03	2.82e+03
Bytes/Up	0.2	70.8	501	1.41e+03	2.82e+03

Table XVI. The WWW-session lengths [s], where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the measured WWW-sessions, IP- and Data-Bytes were reached.

Fig. 78 presents the delays between the WWW-sessions. By the definition it should be same as fig 21. above 5 minutes, and I could not visually find any differences. Figures 79-81 show, that the length of WWW-session varies in large area with the highest probability around 100 ... 1000 seconds. The mean WWW-session duration is 439 / 268 seconds and variance 640 /378 seconds. The low end starts under a second (anomalies ?) and the longest reach to 3550 seconds (~ 1 hour). The 10 % limit is 3,6 / 2,2 seconds, the median is 200 / 112 seconds and 90 % limit is 1120 / 708 seconds. By comparing fig. 39 and 81 we see, that for PC there are no WWW-sessions above 3000 s, but about 100 TCP-sessions. My logic is not capable to explain how parts can be longer than their combination. So there must be some error in the program, that analyses TCP-sessions. Since the amounts are roughly half of the active measurement weeks, it could have something to do with closing data file.

	min.	10%	50 %	90%	max.
Bitrate1/Down (PC)	0.00126	0.158	8.91	501	3.55e+03
Bitrate2/Down	0.00126	2	28.2	631	3.55e+03
Bitrate1/Up	0.000282	0.000631	0.447	31.6	3.55e+03
Bitrate2/Up	0.000282	0.891	5.01	282	3.55e+03
Bitrate1/Down (WS)	0.000794	0.000891	2.24	316	2.82e+03
Bitrate2/Down	0.000794	5.62	79.4	794	2.82e+03
Bitrate1/Up	0.000794	0.000891	0.00112	7.94	2.82e+03
Bitrate2/Up	0.000794	1.26	20	447	2.82e+03

Table XI. The WWW-session lengths, where the minimum, the maximum and the limits of 10 %, 50 % and 90 % of the calculated Bitrate1 [byte/(T+ 1 ms)] and Bitrate2 [byte /(T+ 1m)], were reached.

The average bitrate for WWW-sessions has with the harder limit of bitrate1 the mean 649 / 1463 and variance 3888 / 7628 bytes/s in Uplink and the mean 1489 / 2836 and variance 5629 / 8762 bytes/s in Downlink. With the softer limit of bitrate2 are the mean 248 / 206 and variance 459 / 276 bytes/s in Uplink and the mean 1127 / 1434 and variance 1782 / 4091 bytes/s in Downlink. It is very noteworthy, that bitrate1, which was about equal for Pcs and WSs with bursts, is again about twice as high for the workstations than for PCs. The explanation is the activity. For a WWW-session in a workstation, there is about one third of the time transfer bursts on, when this happens with a PC only a one sixth of the time.

By comparing figures 94 and 95 we see, how the difference between bitrate1 and bitrate2 are caused by very short WWW-sessions. They probably have only minor influence to the quality experienced by the user. In practice WWW-sessions themselves are so long, that bitrate averages over them do not describe the quality users experience. But they might give useful information for the evaluation of system parameters like how many simultaneous users can be supported.

From figures 92-93 we can see, that the WWW-sessions IP- and Data-byte distribution fit quite well together and they increase almost linearly with the length, when the duration is between 1 s and 1000 s. It seems very reasonable, that “the longer session is, the more data is transferred”. The Ethernet is be able to transmit all this traffic in 2233 seconds (evaluated with 30 % usage) from the 1375 050 seconds used all together by the WWW-sessions. Otherwise we might think, that the relation is vise versa. Most of traffic happens in long sessions. If we draw the cumulative distribution as fig. 84 based on the IP-bytes, the 10 % limit is about 3 minutes, the median is about 15 minutes and the 90 % limit is form half an hour to three quarters.

4. COMMENTS

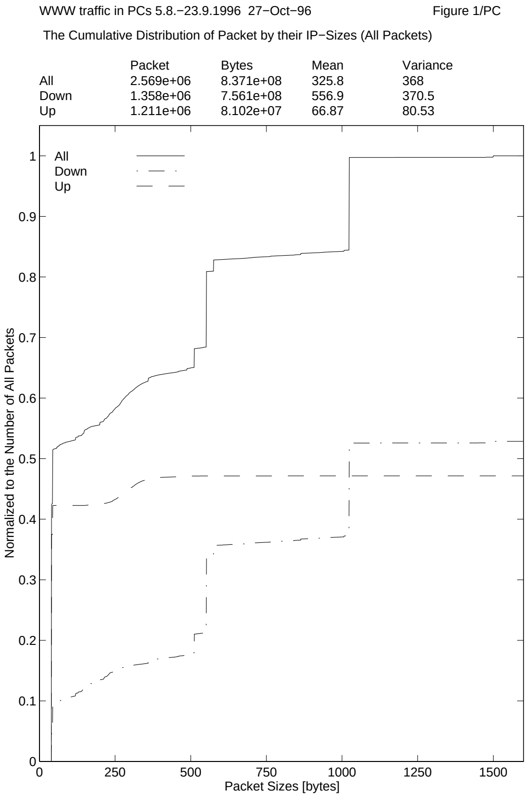
This report has been made to give the measured results, and the necessary background information to the use of other researchers and projects. Due the hurry there are some errors, and the evaluation of the results is based mostly to intuition or guesses, rather than proven facts. Deeper analyses would certify some of them, and show some to be based on errors or misunderstanding. Probably there would also come up few more or less interesting details.

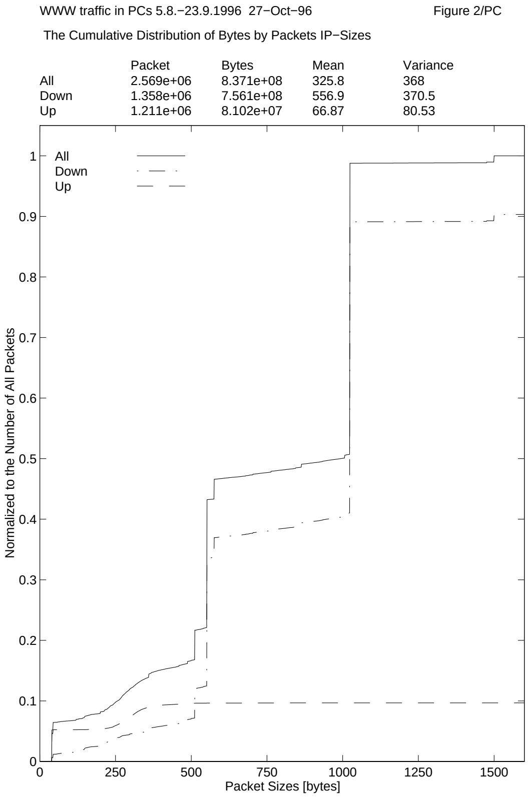
The most important result is obviously the great unsymmetry between Uplink and Downlink. It is not seen in the amount of packets, but in the amount of bytes. This unsymmetry is a direct consequence from the WWW-services primary nature. It is aimed to bring the huge data masses, stored to the internet, easily available to the users.

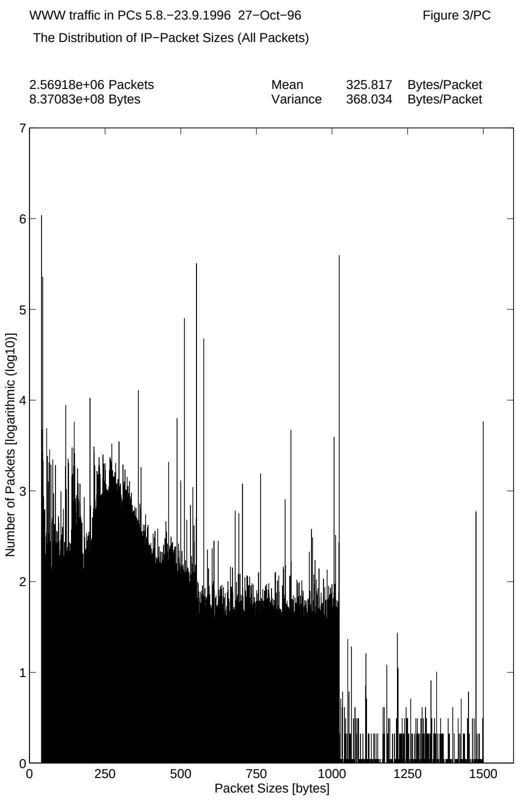
Another important result is the speed, by which data flows from the downlink. These results show, that there are short periods, when only the network bandwidth seems to limits that flow. The protocols planned to LANs do not always get out the optimal performance from a modern wireless or mobile network.

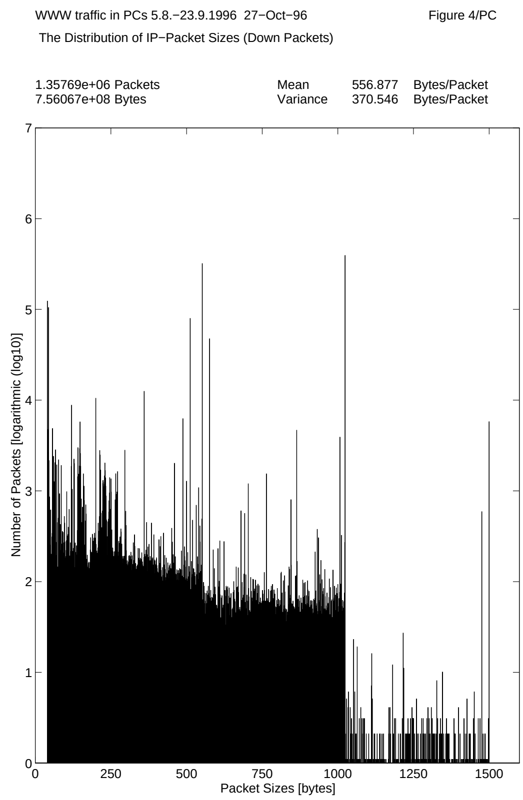
5. LIST OF FIGURES PROCESSED FROM THE MEASURED DATA:

5.1 Figures from the PC





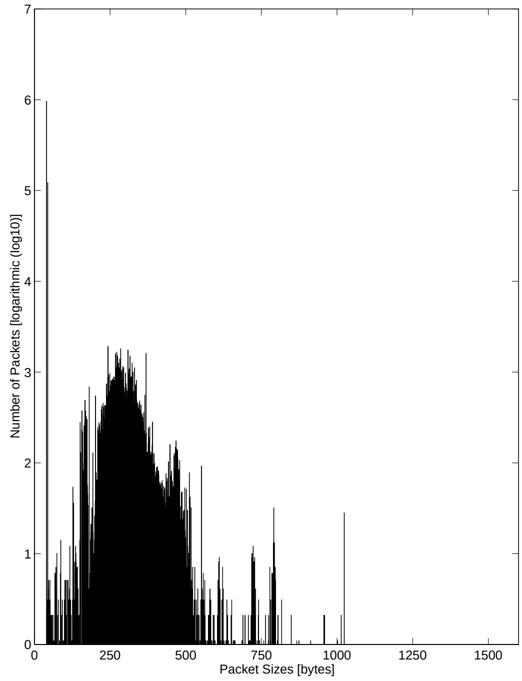




WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 5/PC

The Distribution of IP−Packet Sizes (Up Packets)

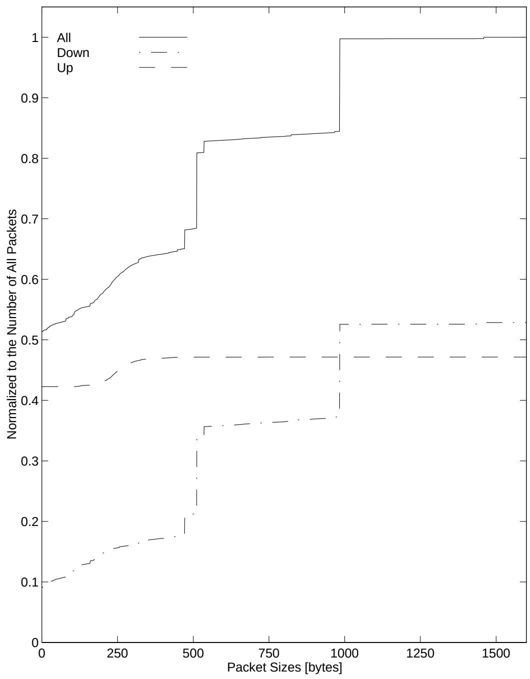
1.21149e+06 Packets	Mean	66.8727	Bytes/Packet
8.10156e+07 Bytes	Variance	80.5321	Bytes/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 6/PC

The Cumulative Distribution of Packet by their Data Sizes

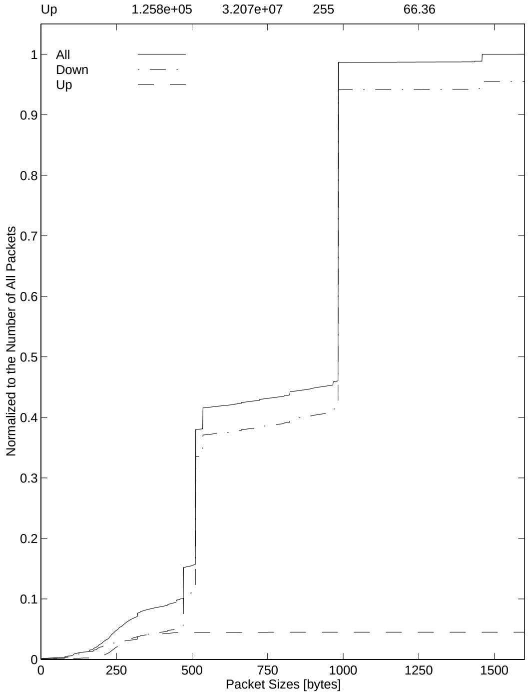
	Packet	Bytes	Mean	Variance
All	1.256e+06	7.334e+08	583.9	321.3
Down	1.13e+06	7.013e+08	620.5	317.5
Up	1.258e+05	3.207e+07	255	66.36



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 7/PC

The Cumulative Distribution of Bytes by Packets Data Sizes (All Packets)

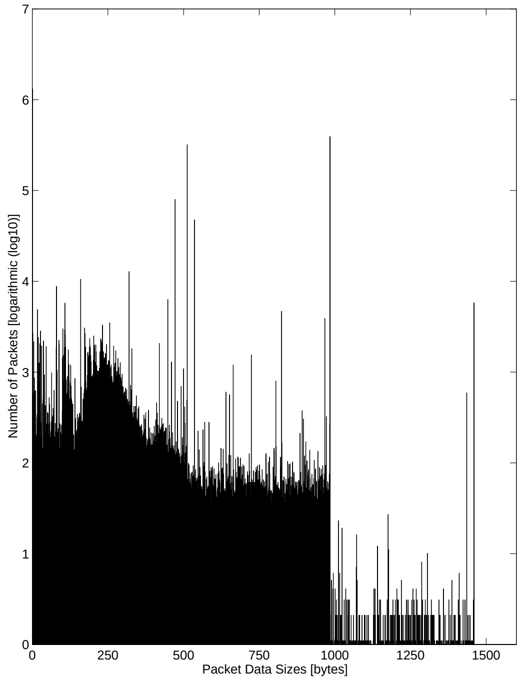
	Packet	Bytes	Mean	Variance
All	1.256e+06	7.334e+08	583.9	321.3
Down	1.13e+06	7.013e+08	620.5	317.5
Up	1.258e+05	3.207e+07	255	66.36



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 8/PC

The Distribution of Packets by Data Sizes (All Packets)

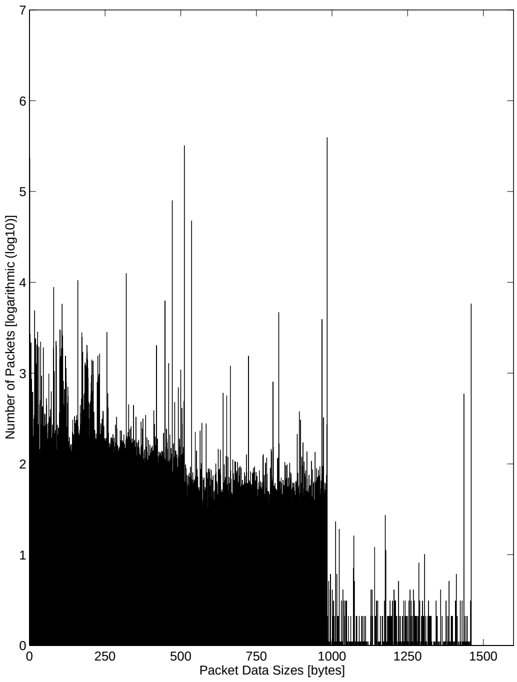
1.25607e+06 Packets	Mean	583.892	Bytes/Packet
7.33411e+08 Bytes	Variance	321.259	Bytes/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 9/PC

The Distribution of Packets by Data Sizes (Down Packets)

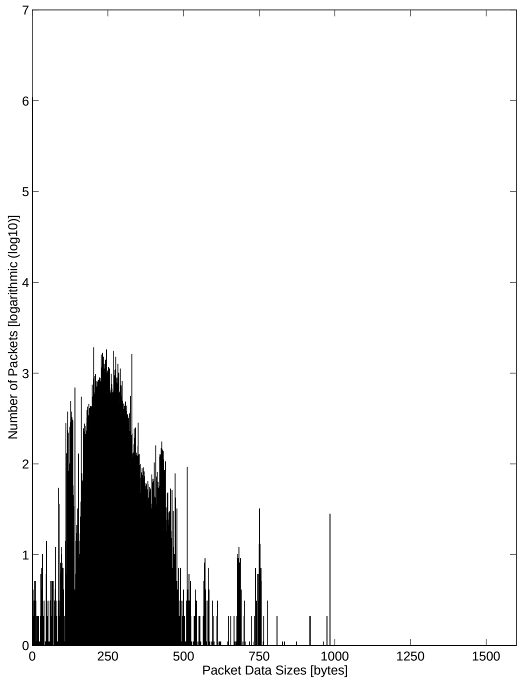
1.1303e+06	Packets	Mean	620.491	Bytes/Packet
7.01344e+08	Bytes	Variance	317.527	Bytes/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 10/PC

The Distribution of Packets by Data Sizes (Up Packets)

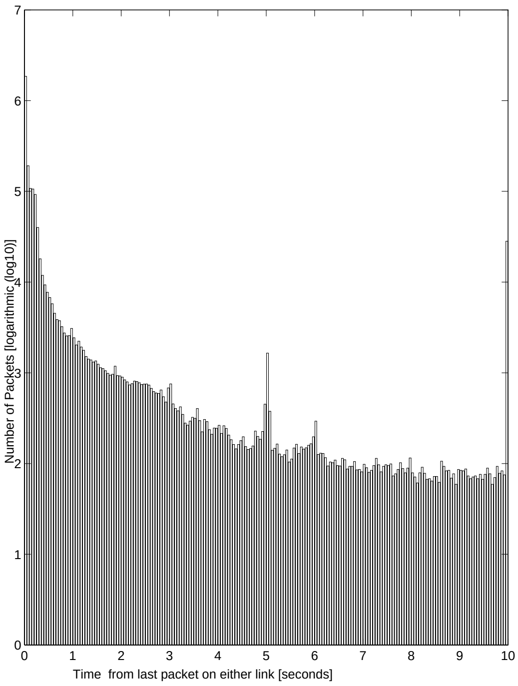
125769	Packets	Mean	254.969	Bytes/Packet
3.20671e+07	Bytes	Variance	66.3577	Bytes/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 11/PC

The Distribution of Packet Interarrival Times (All Packets) 1/3

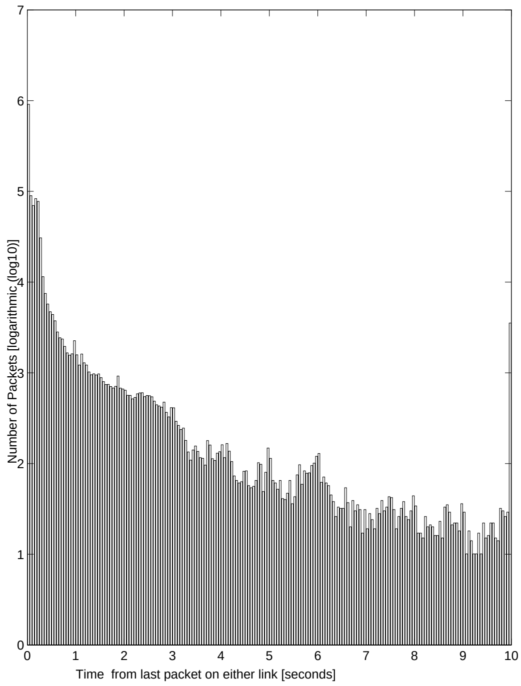
2.56918e+06	Packets	Mean	20.8499	Seconds/Packet
5.35671e+07	Seconds	Variance	1594.31	Seconds/Packet

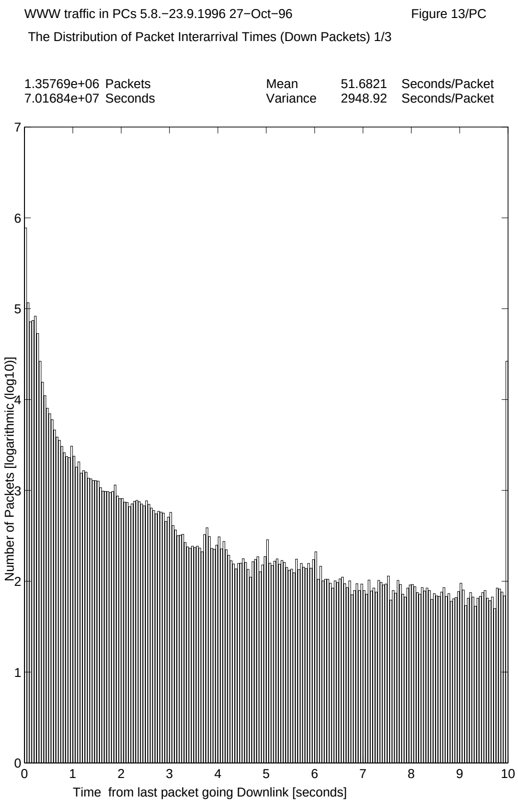


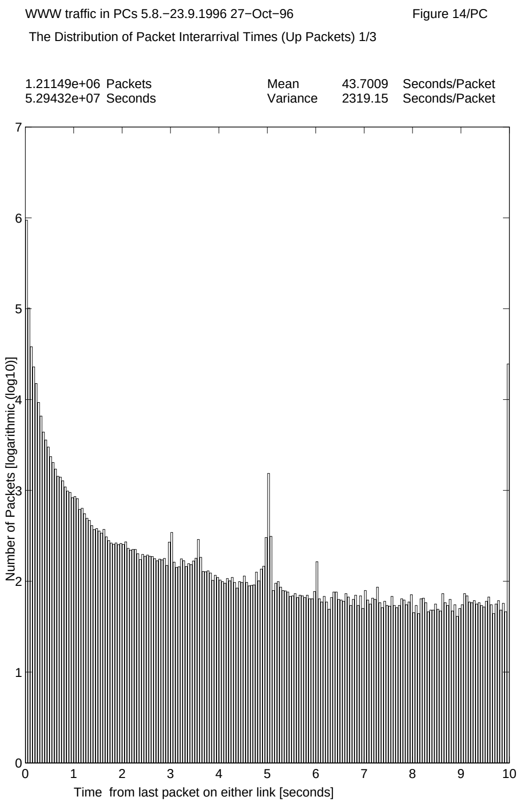
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 12/PC

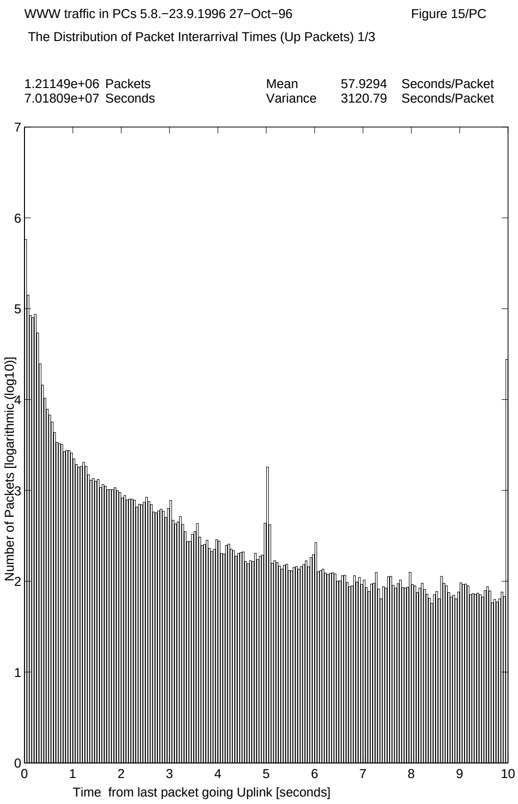
The Distribution of Packet Interarrival Times (Down Packets) 1/3

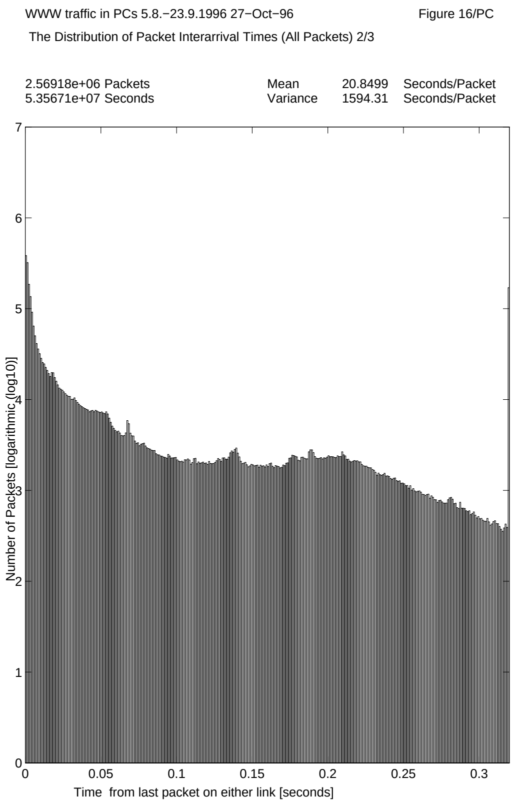
1.35769e+06	Packets	Mean	0.459491	Seconds/Packet
623848	Seconds	Variance	98.8801	Seconds/Packet




WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 13/PC
The Distribution of Packet Interarrival Times (Down Packets) 1/3
1.35769e+06 Packets
7.01684e+07 Seconds
Mean 51.6821 Seconds/Packet
Variance 2948.92 Seconds/Packet
Number of Packets [logarithmic (log10)]
Time from last packet going Downlink [seconds]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 14/PC
The Distribution of Packet Interarrival Times (Up Packets) 1/3
1.21149e+06 Packets
5.29432e+07 Seconds
Mean 43.7009 Seconds/Packet
Variance 2319.15 Seconds/Packet
Number of Packets [logarithmic (log10)]
Time from last packet on either link [seconds]

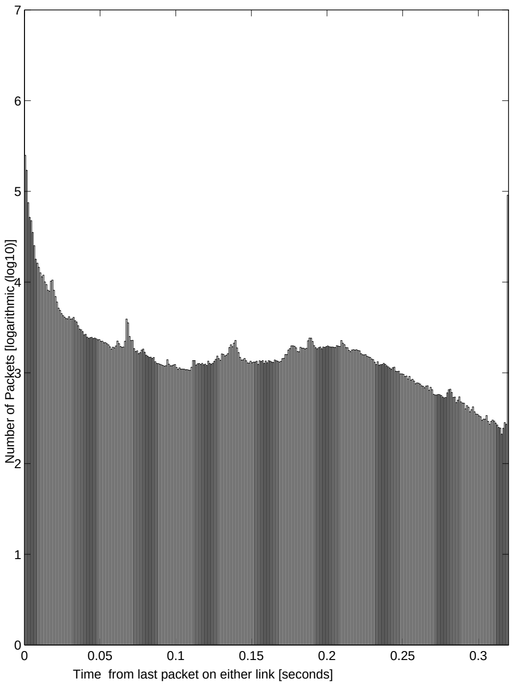

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 15/PC
The Distribution of Packet Interarrival Times (Up Packets) 1/3
1.21149e+06 Packets
7.01809e+07 Seconds
Mean 57.9294 Seconds/Packet
Variance 3120.79 Seconds/Packet
Number of Packets [logarithmic (log10)]
Time from last packet going Uplink [seconds]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 16/PC
The Distribution of Packet Interarrival Times (All Packets) 2/3
2.56918e+06 Packets
5.35671e+07 Seconds
Mean 20.8499 Seconds/Packet
Variance 1594.31 Seconds/Packet
Number of Packets [logarithmic (log10)]
Time from last packet on either link [seconds]

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 17/PC

The Distribution of Packet Interarrival Times (Down Packets) 2/3

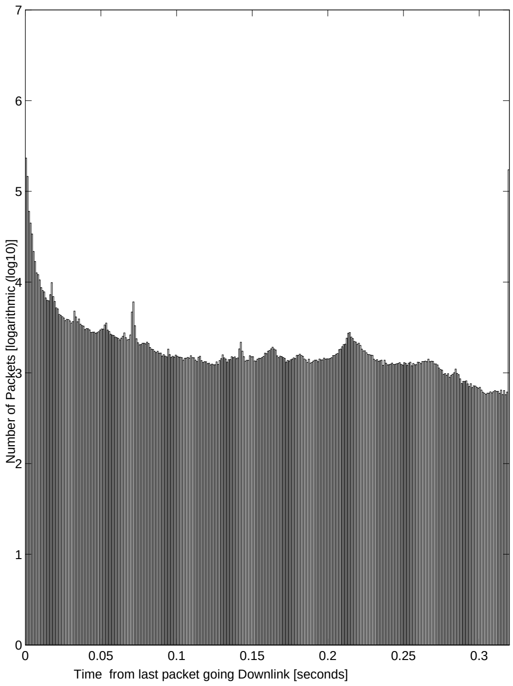
1.35769e+06 Packets Mean 0.459491 Seconds/Packet
623848 Seconds Variance 98.8801 Seconds/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 18/PC

The Distribution of Packet Interarrival Times (Down Packets) 2/3

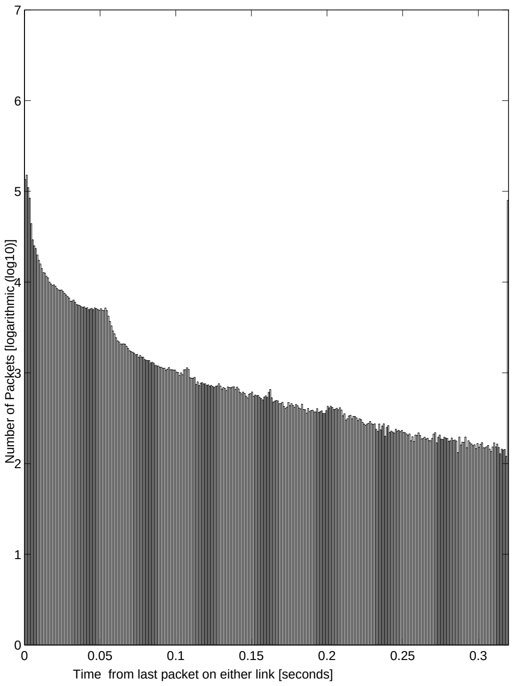
1.35769e+06 Packets Mean 51.6821 Seconds/Packet
7.01684e+07 Seconds Variance 2948.92 Seconds/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 19/PC

The Distribution of Packet Interarrival Times (Up Packets) 2/3

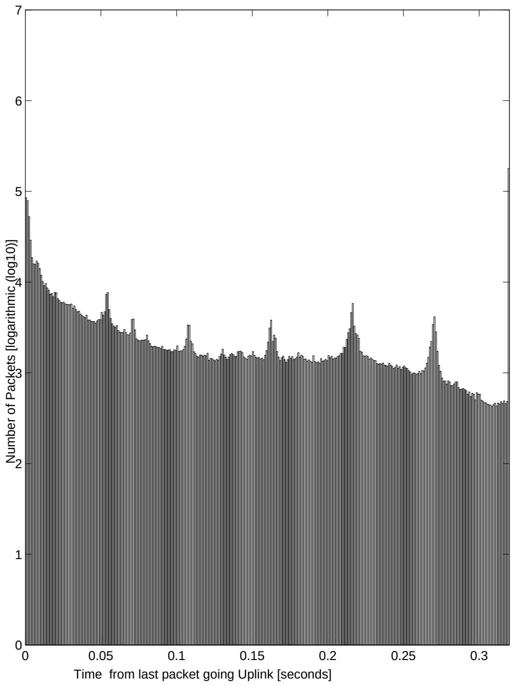
1.21149e+06 Packets Mean 43.7009 Seconds/Packet
5.29432e+07 Seconds Variance 2319.15 Seconds/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 20/PC

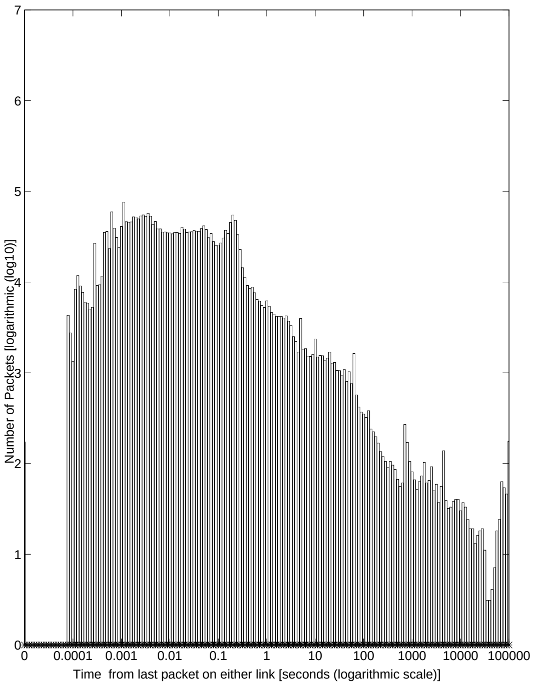
The Distribution of Packet Interarrival Times (Up Packets) 2/3

1.21149e+06 Packets Mean 57.9294 Seconds/Packet
7.01809e+07 Seconds Variance 3120.79 Seconds/Packet



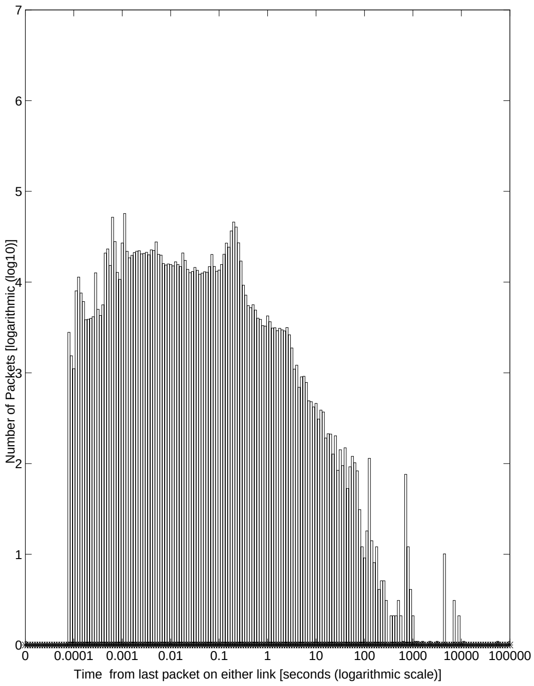
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 21/PC
The Distribution of Packet Interarrival Times (All Packets) 3/3

2.56918e+06 Packets Mean 20.8499 Seconds/Packet
5.35671e+07 Seconds Variance 1594.31 Seconds/Packet



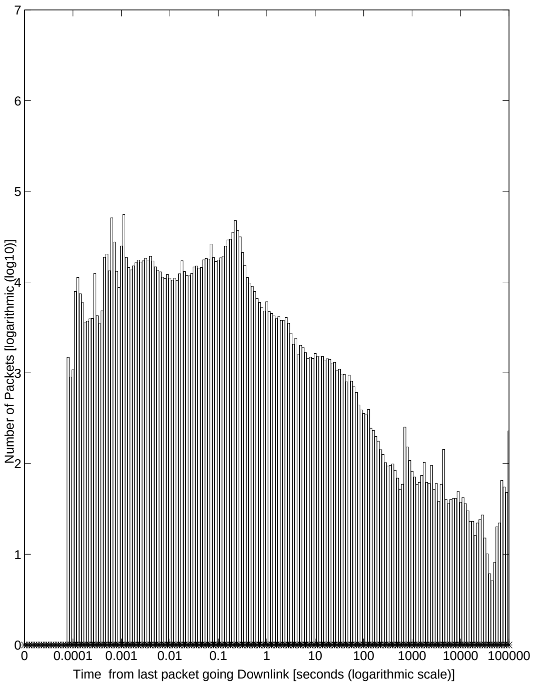
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 22/PC
The Distribution of Packet Interarrival Times (Down Packets) 3/3

1.35769e+06 Packets Mean 0.459491 Seconds/Packet
623848 Seconds Variance 98.8801 Seconds/Packet



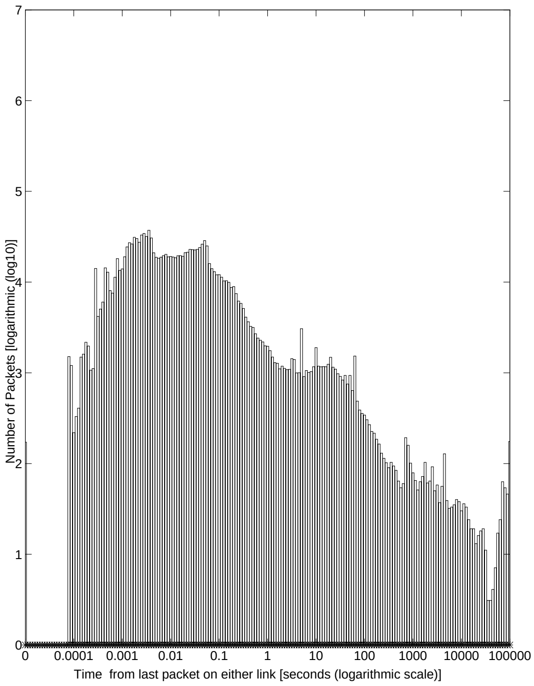
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 23/PC
The Distribution of Packet Interarrival Times (Down Packets) 3/3

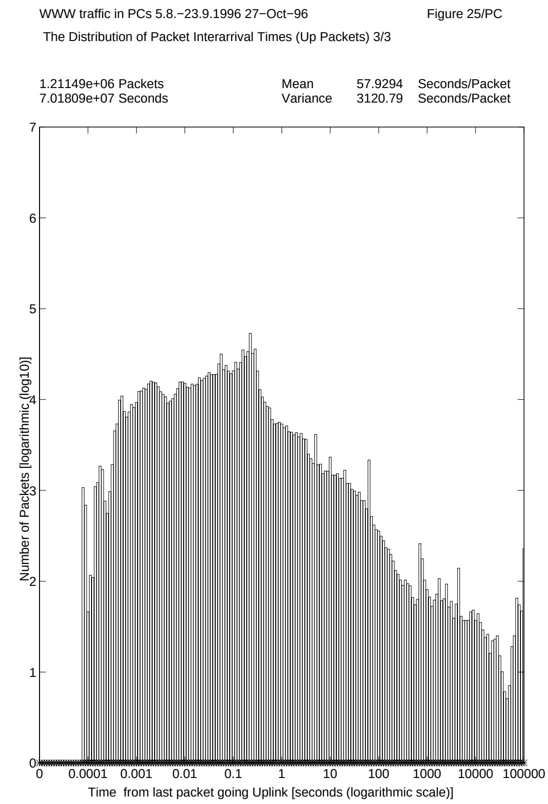
1.35769e+06 Packets Mean 51.6821 Seconds/Packet
7.01684e+07 Seconds Variance 2948.92 Seconds/Packet

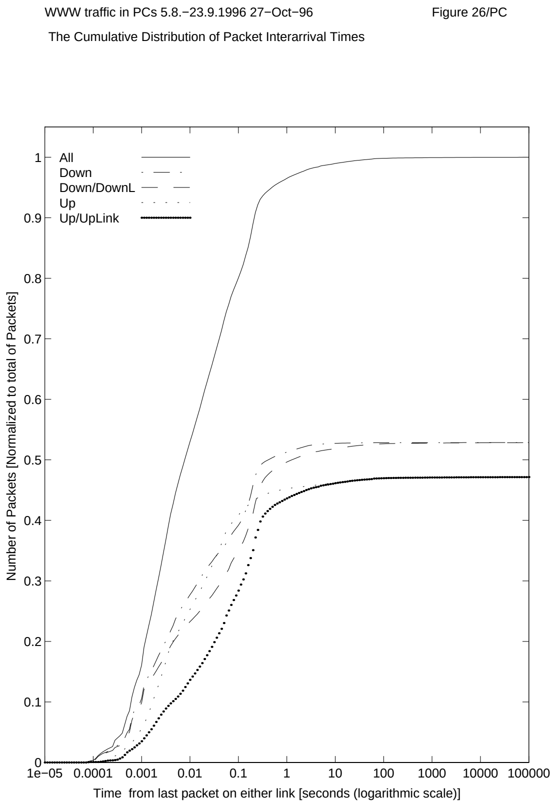


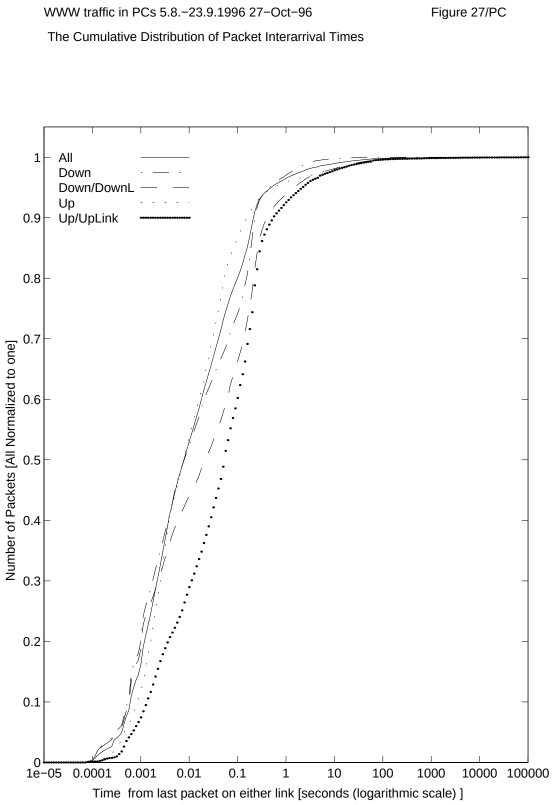
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 24/PC
The Distribution of Packet Interarrival Times (Up Packets) 3/3

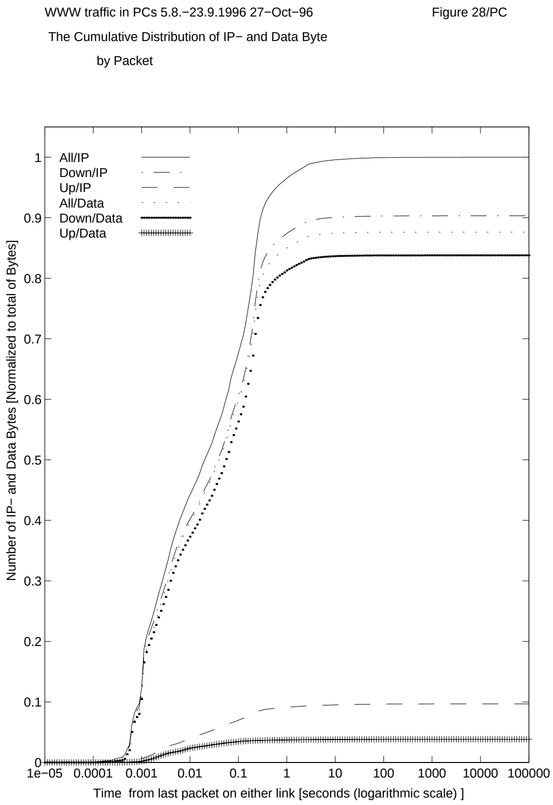
1.21149e+06 Packets Mean 43.7009 Seconds/Packet
5.29432e+07 Seconds Variance 2319.15 Seconds/Packet




WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 25/PC
The Distribution of Packet Interarrival Times (Up Packets) 3/3
1.21149e+06 Packets
7.01809e+07 Seconds
Mean 57.9294 Seconds/Packet
Variance 3120.79 Seconds/Packet
Number of Packets [logarithmic (log10)]
Time from last packet going Uplink [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 26/PC
The Cumulative Distribution of Packet Interarrival Times
All
Down
Down/DownL
Up
Up/UpLink
Number of Packets [Normalized to total of Packets]
Time from last packet on either link [seconds (logarithmic scale)]

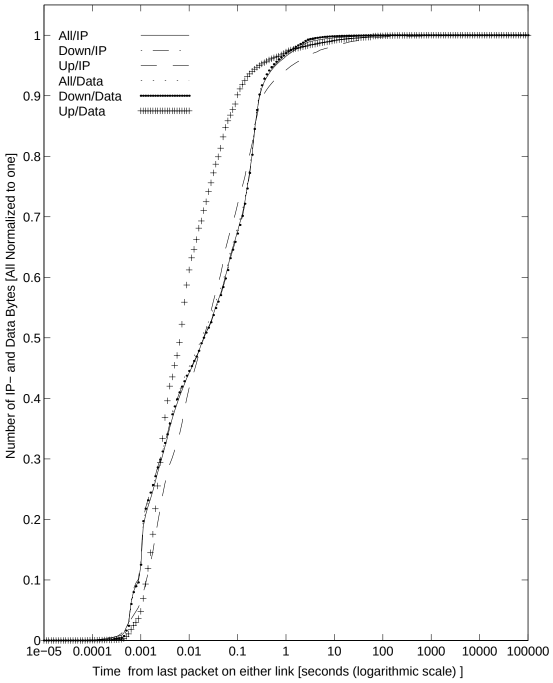

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 27/PC
The Cumulative Distribution of Packet Interarrival Times
All
Down
Down/DownL
Up
Up/UpLink
Number of Packets [All Normalized to one]
Time from last packet on either link [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 28/PC
The Cumulative Distribution of IP− and Data Byte
by Packet
All/IP
Down/IP
Up/IP
All/Data
Down/Data
Up/Data
Number of IP− and Data Bytes [Normalized to total of Bytes]
Time from last packet on either link [seconds (logarithmic scale)]

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 29/PC

The Cumulative Distribution of IP− and Data Byte

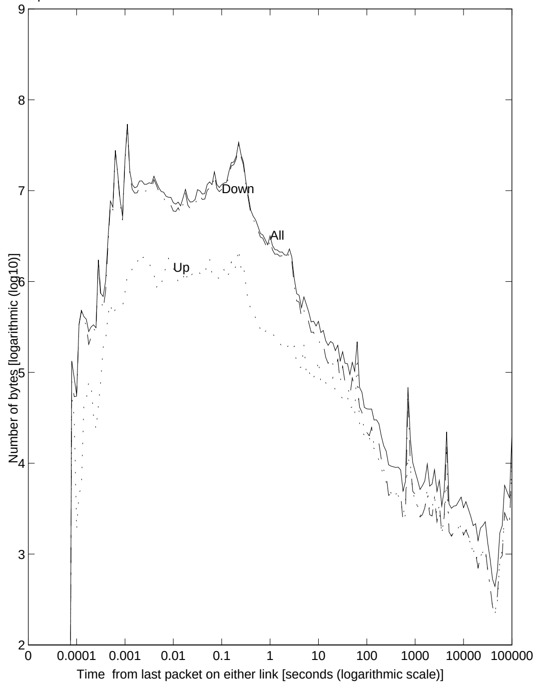
by m last packet on either link



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 30/PC

The Distribution of IP−Bytes by Packet Interarrival Times

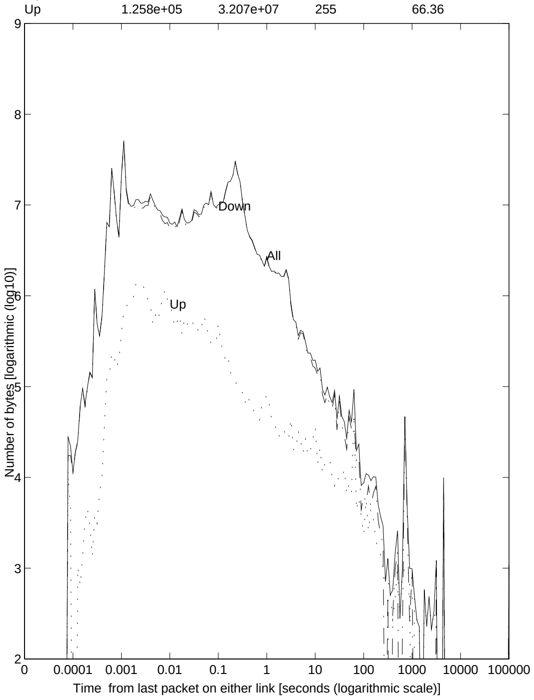
	Packet	Bytes	Mean	Variance
All	2.569e+06	8.371e+08	325.8	368
Down	1.358e+06	7.561e+08	556.9	370.5
Up	1.211e+06	8.102e+07	66.87	80.53



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 31/PC

The Distribution of Data Bytes by Packet Interarrival Times

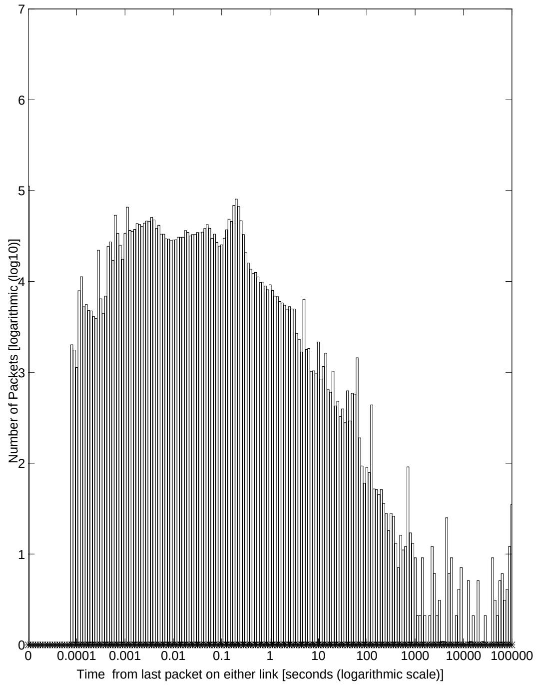
	Packet	Bytes	Mean	Variance
All	1.256e+06	7.334e+08	583.9	321.3
Down	1.13e+06	7.013e+08	620.5	317.5
Up	1.258e+05	3.207e+07	255	66.36



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 32/PC

The Distribution of Packet Interarrival TimesAll in same TCP−session 3/3

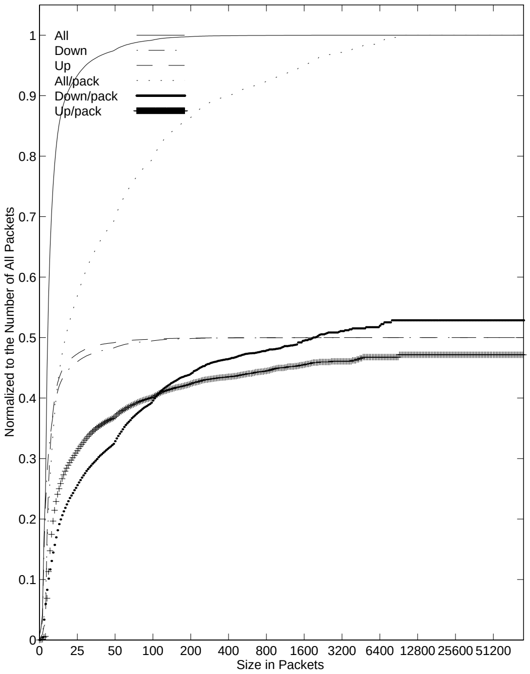
2.56918e+06 Packets	Mean	3.67095	Seconds/Packet
9.43134e+06 Seconds	Variance	610.309	Seconds/Packet



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 33/PC

The Cumulative Distribution of TCP−sessions by their Size in Packets

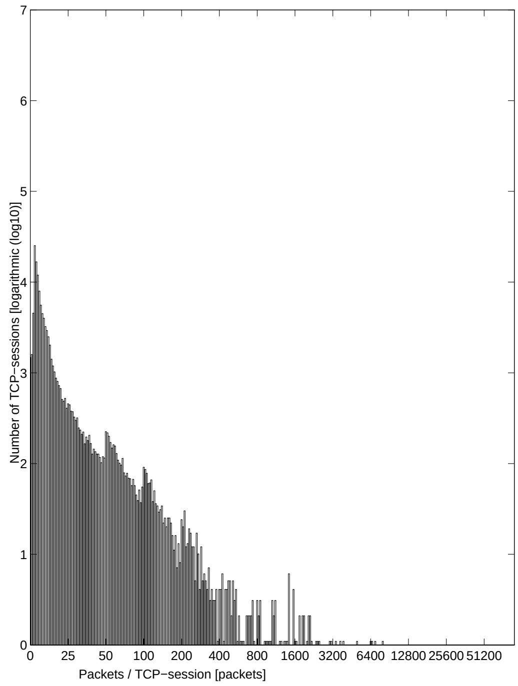
	TCP−session	Bytes	Mean	Variance
All	1.123e+05	2.569e+06	22.88	81.11
Down	1.123e+05	1.358e+06	12.09	66.23
Up	1.123e+05	1.211e+06	10.79	49.54



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 34/PC

The Distribution of TCP−sessions by Size (Down Packets)
A TCP−session (= same TCP−port and IP−address)

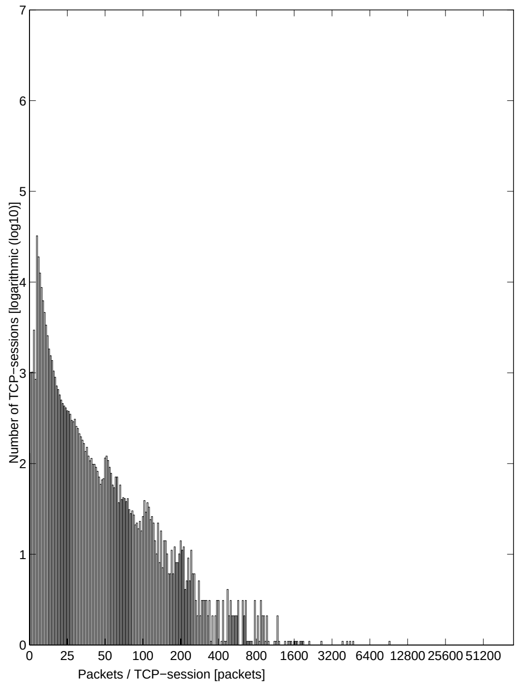
1.122670e+05 TCP−sessions		Mean	12.0934	TCP−sessions
1.357693e+06 Packets		Variance	66.2271	TCP−sessions



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 35/PC

The Distribution of TCP−sessions by Size (Up Packets)
A TCP−session (= same TCP−port and IP−address)

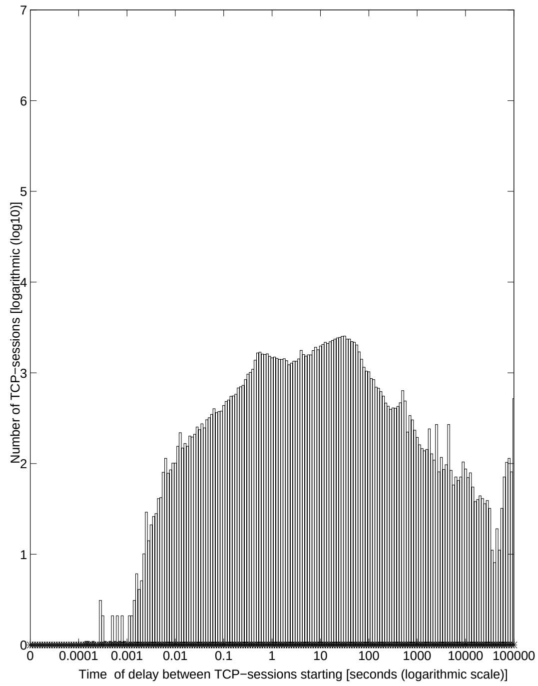
1.122670e+05 TCP−sessions		Mean	10.7911	TCP−sessions
1.211489e+06 Packets		Variance	49.535	TCP−sessions



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 36/PC

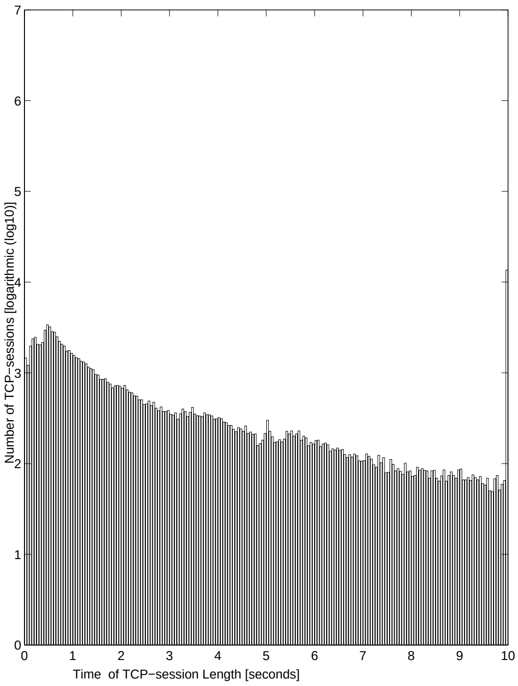
The Distribution of delay between TCP−sessions 3/3

112260	TCP−sessions	Mean	1462.88	Seconds/TCP−session
1.64223e+08	Seconds	Variance	17662.2	Seconds/TCP−session



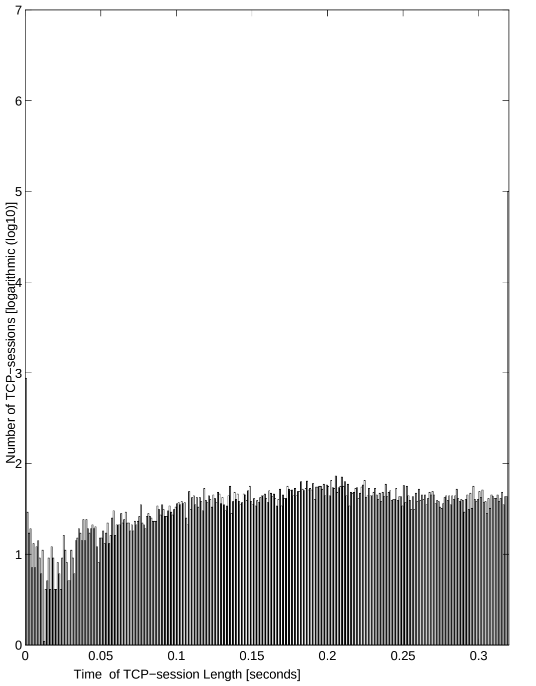
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 37/PC
The Distribution of TCP−session Length 1/3

112267	TCP−sessions	Mean	84.0082	Seconds/TCP−session
9.43134e+06	Seconds	Variance	2919.9	Seconds/TCP−session



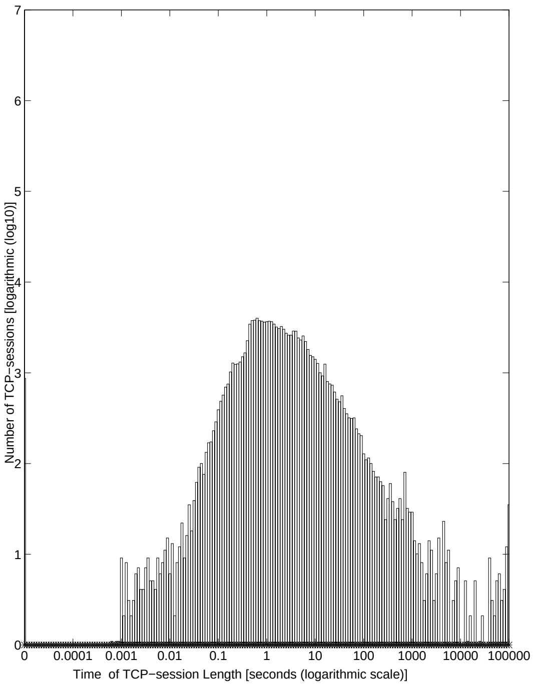
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 38/PC
The Distribution of TCP−session Length 2/3

112267	TCP−sessions	Mean	84.0082	Seconds/TCP−session
9.43134e+06	Seconds	Variance	2919.9	Seconds/TCP−session

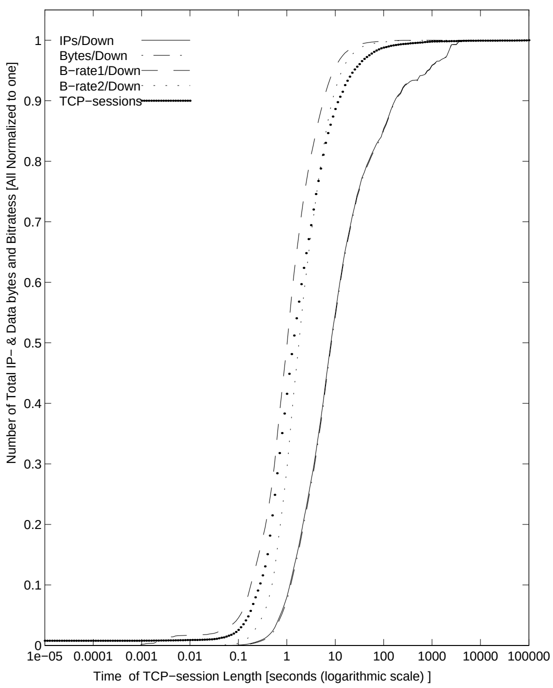


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 39/PC
The Distribution of TCP−session Length 3/3

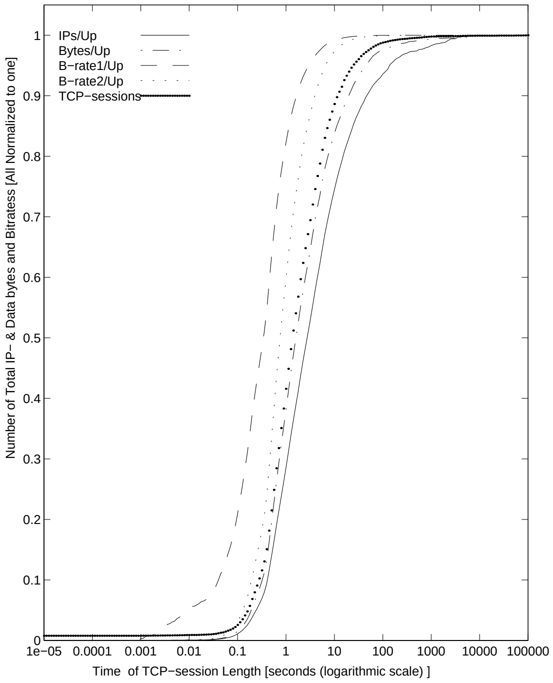
112267	TCP−sessions	Mean	84.0082	Seconds/TCP−session
9.43134e+06	Seconds	Variance	2919.9	Seconds/TCP−session



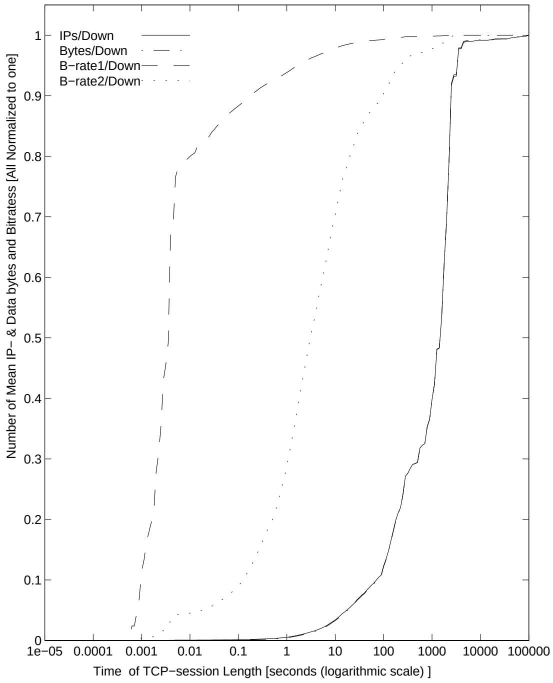
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 40/PC
The Cumulative Distribution of Total IP− & Data bytes and Bitrates
by TCP−session Length



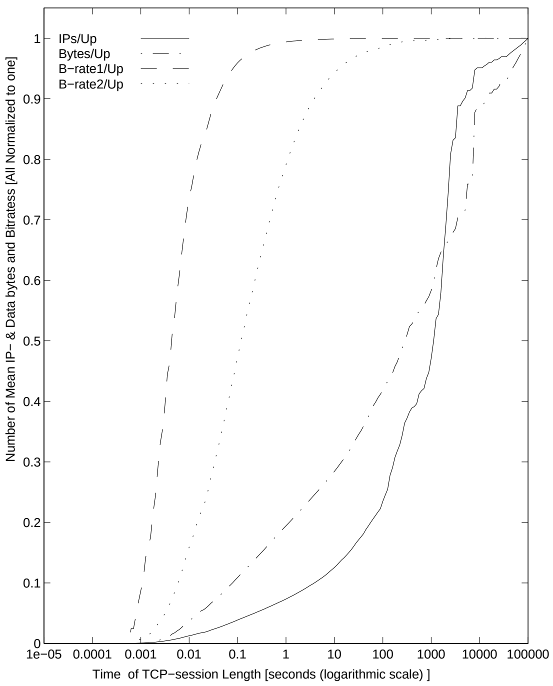
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 41/PC
The Cumulative Distribution of Total IP− & Data bytes and Bitrates
by TCP−session Length



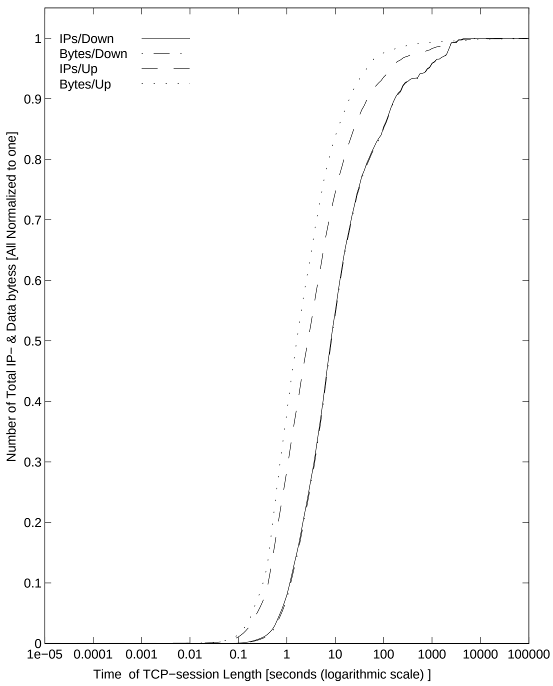
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 42/PC
The Cumulative Distribution of Mean IP− & Data bytes and Bitrates
by TCP−session Length



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 43/PC
The Cumulative Distribution of Mean IP− & Data bytes and Bitrates
by TCP−session Length



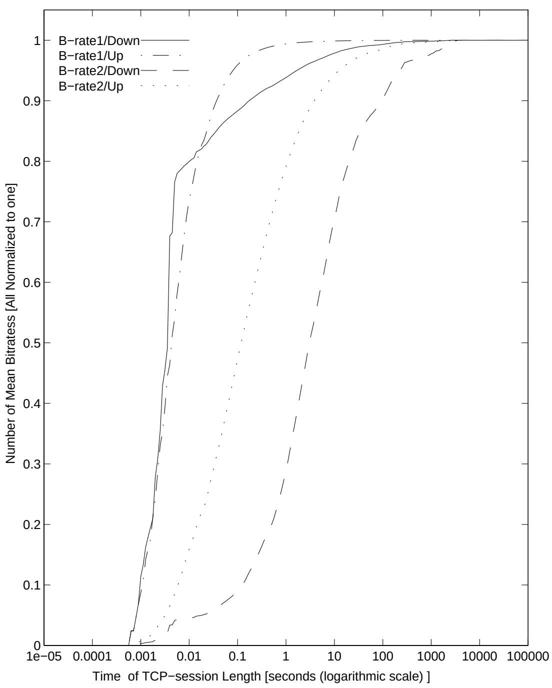
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 44/PC
The Cumulative Distribution of Total IP− & Data bytes
by TCP−session Length



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 45/PC

The Cumulative Distribution of Mean Bitrates

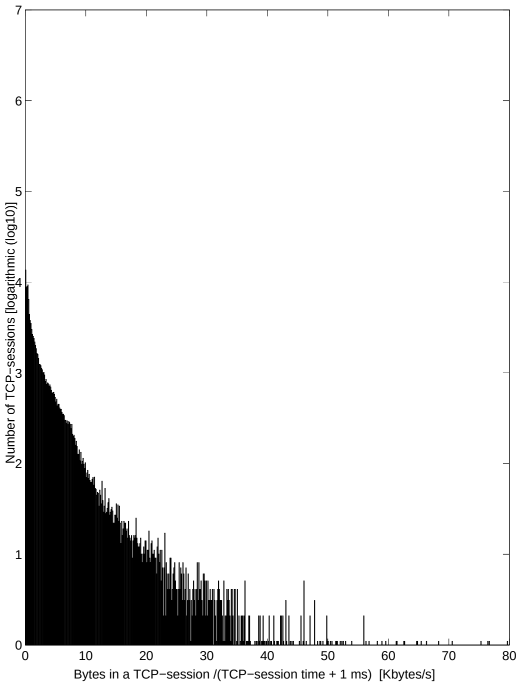
by TCP−session Length



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 46/PC

The Distribution of TCP−sessions by Average Bitrate (Down Packets)
A TCP−session (= same TCP−port and IP−address)

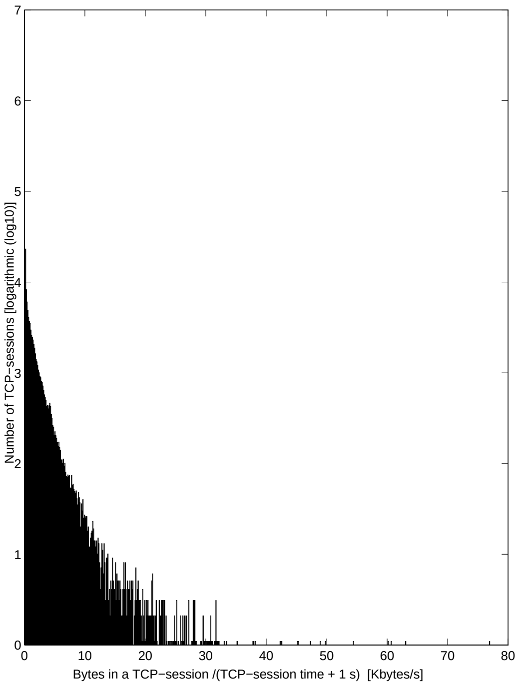
1.122670e+05 TCP−sessions Mean 2243.18 bytes/s
Variance 4411.02 bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 47/PC

The Distribution of TCP−sessions by Average Bitrate (Down Packets)
A TCP−session (= same TCP−port and IP−address)

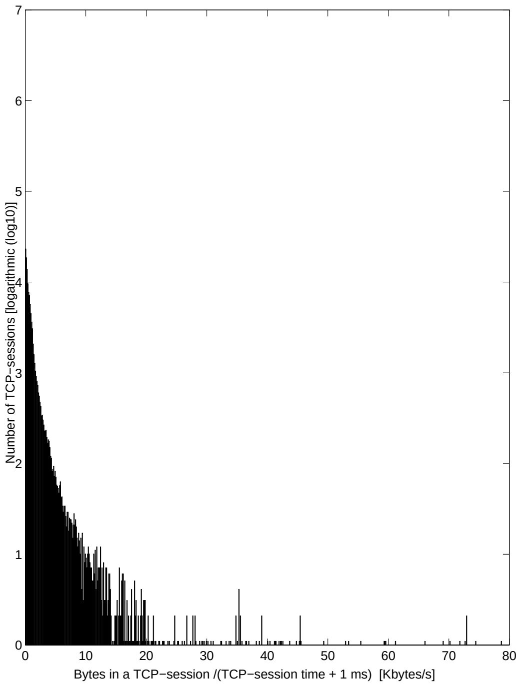
1.122670e+05 TCP−sessions Mean 1154.36 bytes/s
Variance 2003.34 bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 48/PC

The Distribution of TCP−sessions by Average Bitrate (Up Packets)
A TCP−session (= same TCP−port and IP−address)

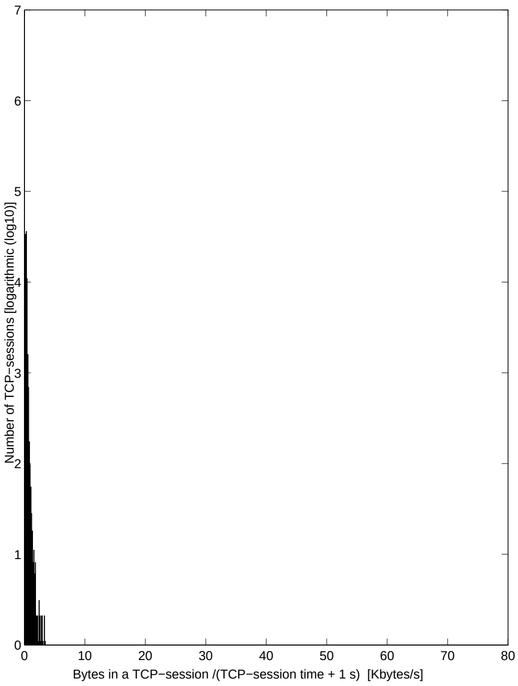
1.122670e+05 TCP−sessions Mean 766.104 bytes/s
Variance 1869.3 bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 49/PC

The Distribution of TCP−sessions by Average Bitrate (Up Packets)
A TCP−session (= same TCP−port and IP−address)

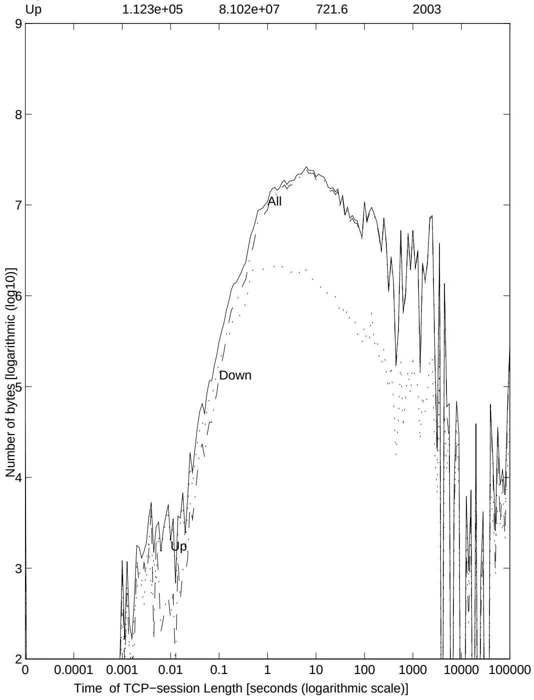
1.122670e+05 TCP−sessions Mean 230.772 bytes/s
Variance 141.433 bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 50/PC

The Distribution of IP−Bytes by TCP−session Length

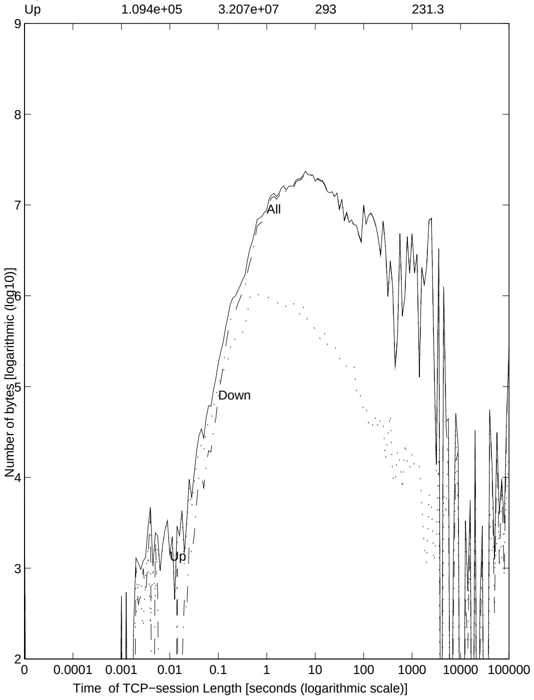
	TCP−session	Bytes	Mean	Variance
All	1.123e+05	8.371e+08	7456	5.008e+04
Down	1.123e+05	7.561e+08	6735	5.014e+04
Up	1.123e+05	8.102e+07	721.6	2003



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 51/PC

The Distribution of Data−Bytes by TCP−session Length

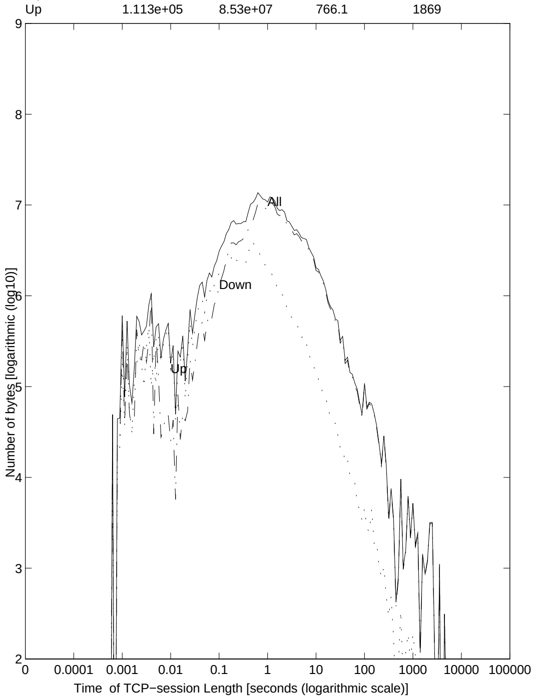
	TCP−session	Bytes	Mean	Variance
All	1.094e+05	7.334e+08	6702	4.821e+04
Down	1.06e+05	7.013e+08	6617	4.901e+04
Up	1.094e+05	3.207e+07	293	231.3

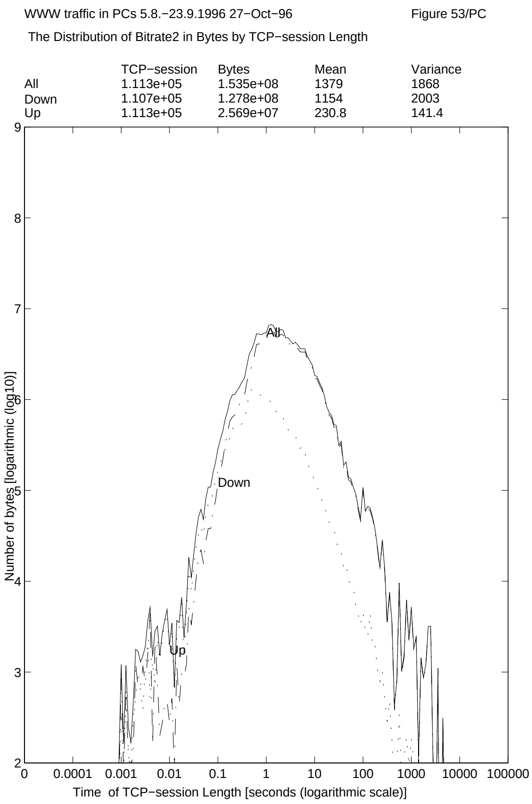


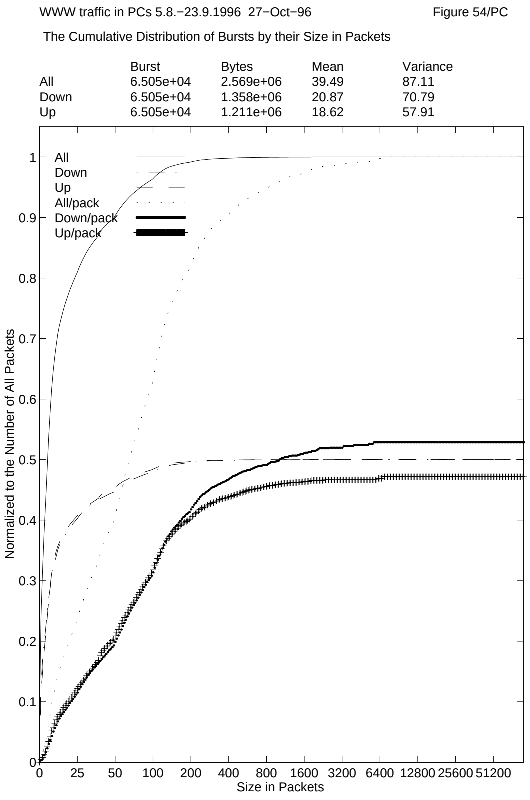
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 52/PC

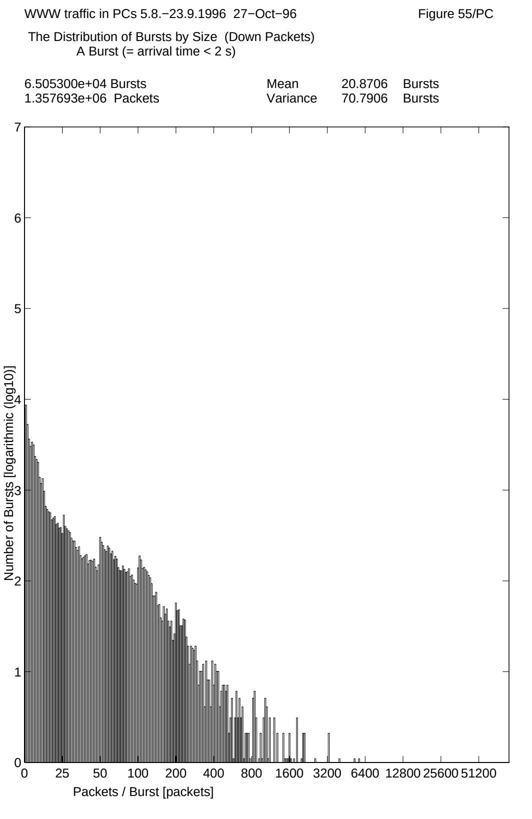
The Distribution of Bitrate1 in Bytes by TCP−session Length

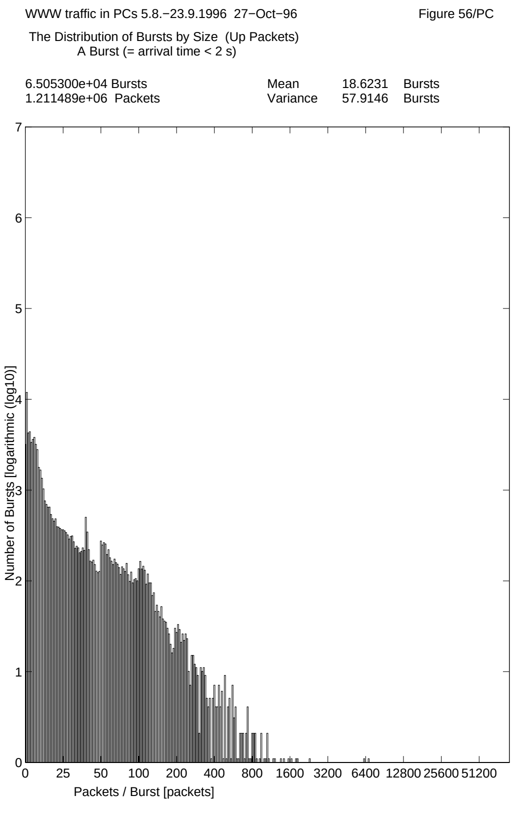
	TCP−session	Bytes	Mean	Variance
All	1.113e+05	3.337e+08	2997	4410
Down	1.107e+05	2.484e+08	2243	4411
Up	1.113e+05	8.53e+07	766.1	1869

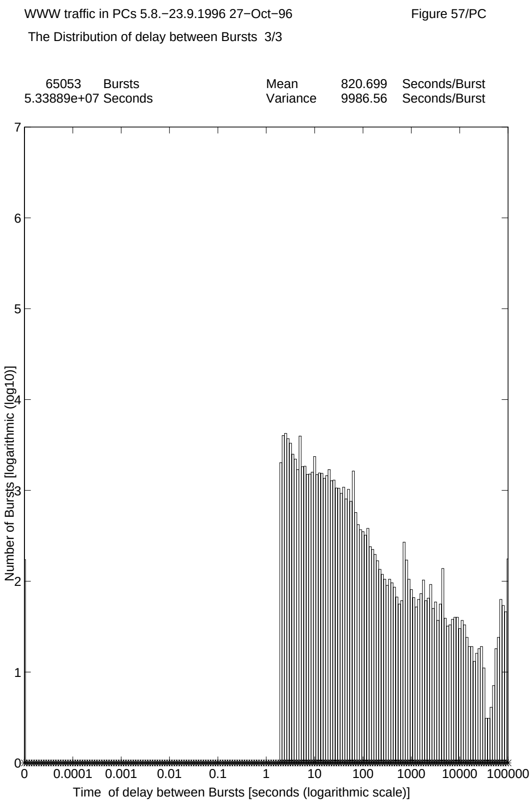


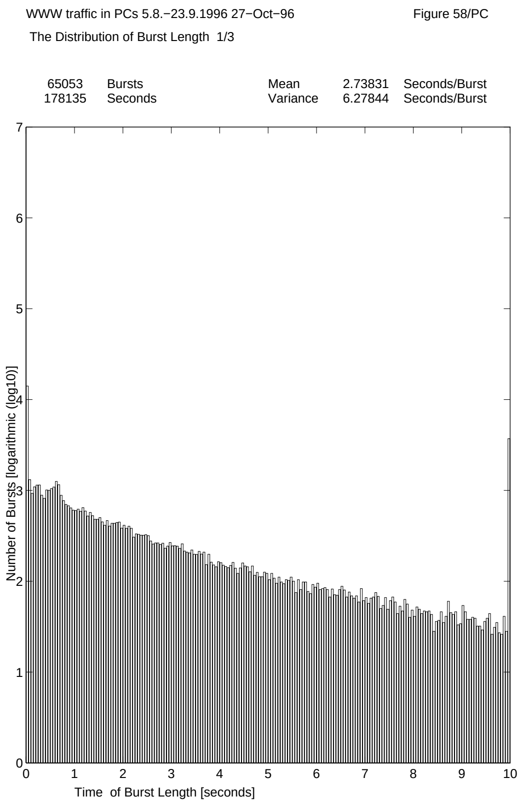

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 53/PC
The Distribution of Bitrate2 in Bytes by TCP−session Length
TCP−session Bytes Mean Variance
All 1.113e+05 1.535e+08 1379 1868
Down 1.107e+05 1.278e+08 1154 2003
Up 1.113e+05 2.569e+07 230.8 141.4
Number of bytes [logarithmic (log10)]
Time of TCP−session Length [seconds (logarithmic scale)]
All
Down
Up

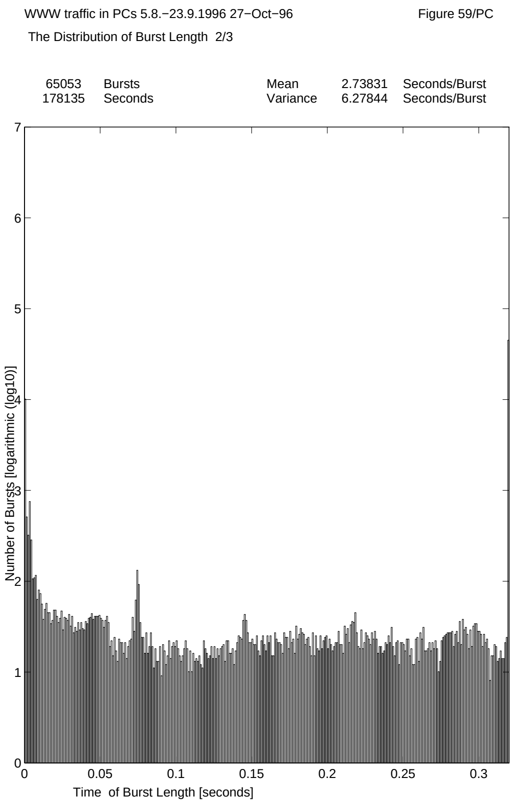

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 54/PC
The Cumulative Distribution of Bursts by their Size in Packets
Burst Bytes Mean Variance
All 6.505e+04 2.569e+06 39.49 87.11
Down 6.505e+04 1.358e+06 20.87 70.79
Up 6.505e+04 1.211e+06 18.62 57.91
All
Down
Up
All/pack
Down/pack
Up/pack
Normalized to the Number of All Packets
Size in Packets

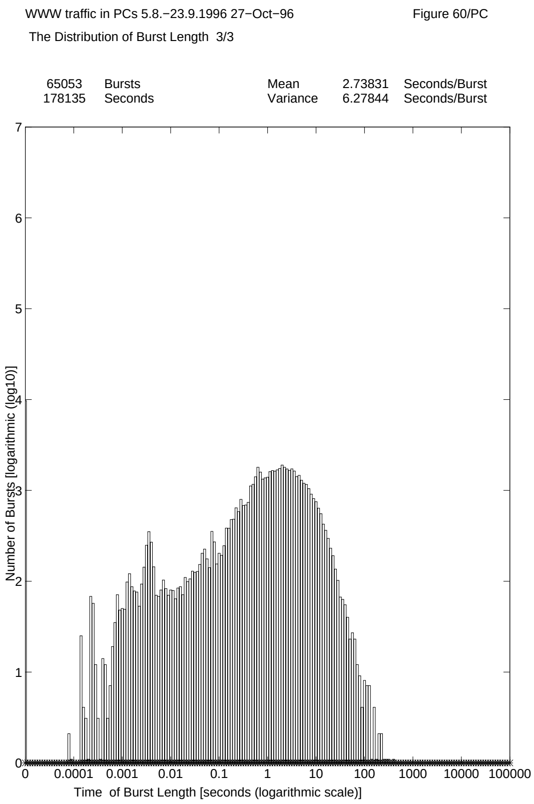

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 55/PC
The Distribution of Bursts by Size (Down Packets)
A Burst (= arrival time < 2 s)
6.505300e+04 Bursts
1.357693e+06 Packets
Mean 20.8706 Bursts
Variance 70.7906 Bursts
Number of Bursts [logarithmic (log10)]
Packets / Burst [packets]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 56/PC
The Distribution of Bursts by Size (Up Packets)
A Burst (= arrival time < 2 s)
6.505300e+04 Bursts
1.211489e+06 Packets
Mean 18.6231 Bursts
Variance 57.9146 Bursts
Number of Bursts [logarithmic (log10)]
Packets / Burst [packets]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 57/PC
The Distribution of delay between Bursts 3/3
65053 Bursts
5.33889e+07 Seconds
Mean 820.699 Seconds/Burst
Variance 9986.56 Seconds/Burst
Number of Bursts [logarithmic (log10)]
Time of delay between Bursts [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 58/PC
The Distribution of Burst Length 1/3
65053 Bursts
178135 Seconds
Mean 2.73831 Seconds/Burst
Variance 6.27844 Seconds/Burst
Number of Bursts [logarithmic (log10)]
Time of Burst Length [seconds]

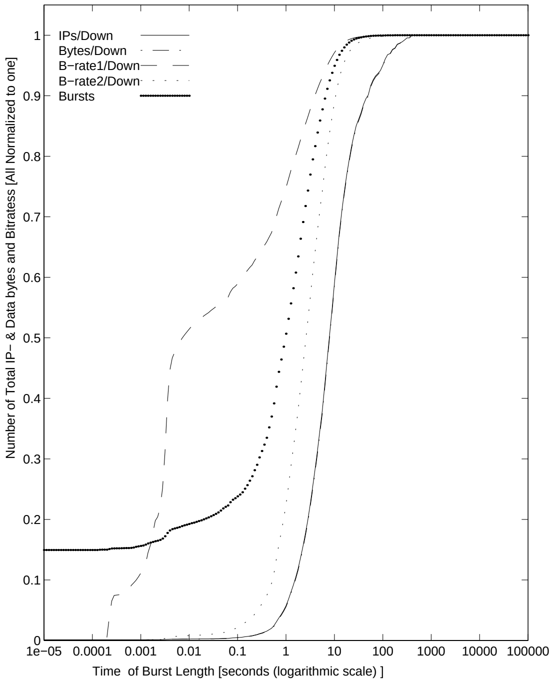

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 59/PC
The Distribution of Burst Length 2/3
65053 Bursts
178135 Seconds
Mean 2.73831 Seconds/Burst
Variance 6.27844 Seconds/Burst
Number of Bursts [logarithmic (log10)]
Time of Burst Length [seconds]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 60/PC
The Distribution of Burst Length 3/3
65053 Bursts
178135 Seconds
Mean 2.73831 Seconds/Burst
Variance 6.27844 Seconds/Burst
Number of Bursts [logarithmic (log10)]
Time of Burst Length [seconds (logarithmic scale)]

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 61/PC

The Cumulative Distribution of Total IP− & Data bytes and Bitrates

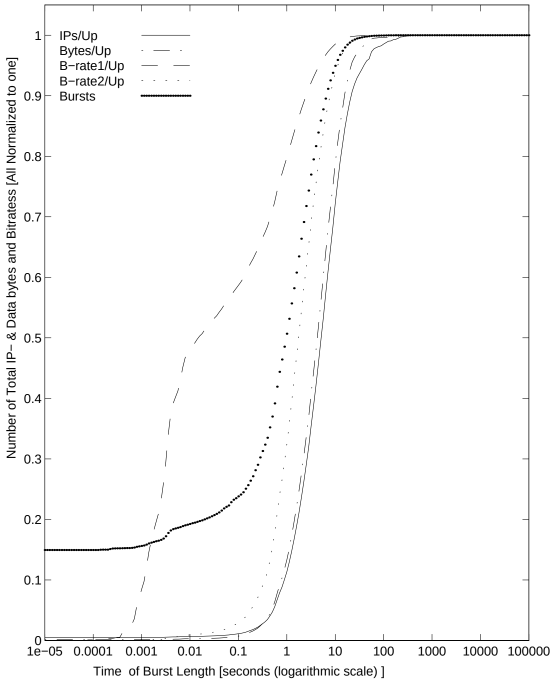
by Burst Length



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 62/PC

The Cumulative Distribution of Total IP− & Data bytes and Bitrates

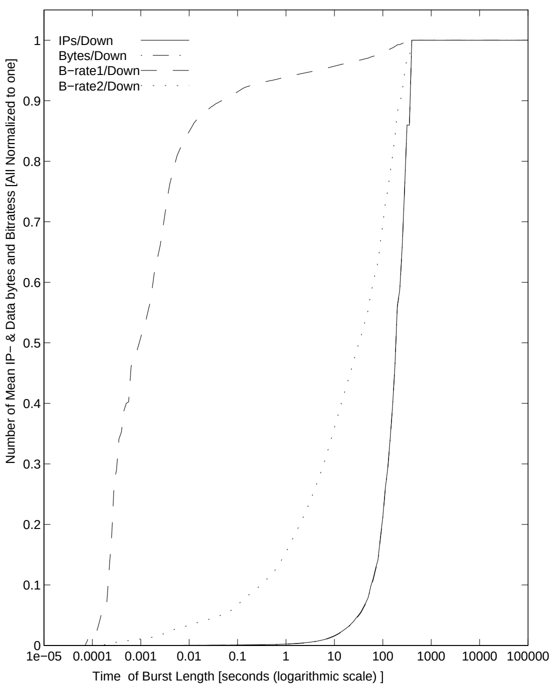
by Burst Length



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 63/PC

The Cumulative Distribution of Mean IP− & Data bytes and Bitrates

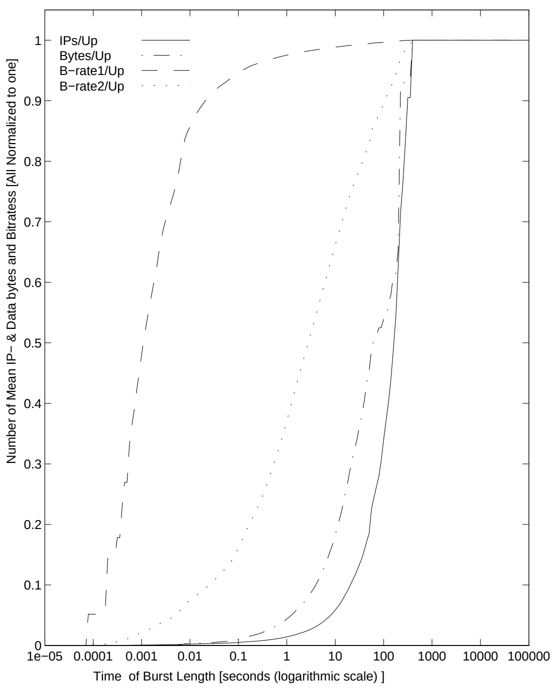
by Burst Length

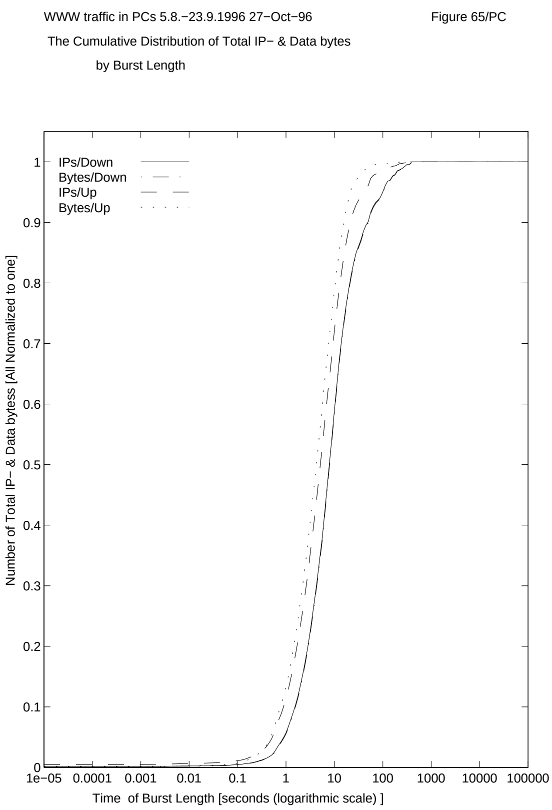


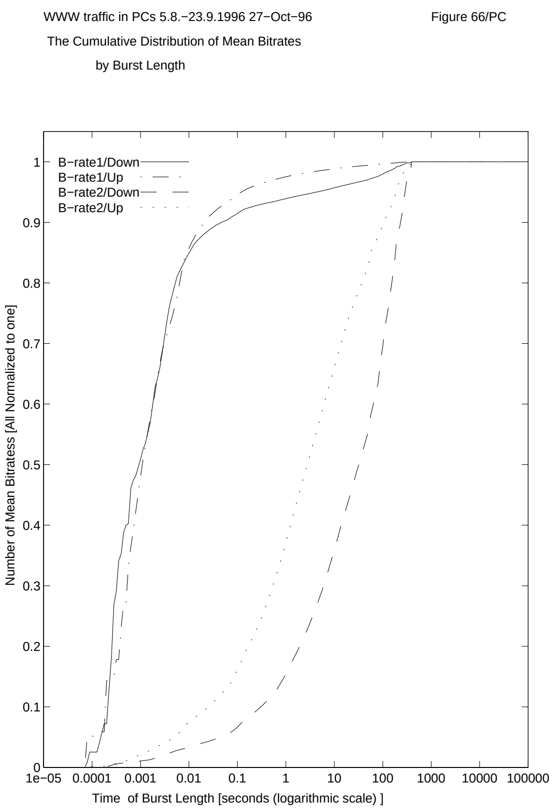
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 64/PC

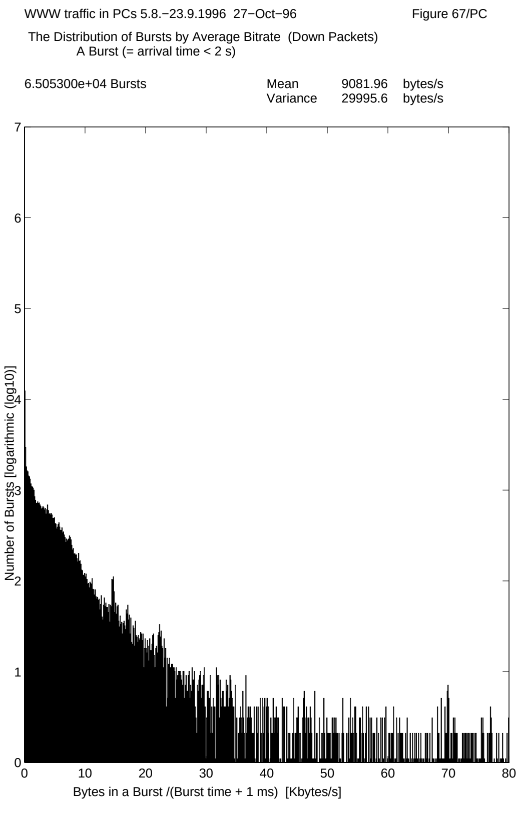
The Cumulative Distribution of Mean IP− & Data bytes and Bitrates

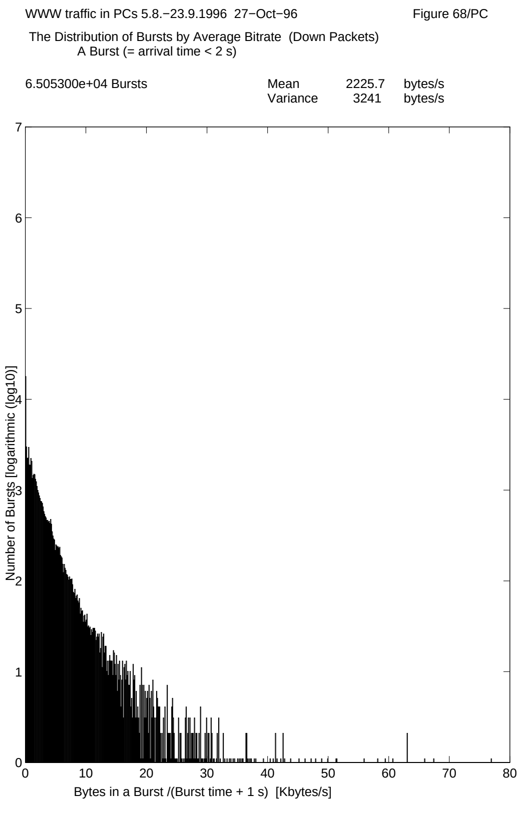
by Burst Length




WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 65/PC
The Cumulative Distribution of Total IP− & Data bytes
by Burst Length
IPs/Down
Bytes/Down
IPs/Up
Bytes/Up
Number of Total IP− & Data bytess [All Normalized to one]
Time of Burst Length [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 66/PC
The Cumulative Distribution of Mean Bitrates
by Burst Length
B−rate1/Down
B−rate1/Up
B−rate2/Down
B−rate2/Up
Number of Mean Bitratess [All Normalized to one]
Time of Burst Length [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 67/PC
The Distribution of Bursts by Average Bitrate (Down Packets)
A Burst (= arrival time < 2 s)
6.505300e+04 Bursts
Mean 9081.96 bytes/s
Variance 29995.6 bytes/s
Number of Bursts [logarithmic (log10)]
Bytes in a Burst /(Burst time + 1 ms) [Kbytes/s]

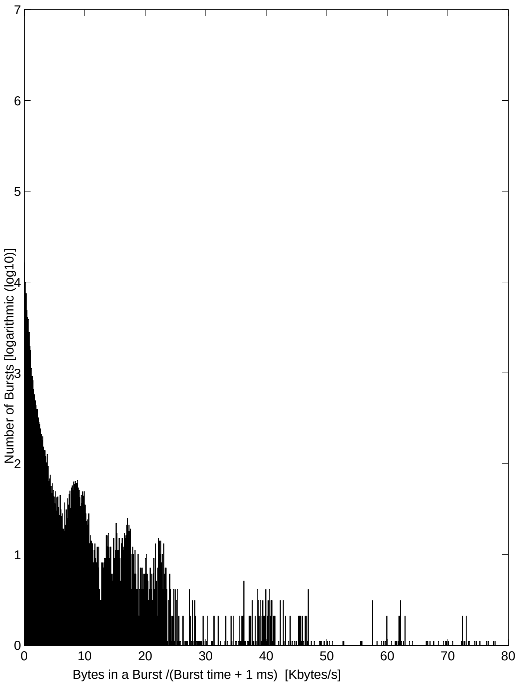

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 68/PC
The Distribution of Bursts by Average Bitrate (Down Packets)
A Burst (= arrival time < 2 s)
6.505300e+04 Bursts
Mean 2225.7 bytes/s
Variance 3241 bytes/s
Number of Bursts [logarithmic (log10)]
Bytes in a Burst /(Burst time + 1 s) [Kbytes/s]

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 69/PC

The Distribution of Bursts by Average Bitrate (Up Packets)
A Burst (= arrival time < 2 s)

6.505300e+04 Bursts

Mean	1489.5	bytes/s
Variance	4473.17	bytes/s

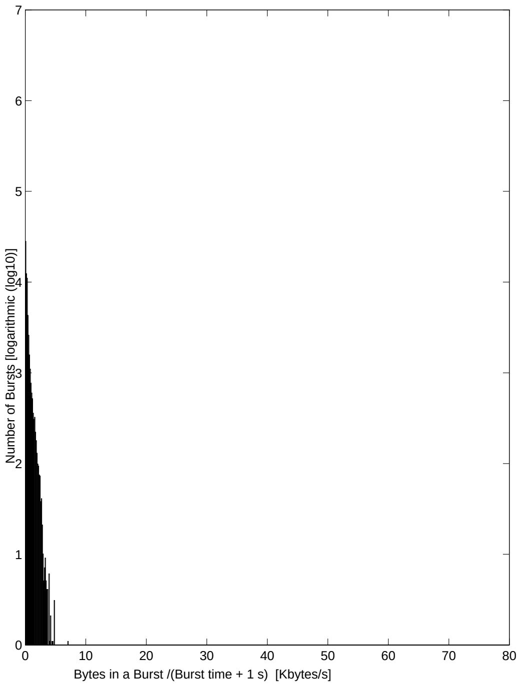


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 70/PC

The Distribution of Bursts by Average Bitrate (Up Packets)
A Burst (= arrival time < 2 s)

6.505300e+04 Bursts

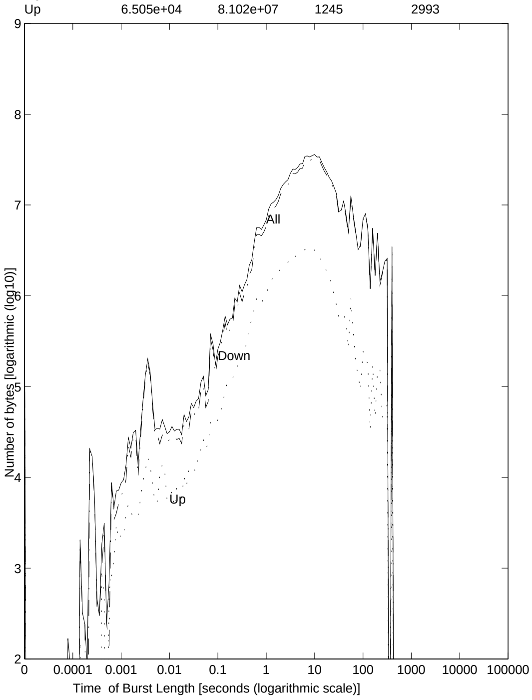
Mean	324.088	bytes/s
Variance	380.555	bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 71/PC

The Distribution of IP−Bytes by Burst Length

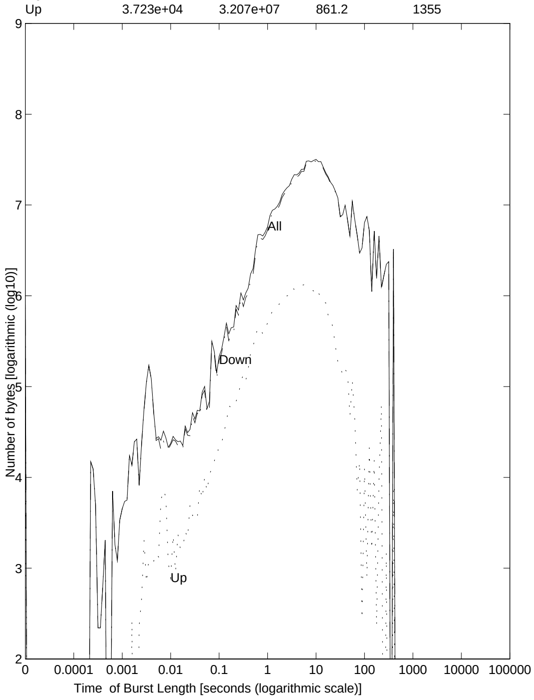
	Burst	Bytes	Mean	Variance
All	6.505e+04	8.371e+08	1.287e+04	4.884e+04
Down	6.505e+04	7.561e+08	1.162e+04	4.904e+04
Up	6.505e+04	8.102e+07	1245	2993



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 72/PC

The Distribution of Data−Bytes by Burst Length

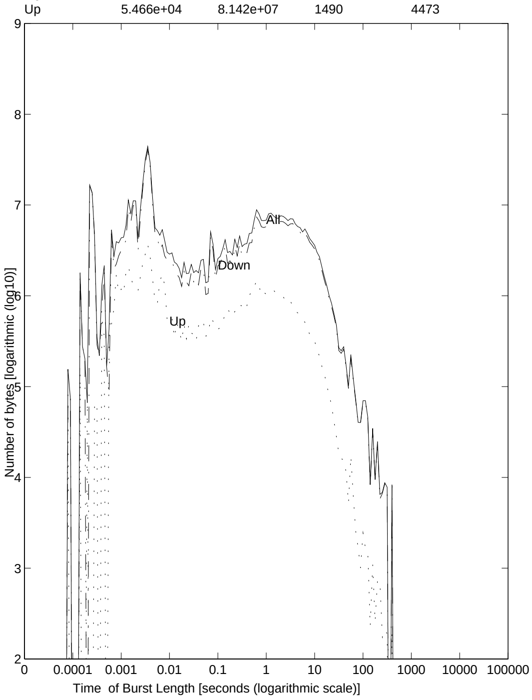
	Burst	Bytes	Mean	Variance
All	4.978e+04	7.334e+08	1.473e+04	5.244e+04
Down	4.978e+04	7.013e+08	1.409e+04	5.26e+04
Up	3.723e+04	3.207e+07	861.2	1355



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 73/PC

The Distribution of Bitrate1 in Bytes by Burst Length

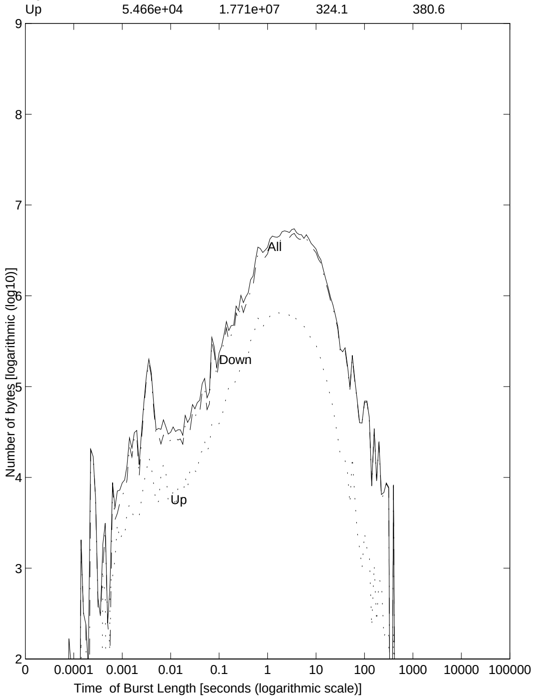
	Burst	Bytes	Mean	Variance
All	5.466e+04	5.772e+08	1.056e+04	2.986e+04
Down	5.459e+04	4.957e+08	9082	3e+04
Up	5.466e+04	8.142e+07	1490	4473



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 74/PC

The Distribution of Bitrate2 in Bytes by Burst Length

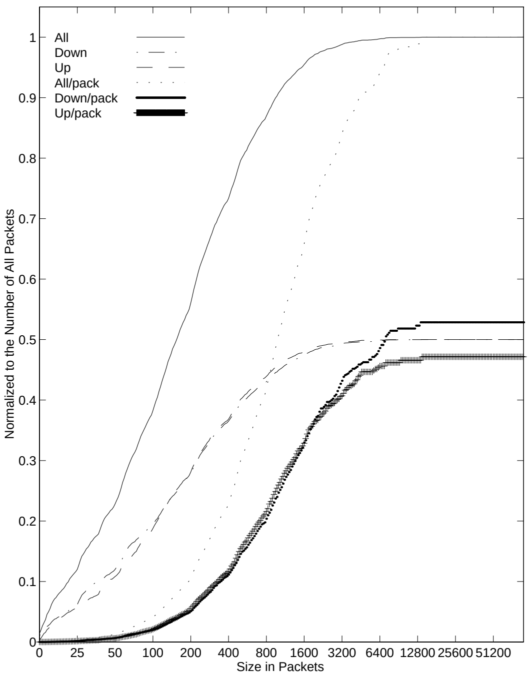
	Burst	Bytes	Mean	Variance
All	5.466e+04	1.392e+08	2547	3033
Down	5.459e+04	1.215e+08	2226	3241
Up	5.466e+04	1.771e+07	324.1	380.6



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 75/PC

The Cumulative Distribution of WWW−sessions by their Size in Packets

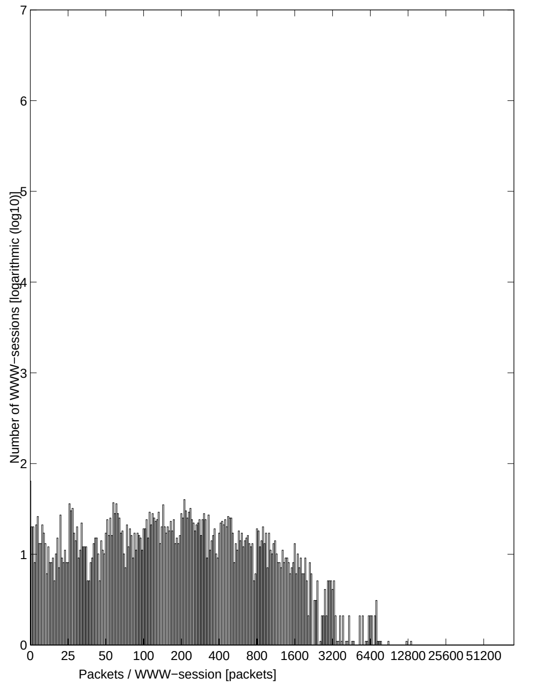
	WWW−session	Bytes	Mean	Variance
All	3132	2.569e+06	820.3	942.7
Down	3132	1.358e+06	433.5	855.5
Up	3132	1.211e+06	386.8	701.5



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 76/PC

The Distribution of WWW−sessions by Size (Down Packets)
A WWW−session (= no pause > 5 min)

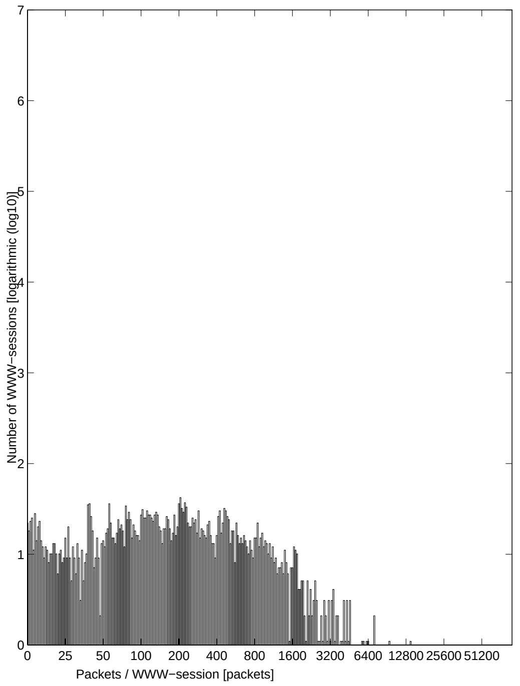
3.132000e+03 WWW−sessions	Mean	433.491	WWW−sessions
1.357693e+06 Packets	Variance	855.528	WWW−sessions



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 77/PC

The Distribution of WWW−sessions by Size (Up Packets)
A WWW−session (= no pause > 5 min)

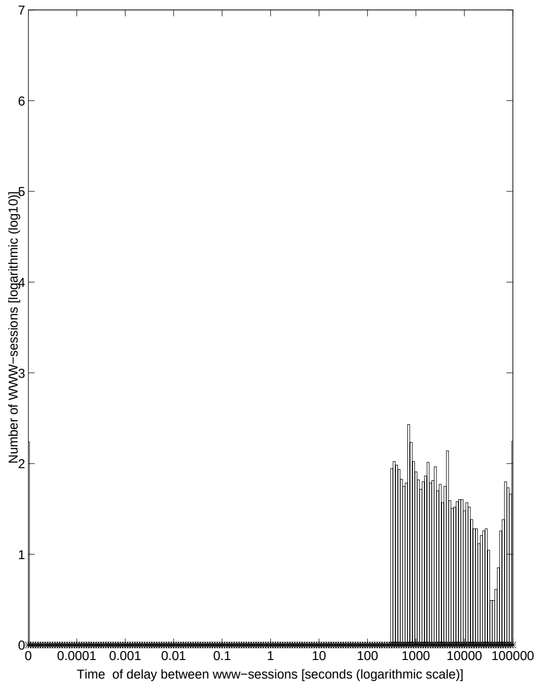
3.132000e+03 WWW−sessions Mean 386.81 WWW−sessions
1.211489e+06 Packets Variance 701.538 WWW−sessions



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 78/PC

The Distribution of delay between www−sessions 3/3

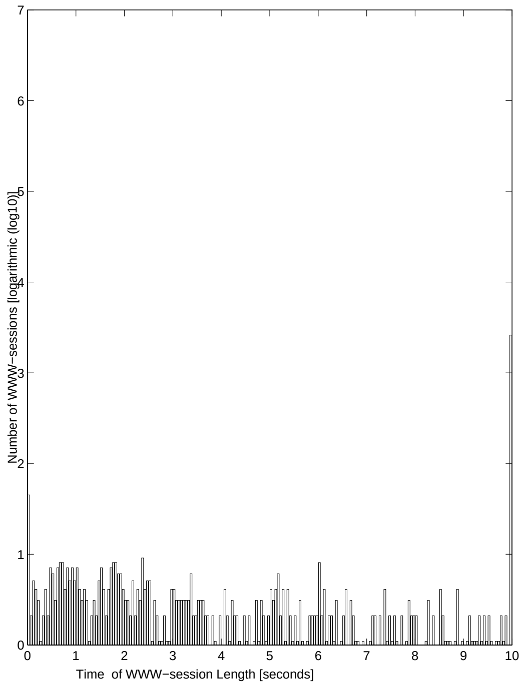
3132 WWW−sessions Mean 16664.1 Seconds/WWW−session
5.2192e+07 Seconds Variance 42523.9 Seconds/WWW−session



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 79/PC

The Distribution of WWW−session Length 1/3

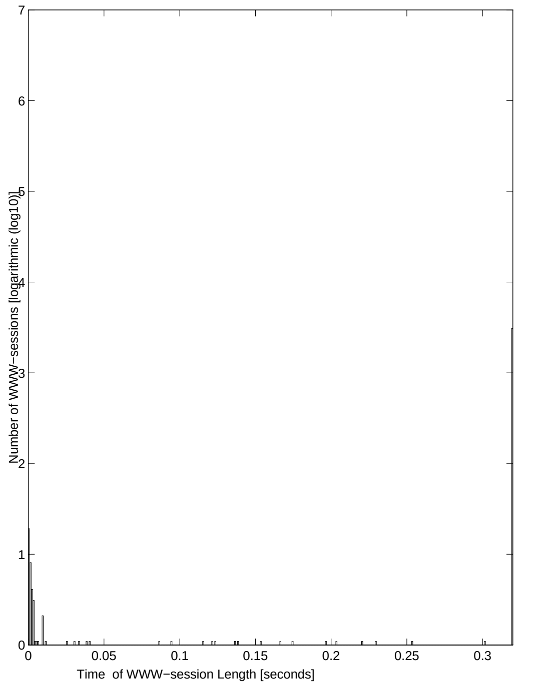
3132 WWW−sessions Mean 439.034 Seconds/WWW−session
1.37505e+06 Seconds Variance 640.448 Seconds/WWW−session



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 80/PC

The Distribution of WWW−session Length 2/3

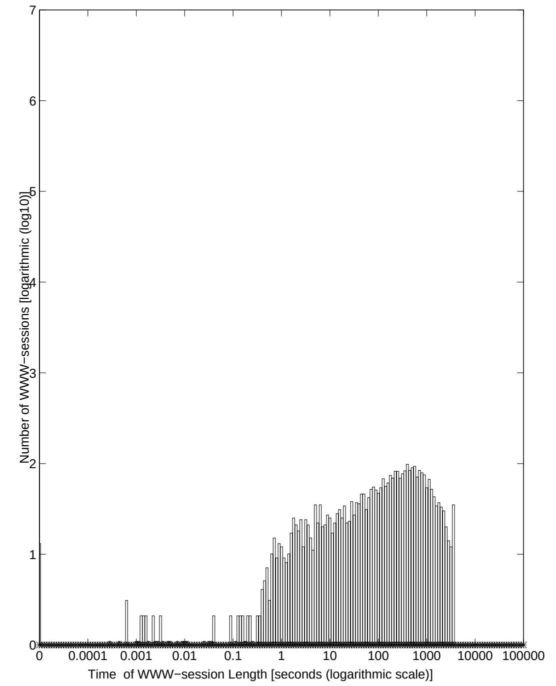
3132 WWW−sessions Mean 439.034 Seconds/WWW−session
1.37505e+06 Seconds Variance 640.448 Seconds/WWW−session



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 81/PC

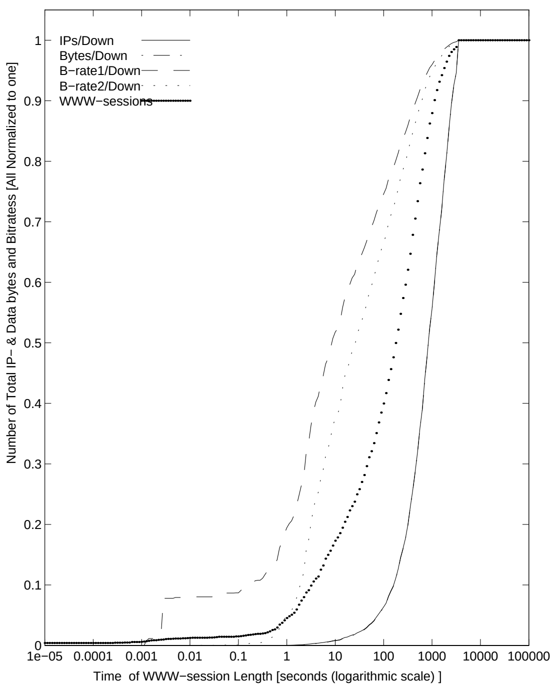
The Distribution of WWW−session Length 3/3

3132 WWW−sessions Mean 439.034 Seconds/WWW−session
1.37505e+06 Seconds Variance 640.448 Seconds/WWW−session



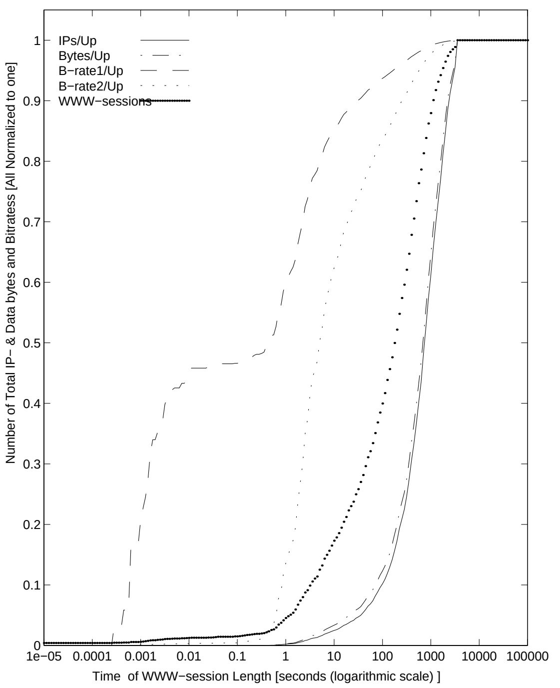
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 82/PC

The Cumulative Distribution of Total IP− & Data bytes and Bitrates by WWW−session Length



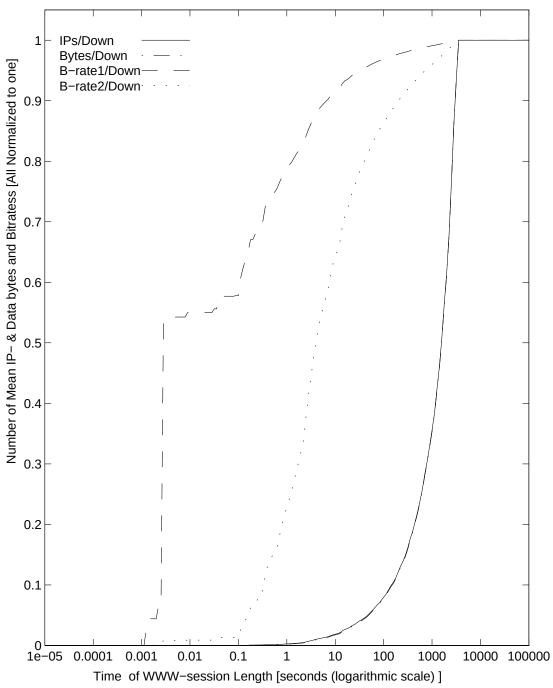
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 83/PC

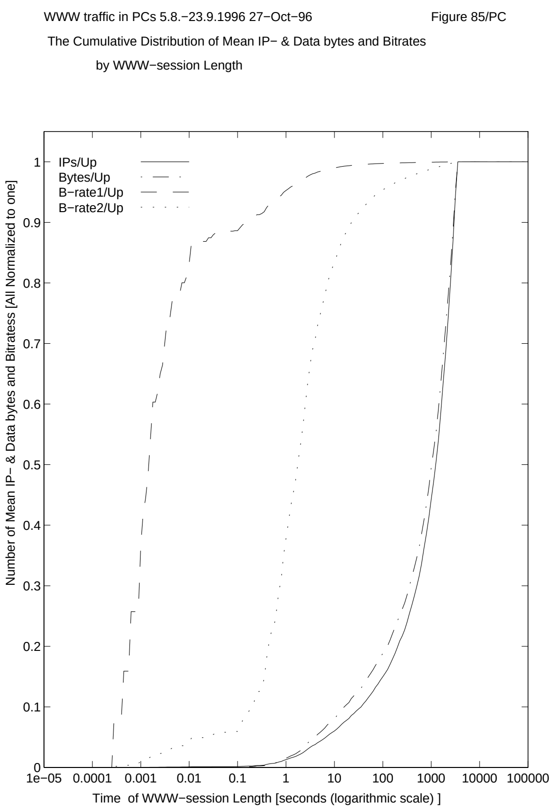
The Cumulative Distribution of Total IP− & Data bytes and Bitrates by WWW−session Length

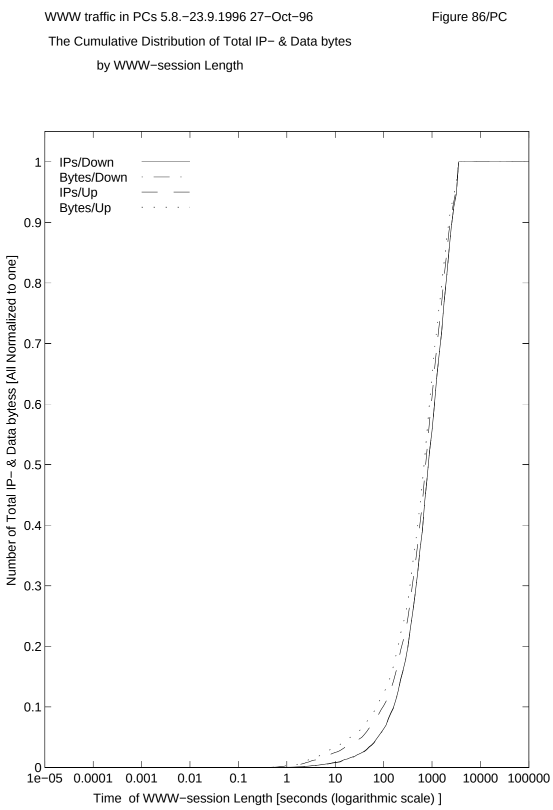


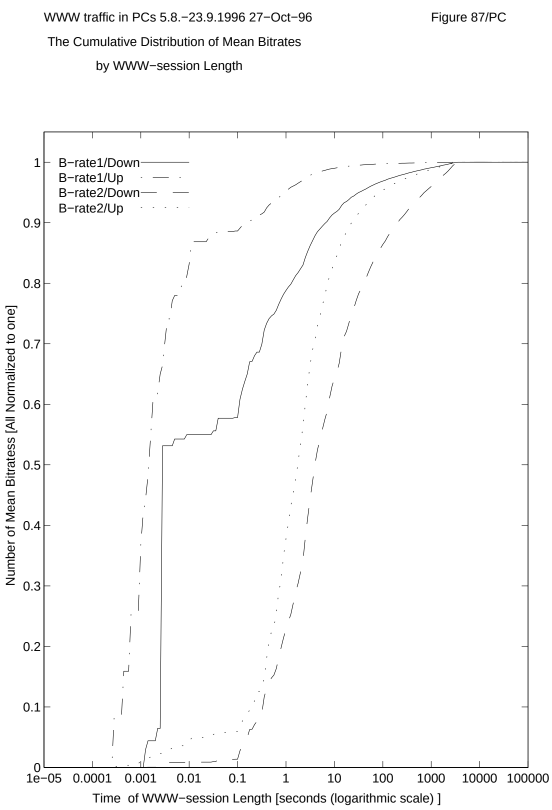
WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 84/PC

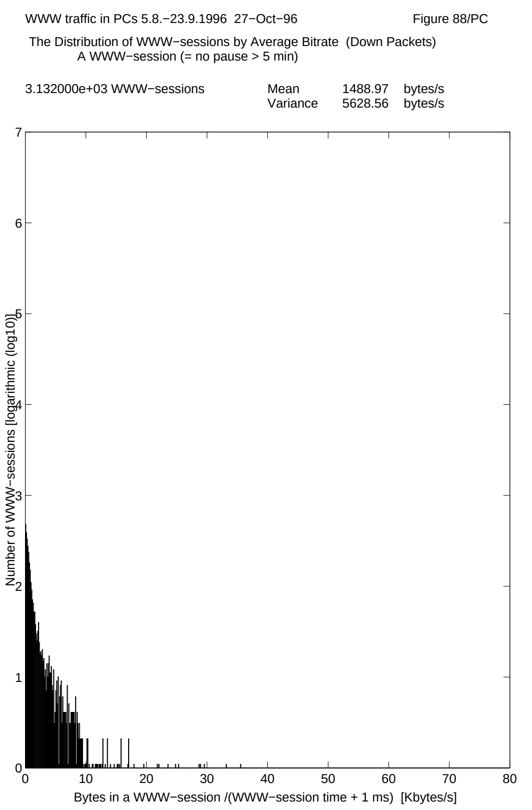
The Cumulative Distribution of Mean IP− & Data bytes and Bitrates by WWW−session Length




WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 85/PC
The Cumulative Distribution of Mean IP− & Data bytes and Bitrates
by WWW−session Length
IPs/Up
Bytes/Up
B−rate1/Up
B−rate2/Up
Number of Mean IP− & Data bytes and Bitratess [All Normalized to one]
Time of WWW−session Length [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 86/PC
The Cumulative Distribution of Total IP− & Data bytes
by WWW−session Length
IPs/Down
Bytes/Down
IPs/Up
Bytes/Up
Number of Total IP− & Data bytess [All Normalized to one]
Time of WWW−session Length [seconds (logarithmic scale)]

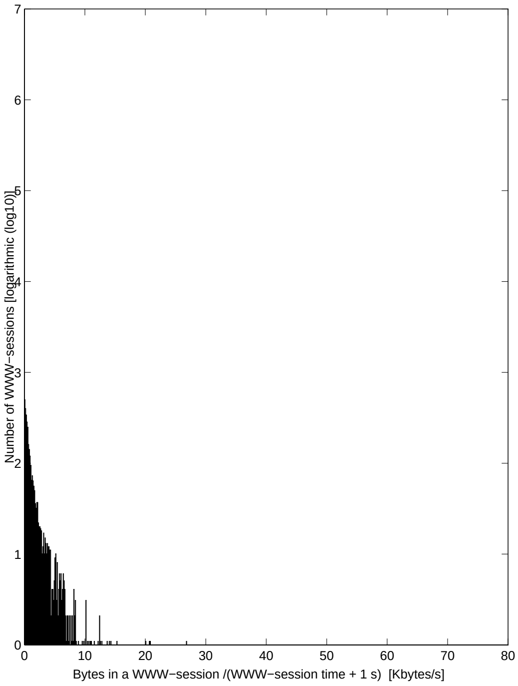

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 87/PC
The Cumulative Distribution of Mean Bitrates
by WWW−session Length
B−rate1/Down
B−rate1/Up
B−rate2/Down
B−rate2/Up
Number of Mean Bitratess [All Normalized to one]
Time of WWW−session Length [seconds (logarithmic scale)]


WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96
Figure 88/PC
The Distribution of WWW−sessions by Average Bitrate (Down Packets)
A WWW−session (= no pause > 5 min)
3.132000e+03 WWW−sessions
Mean 1488.97 bytes/s
Variance 5628.56 bytes/s
Number of WWW−sessions [logarithmic (log10)]
Bytes in a WWW−session /(WWW−session time + 1 ms) [Kbytes/s]

WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 89/PC

The Distribution of WWW−sessions by Average Bitrate (Down Packets)
A WWW−session (= no pause > 5 min)

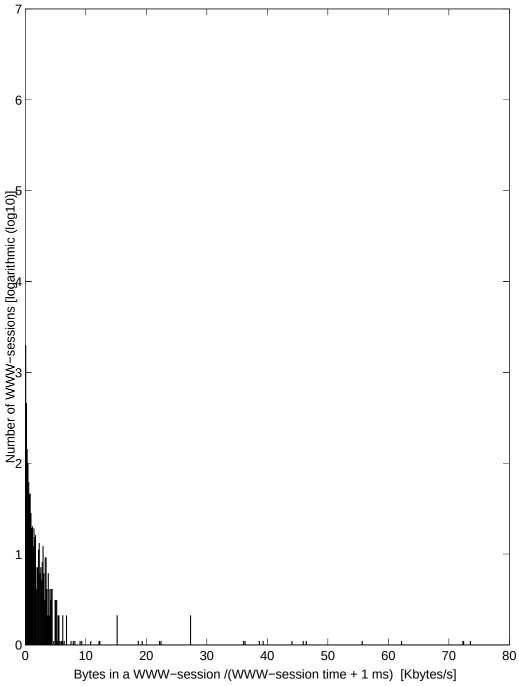
3.132000e+03 WWW−sessions	Mean	1127.5	bytes/s
	Variance	1782	bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 90/PC

The Distribution of WWW−sessions by Average Bitrate (Up Packets)
A WWW−session (= no pause > 5 min)

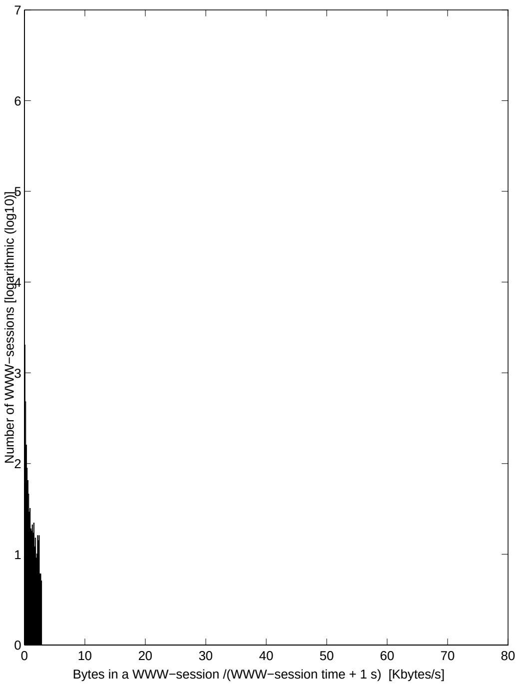
3.132000e+03 WWW−sessions	Mean	648.874	bytes/s
	Variance	3887.53	bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 91/PC

The Distribution of WWW−sessions by Average Bitrate (Up Packets)
A WWW−session (= no pause > 5 min)

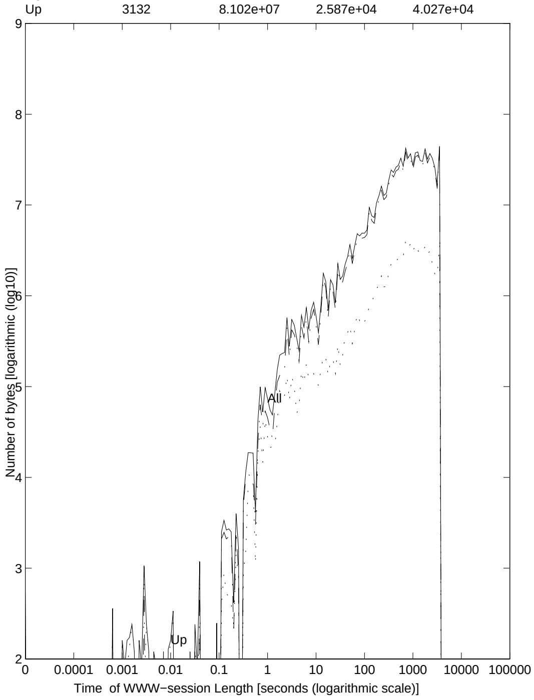
3.132000e+03 WWW−sessions	Mean	247.83	bytes/s
	Variance	458.606	bytes/s



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 92/PC

The Distribution of IP−Bytes by WWW−session Length

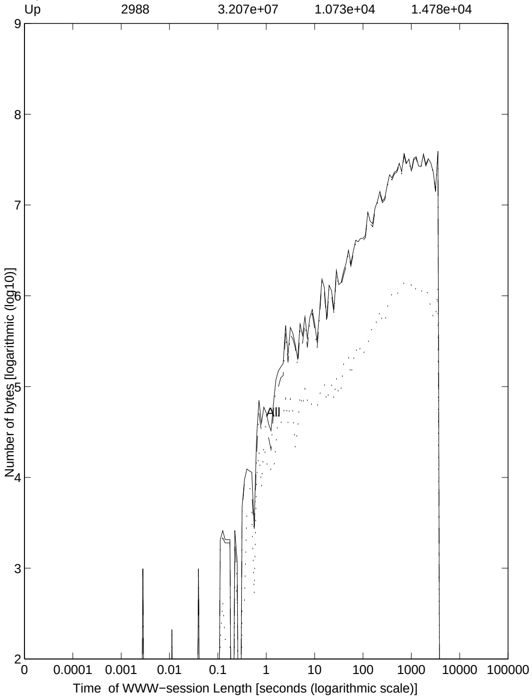
	WWW−session	Bytes	Mean	Variance
All	3132	8.371e+08	2.673e+05	5.467e+05
Down	3132	7.561e+08	2.414e+05	5.565e+05
Up	3132	8.102e+07	2.587e+04	4.027e+04



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 93/PC

The Distribution of Data−Bytes by WWW−session Length

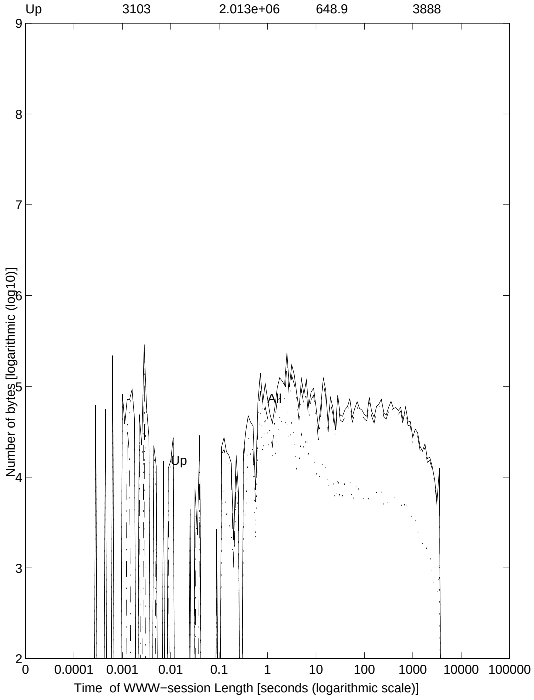
	WWW−session	Bytes	Mean	Variance
All	3006	7.334e+08	2.44e+05	5.281e+05
Down	3006	7.013e+08	2.333e+05	5.326e+05
Up	2988	3.207e+07	1.073e+04	1.478e+04



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 94/PC

The Distribution of Bitrate1 in Bytes by WWW−session Length

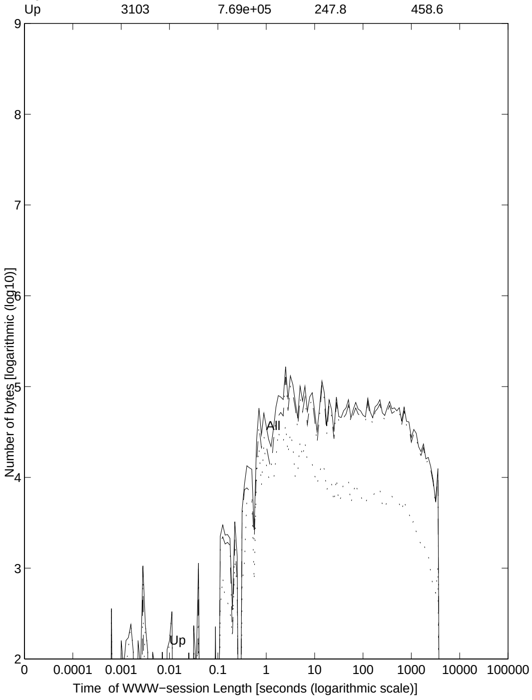
	WWW−session	Bytes	Mean	Variance
All	3103	6.573e+06	2118	6671
Down	3062	4.559e+06	1489	5629
Up	3103	2.013e+06	648.9	3888



WWW traffic in PCs 5.8.−23.9.1996 27−Oct−96 Figure 95/PC

The Distribution of Bitrate2 in Bytes by WWW−session Length

	WWW−session	Bytes	Mean	Variance
All	3103	4.221e+06	1360	1676
Down	3062	3.452e+06	1127	1782
Up	3103	7.69e+05	247.8	458.6



5.2 Figures from the HP-workstations