When a connection is initially set up, the sender does not know the receiver's capabilities and thus uses default values for rate control. *ALLOC* and *BURST* are usually set to the MTU size of the underlying network, while *RATE* is set equal to *N*BURST* where *N* equals the number of packets per second the receiver can handle. *N* for every station is normally set equal to the capability of the slowest receiver on the network.

This rate control feature may be disabled by setting rate equal to all ones in outgoing CONTROL packets.

E.7 Error Control

Errors are detected using the *DCHECK* and *HTCHECK* fields in the common trailer segment. If either of these checksum fields does not match the recomputed checksums in the receiver, the packet is assumed garbled and the receiver discards it. When packets are lost, several error handling methods are used to correct the problems.

E.7.1 Packet Acknowledgement

The sender of data is responsible for detecting lost acknowledgements. It requests acknowledgement by setting SREQ or DREQ in the common trailer. A timer, WTIMER, is used by the transmitter to determine if acknowledgement or status request has failed. If WTIMER expires, the source retransmits a request for data acknowledgement. On the other hand when the destination terminates a connection, the source must acknowledge context termination so that the receiver can be sure the context is closed. In the event this last packet is corrupted or lost, the receiver's WTIMER will eventually expire and the context close.

DREQ and SREQ differ in when the acknowledgement is actually sent. In the case of the source setting SREQ, the acknowledgement is sent after all packets up to the packet with SREQ set are processed. In the case of DREQ being set, acknowledgement follows when *all* data packets have been sent by the source and processed by the destination. In closing a connection, SREQ behaviour will follow that of DREQ in that the context is closed only after all data packets have been received.

When re-requesting acknowledgement only a control frame is sent and the receiver indicates which packet is lost (if any). XTP uses selective retransmission to retransmit information packets that have been lost.

E.7.2 Gaps and Selective Retransmissions

Gaps are the missing blocks of bytes in the sequence of bytes that should be received at the receiver. XTP uses ***selective acknowledgement*** to inform a sender of the blocks of sequential bytes correctly received. The gaps are then inferred to be between the groups of sequential bytes acknowledged by means of ***spans***. Each span is composed of two sequential numbers indicating respectively the first and last byte in the group that were received correctly. The *SPAN* field contains these descriptors for the sequences of bytes correctly received (the spans). With this information the sender of the data uses ***selective retransmission*** to retransmit the lost sequences of bytes. (Up to 16 *SPAN* fields of 8 bytes each can be present in a control packet.)

This ***selective retransmission*** policy is not the only one available, but receivers can use a ***go-back-n*** retransmission policy meaning no gaps will be allowed to be present in the input buffer. As soon as a packet is incorrectly received (bytes out of sequence) the receiver notifies the sender and tells it from what point to retransmit the sequential data.

E.7.3 Re-synchronization

When *WTIMER* expires after a sender's SREQ packet has not been responded to, the sender will attempt re-synchronization.

The sender will send *synchronizing* frames with SREQ set to the receiver to attempt resynchronization. If no response is received after a timer *CTIMER* expires, the connection is assumed severed and the application process of the local station will be notified of the failure.

For each receiver-generated CONTROL packet, the sender associates a SREQ synchronizing with it. A field contained in the SREQ synchronizing frame, *SYNC*, is used to uniquely identify and keep track of acknowledgements. When the acknowledgement is generated, the value from the *SYNC* field of the SREQ packet is copied to the *ECHO* field of the outgoing CONTROL packet (called an *echo* packet).

The value of *WTIMER* is set to twice the round trip time (RTT) estimate. The RTT is calculated from the timer value *TIME* in the echo packet's control segment and the present time. This *TIME* value is set when the synchronizing frame is first sent and is copied to the echo packet when it is transmitted.

E.7.4 Packet lifetimes

Each packet has a maximum lifetime duration specified in the time-to-live field (TTL). The value in TTL specifies the amount of time the packet may exist in "10 msec" ticks. Whenever the packet is passed through a store-and-forward device (eg. router or bridge) this value is decremented and if it reaches zero in one of these devices, the packet is dropped. When a packet is received with this value already zero, the TTL mechanism is disabled; this condition being necessary for very large networks.

APPENDIX F: DERIVATIONS OF INDICES USED IN ANALYTICAL COMPARISONS

F.1 Absolute Maximum MAC layer Throughput

The following protocol parameters, illustrated in figure F1, are used in the derivations:

F_{MAX} = Maximum frame size, the maximum packet size determined by the protocol (bytes)

GAP_{IF} = Inter-frame gap, the interval of time found between consecutive packet transmissions on one line (seconds)

F_{minPRE} = Minimum frame preamble length, the preamble being the front part of the packet that carries no information and is generally used for synchronising receiving station clocks for correct data reception (bytes)

$F_{minHEAD}$ = Minimum header length, the minimum permissible length of the header, which is situated at the front of the packet before the data and after the preamble (bytes)

$F_{minTRAIL}$ = Minimum trailer length, the minimum permissible length of the trailer, which is situated at the end of the packet (bytes)

B = Capacity of one link between two stations

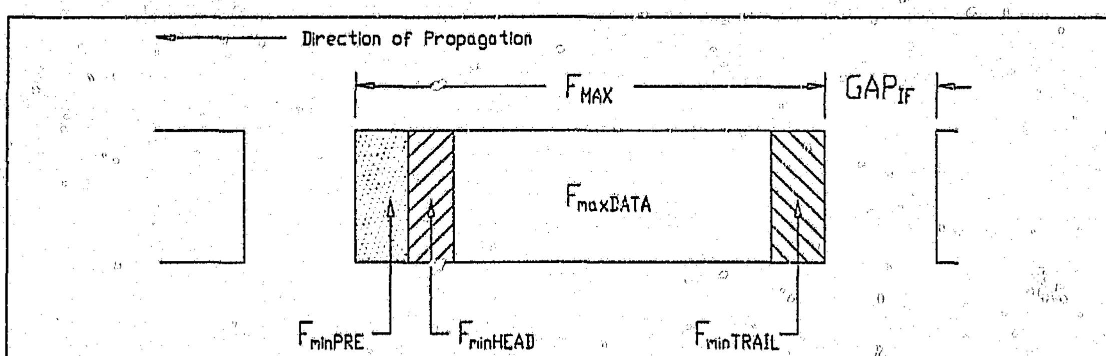

Figure F1 Components of a data frame (generalized for comparison of different formats)

From these quantities, the maximum MAC data length per frame can be found:

$F_{maxDATA}$ = Maximum MAC data length per frame (bytes)

$$F_{maxDATA} = F_{MAX} - F_{minPRE} - F_{minHEAD} - F_{minTRAIL}$$

The maximum MAC efficiency, MAC_η, can also be found from these values:

$$MAC_\eta = \frac{F_{maxDATA}}{F_{MAX} + GAP_{IF} . B}$$

Subsequently, the absolute maximum MAC layer throughput, T_{maxMAC}, can be found:

$T_{maxMAC} = B.MAC_n$

F.2 Allocated Bandwidth

An extra parameter is used in calculating this index:

N = The number of stations on the network.

The allocated bandwidth, b, is the bandwidth that is available to a station for transmissions on the network. The derivation of b from the previous quantities differs for each of the example MANs:

FDDI:

With FDDI, one path (which is the ring) is used for all stations to transmit on. The bandwidth of this physical path (or link) is thus shared:

$$b = B/N$$

DQDB:

Every station is connected to two transmitting paths ie. the two busses, which must serve all stations on the network. Thus there is twice the capacity as there is with FDDI:

$$b = 2B/N$$

Metroring:

Here every station is connected to at least two dedicated physical outgoing links. The full capacity of each link is thus available to the station. (Refer to section 5.2.2 for further discussion of bandwidth allocation in Metroring stations.)

$$b = nB$$

where n = the number of ports on the station for which the bandwidth is being assessed.

For the standard configuration, each station is assumed to have only two ports.

F.3 Packet Transmission Delays

These are the delays occurring between the time when a packet is transmitted on the network to the time it is received. Five extra parameters are defined in determining transmission delays in MANs:

l_{ring} = The complete length of the ring cable (metres).

c = The speed of light in a vacuum
$\approx 3 \times 10^8$ metres/ sec

t_{REC} = The delay incurred by the receiving electronics/ components in the station (sec)

t_{TRANS} = The delay incurred by the transmitting electronics/ components in the station (sec)

t_{PROC} = The processing delay on a packet incurred by the station

The delays occurring can be easily be derived by considering the three separate components of the delay experienced by a packet:

(1) The processing delays of the packet when a station has to process a packet before forwarding it.
(2) Receiving and transmission delays due to electronics delays in the stations.
(3) Propagation delays of the packet over the network medium.

Figure F2 depicts the three MAN's configurations in a way that is beneficial for deriving the delays in terms of the newly defined parameters. The representation distinguishes between the

- physical paths over which packets travel,
- receiving and transmitting components of stations and
- processing elements (MAC entities) of stations.

The representation then links these three components in the manner the protocol topology specifies.

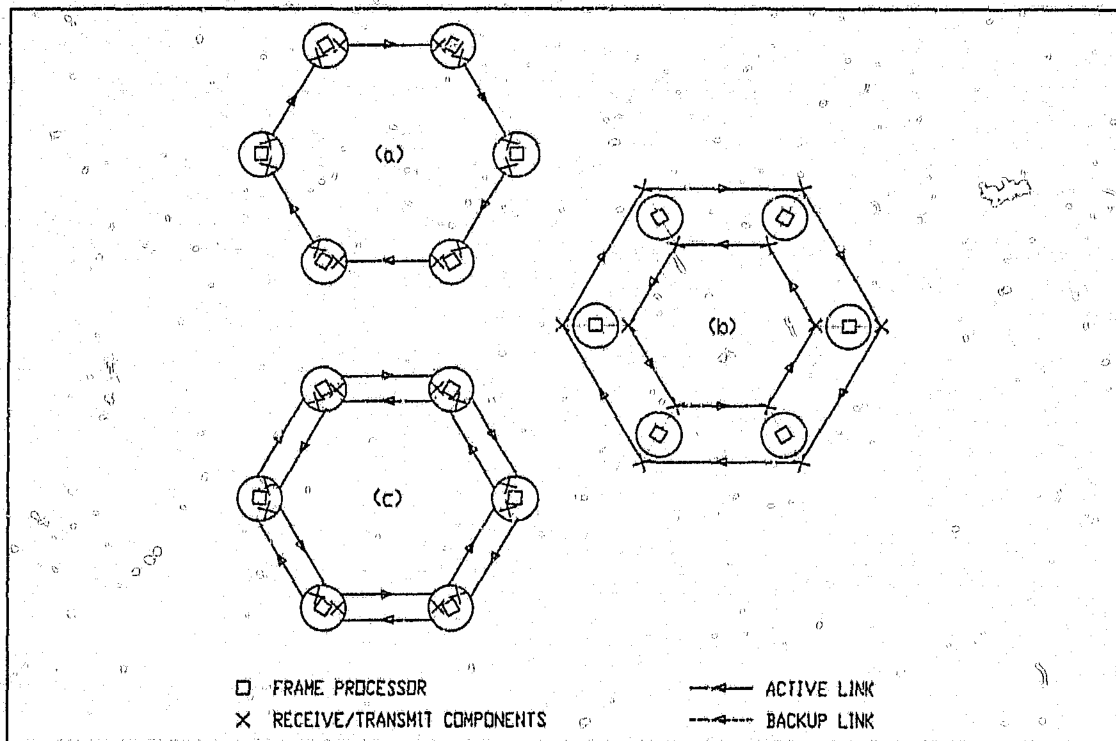

Figure F2 Symbolic representation of (a) FDDI, (b) DQDB and (c) Metroring for aiding derivation of transmission delay formulae

F.3.1 Maximum Transmission Delays

t_{max} is derived by looking at the longest possible path the packet can travel on from source to destination station.

FDDI:

$$t_{max} = \left(\frac{N-1}{N}\right)\frac{l_{ring}}{n_{FIBRE}\,c} + (N-1)(t_{REC}+t_{TRANS}) + (N-2)t_{PROC}$$

DQDB:

$$t_{max} = \left(\frac{N-1}{N}\right)\frac{l_{ring}}{n_{FIBRE}\,c} + (N-1)(t_{REC}+t_{TRANS})$$

Metroring:

$$t_{max} = N\,div\,2\left(\frac{l_{ring}}{n_{FIBRE}\,c\,N} + t_{REC}+t_{TRANS}\right) + (N\,div\,2-1)t_{PROC}$$

This relationship holds as long as the routing logic always finds the shortest path possible.

F.3.2 Minimum Transmission Delays

t_{min} is derived by determining the shortest possible path a packet travels, ie. with adjacent source and destination stations. As this is a simple case, it turns out the delay is the same for all the MANs considered:

$$t_{min} = \frac{l_{ring}}{n_{FIBRE}\,c\,N} + t_{REC}+t_{TRANS}$$

F.3.3 Average Transmission Delays

The average transmission delay, t_{ave} is the average of the delays as the number of packets transmitted on the network tends to infinity. This again is not difficult to work out, the average delay is half the maximum transmission delay of the respective network type:

$$t_{ave} = \frac{1}{2}t_{max}$$

APPENDIX G: CONSTRUCTING CONFIDENCE INTERVALS FOR STEADY-STATE SIMULATION

The monitoring of steady-state simulation involves the monitoring of samples, $Y_1, Y_2, \ldots$ from an output process of a single simulation run. The concept of steady-state simulation implies that the average of all the samples from the infinite output process tends to a fixed value, v, this is defined by:

$$v = \lim_{m \to \infty} \frac{\sum_{i=1}^{m} Y_i}{m}$$

with probability 1

A sequential procedure was used in constructing the confidence intervals. This simply means the length of the simulation is sequentially increased until an acceptable confidence interval can be constructed. The procedure used is known as the sequential procedure of Law and Carson [Sauer et al 83].

The samples are divided into n batches each of length l, and statistical analyses performed on the batches. The number of samples is then $m = nl$. Two important measures are:

the batch mean:

$\bar{Y}_j(l) \quad (j = 1, 2, \ldots, n)$,

which is the sample mean of the l observations in the jth batch, and the grand sample mean,

$$\bar{\bar{Y}}(n, l) = \sum_{i=1}^{m} Y_i / m$$

A key measure used in the decision making of the procedure is the lag i correlation, $\rho_i(l)$. This measure allows bias in the batches of samples to be determined as a function of the batch length, l. The ideal situation is for $\rho_i(l)$ to tend to zero. However this implies l tends to infinity, an impractical situation in simulation. To make the problem of correlation determination tractable, the number of batches is fixed and the length of the batches increased until $\rho_1(l)$ is small enough, say less than 0.05.

Several investigations by Law and Carson proved that three types of behaviour of $\rho_1(l)$ as a function of l are predominant in varying systems:

(1) As l increases, $\rho_1(l)$ strictly decreases to 0.
(2) As l increases, $\rho_1(l)$ changes direction 1 or more times then strictly decreases to 0.
(3) $\rho_1(l) < 0$, for all l.

However for type 1 and 2 behaviour (and a few less common types) it was found, if for some l, $0 < \rho_1(l) < 0{,}4$ then $\rho_1(10l) < 0{,}05$. Only one exception occurred where $\rho_1(10l) = 0{,}059$. Thus the investigations resulted in an acceptable way of reducing the number of samples needed for many of the types of correlation behaviours.

A jackknifed estimator reduces the bias present in estimations of the correlations. Thus, for these correlations to be made with as little bias as possible, a jackknifed estimator is used to approximate $\rho_1(l)$,

$$\tilde{\rho}_1(n, l) = \hat{\rho}_1(n, l) - \frac{\hat{\rho}_1^1(n/2, l) + \hat{\rho}_1^2(n/2, l)}{2}$$

where

$$\hat{\rho}_1(n,l) = \frac{\sum_{j=1}^{n-1}\left[\overline{Y}_j(l)-\overline{\overline{Y}}(n,l)\right]\left[\overline{Y}_{j+1}(l)-\overline{\overline{Y}}(n,l)\right]}{\sum_{j=1}^{n}\left[\overline{Y}_j(l)-\overline{\overline{Y}}(n,l)\right]^2}$$

and $\tilde{\rho}_1^1(n,l)$ and $\tilde{\rho}_1^2(n,l)$ are respectively, $\hat{\rho}_1(n,l)$ based on the first n/2 and last n/2 batches.

7.1 The sequential procedure of Law and Carson:

This procedure consists of several steps that determine the number of samples collected for the whole simulation:

(0) Set n = 40, f = 10 (the batch size scaling factor), m_0 = 600, m_1 =800, u = 0,4 (the stopping factor), $\gamma > 0$ (the relative precision), let i = 1 (check number); collect m_1 observations.

(1a) Divide the m_i observations into fn batches of size $l = m_i/fn$. Compute $\tilde{\rho}_1(fn,l)$ from $\overline{Y}_j(l)$ $(j=1,2,\ldots,fn)$.
If $\tilde{\rho}_1(fn,l) \geq u$, go to step 2.
If $\tilde{\rho}_1(fn,l) \leq 0$, go to step 1c.
Otherwise, go to step 1b.

b) Divide the m_i observations into $fn/2$ batches of size $2l$. Compute $\tilde{\rho}_1(fn/2,2l)$ from $\overline{Y}_j(2l)$ $(j=1,2,\ldots,fn/2)$.
If $\tilde{\rho}_1(fn/2,2l) < \tilde{\rho}_1(fn,l)$, go to step 1c.
Otherwise, go to step 2.

c) Divide the m_i observations into n batches of size fl. Compute $\overline{\overline{Y}}(n,fl)$ and $\delta = t_{n-1,1-\alpha/2}\sqrt{\hat{\sigma}^2[\overline{\overline{Y}}(n,fl)]}$
from $\overline{Y}_j(fl)$ $(j=1,2,\ldots,n)$.
If $\delta/|\overline{\overline{Y}}(n,fl)| \leq \gamma$, use $\overline{\overline{Y}}(n,fl) \pm \delta$ as an approximate $100(1-\alpha)$ confidence interval for and stop.
Otherwise, go to step 2.

(2) Replace i by i+1, set $m_i = 2m_{i-2}$, collect the additional samples $m_i - m_{i-1}$ then go to step 1a.

NOTE: (1) The stopping factor relates to the results of the investigations by Law and Carson, as discussed above.
(2) The relative precision is defined as the confidence-interval half length divided by the point estimator.
(3) The Check Number refers to which confidence interval construction check is taking place.

APPENDIX H: SIMULATOR TEST RESULTS

H.1 LANES Results for FDDI Simulations

Offered Load (fraction of medium capacity)	Average frame delay (msec)	Channel Utilization (%)
0,20	0,378	20
0,40	0,436	40
0,60	0,618	60
0,80	0,996	80
0,90	1,640	90
1,00		99,9
1,20		99,9
1,40		99,9

No measures of reading accuracies of channel utilization and average frame delay were given with these results.

H.2 LANNET II.5 Results for FDDI Simulations

Offered Load (fraction of medium capacity)	Average Inter-arrival Time (msec)	Average frame delay (msec)	Frame delay standard deviation (msec)	Channel Utilization (%)
0,40	16,16	0,411	0,181	39,5
0,60	10,774	0,518	0,307	59,9
0,80	8,08	0,835	0,661	78,9
1,00	6,464	3,178	1,706	98,4
1,20	5,386	6,067	1,017	100,0

The standard deviation of channel utilization was given as zero for all readings.

H.3 MANSIM Results for FDDI Simulations

Offered Load (fraction of medium capacity)	Average Inter-arrival Time (msec)	Average User end-to-end delay (msec)	95% confidence interval size (msec)	Average Physical Throughput (Mbps)	Channel Utilization (%)
0,20	1,616	0,424	0,0202	20,2	20,2
0,40	0,808	0,542	0,0199	39,9	39,9
0,60	0,539	0,811	0,0194	59,5	59,5
0,80	0,404	1,552	0,0244	80,4	80,4
0,90	0,359	3,290	0,0187	90,8	90,8
1,00	0,323	61,155	0,0168	99,7	99,7
1,20	0,269	479,5	0,0234	99,8	99,8

NOTE: The 95% confidence interval size is given for a randomly selected station on the network - it can thus be interpreted as a worst case value for the network average. No measures of reading accuracies of physical throughput are available for these results.

H.4 RESQ Results for DQDB Simulations

Offered Load (fraction of medium capacity)	Average MAC delay (µsec)	MAC delay variance
0,80	15,1	0,32
0,90	28,0	0,72
0,95	44,1	1,32
1,05	148,1	2,15
1,10	152,0	1,99
1,20	158,6	1,74

H.5 MANSIM Results for DQDB Simulations

Offered Load (fraction of medium capacity)	Average Inter-arrival Time (µsec)	Average physical delay (µsec)	Physical delay standard deviation (µsec)	Average end-to-end user delay (µsec)	End-to-end user delay standard deviation (µsec)
0,50	2,826	98,2	68,7	108	69
0,70	2,019	105,0	70,7	117	71,5
0,80	1,7667	101,0	68,0	119	67,2
0,90	1,5704	101,0	71,4	126	73,2
1,00	1,413	102,0	70,5	132	77,1
1,10	1,285	91,1	66,3	138	100,0
1,20	1,178	97,0	67,9	188	137,0
1,50	0,942	99,6	69,0	267	206

H.6 Ideal Access Delay for DQDB

Offered Load (fraction of medium capacity)	Average Access delay (µsec)	Average Access delay tolerance (µsec)
0,0	16,3	2,5
0,4	14,9	2,5
0,6	15,3	2,5
0,7	17,7	2,5
0,8	20,0	2,5
0,9	32,6	2,5
0,95	61,9	5,0
0,975	125,6	14,0

APPENDIX I: RESULTS FOR LAN BACKBONE INVESTIGATION

I.1 Settings for FDDI Simulation

a) Distributed Sites on Backbone

Offered Load (% of 100 Mbps)	Required average inter-arrival time (msec)
50	0,72
100	0,36
150	0,24

b) LAN Domains on Backbone

To derive the final average inter-arrival times for each node's load specification, divide the normalized value by the weighting factors (WT) as shown in figure 8.3.

Offered Load (% of 100 Mbps)	Required average inter-arrival time - normalized (msec)
50	23,04
100	11,52
150	7,68

I.2 Settings for DQDB Simulation

a) Distributed Sites on Backbone

Offered Load (% of 100 Mbps)	Required average inter-arrival time (μsec)
50	8,480
100	4,240
150	2,827

b) LAN Domains on Backbone

To derive the final average inter-arrival times for each node's load specification, divide the normalized value by the weighting factors as shown in figure 8.3.

Offered Load (% of 100 Mbps)	Required average inter-arrival time - normalized (μsec)
50	271,36
100	135,68
150	90,453

I.3 Settings for Metroring Simulation

a) Distributed Sites on Backbone

Offered Load (% of 100 Mbps)	Required average inter-arrival time (msec)
50	0,6554
100	0,3277
150	0,2185

b) LAN Domains on Backbone

To derive the final average inter-arrival times for each node's load specification, divide the normalized value by the weighting factors as shown in figure 8.5.

Offered Load (% of 100 Mbps)	Required average inter-arrival time - normalized (msec)
50	20,971
100	10,486
150	6,991

I.4 Results of MANSIM Simulations

These are the results for the LAN backbone simulations.

I.4.1 FDDI Simulation

Distributed Sites on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (msec)	
	Average	Average	Standard deviation
50	49,5	0,752	0,776
75	74,7	1,53	1,95
100	98,1	44,9	45,8
125	98,9	630	391
150	98,8	592,8	381,3

Collision Domains on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (msec)	
	Average	Average	Standard deviation
50	50,3	0,907	0,867
75	74,7	2,20	2,85
100	94,6	41,9	57,1
125	95,6	236	203
150	95,7	368	287

I.4.2 DQDB Simulation

Distributed Sites on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (µsec)	
	Average	Average	Standard deviation
50	23,7	14,8	6,83
75	31,2	14,4	6,99
100	42,6	15,0	7,42
125	60,1	16,2	7,81
150	59,7	16,3	8,24

Collision Domains on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (µsec)	
	Average	Average	Standard deviation
50	21,9	15,0	6,61
75	25,9	14,0	6,32
100	27,4	14,9	6,42
125	29,1	16,6	7,59
150	26,6	17,3	7,50

I.4.3 Metroring Simulation

Distributed Sites on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (msec)	
	Average	Average	Standard deviation
50	34,3	4,18	4,94
75	61,2	5,56	5,77
100	77,6	5,69	5,00
125	102,1	6,05	5,20
150	110,0	5,93	5,38

Collision Domains on Backbone

Offered load (% of 100 Mbps)	User layer throughput (Mbps)	End-to-end user layer delay (msec)	
	Average	Average	Standard deviation
50	39,9	4,63	5,80
75	84,4	3,50	4,15
100	98,5	3,01	3,51
125	117,3	3,01	3,61
150	146,3	2,33	2,57

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