The University of Kansas

Information and Telecommunication Technology Center

A Technical Report of ITTC's
Networking and Distributed Systems Laboratory

Relating AAL-2 Level and ATM-Level Performance

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Contents

Chapter 1

Introduction

1.1 Objective

This study aims to relate the performance of ATM layer cell streams and the corresponding AAL2 layer packet streams. The performance measures considered are Cell/Packet loss and Cell/Packet delay variation which is also called jitter. The simulation study takes into account the various packet sizes with the corresponding number of sources and how the performance is affected by these parameters. The various losses/delays of the cells and the packets along with other parameters are documented and analyzed. These analyses reveal the performance correlations of the packets and the cells existing between different layers of an ATM network.

In order to execute the simulations, different methods of cell-level error and delay are implemented. These methods are intended to approximate conditions that happen in an actual ATM network. Three different types of Loss/Delay networks are taken into consideration, viz.

a. Using a model to create cell losses according to:

  i. A Bernoulli distribution.

  ii. A 2-State Discrete Time Markov Chain (DTMC)(Bursty Losses)

b. Using a model to create cell jitter according to:

  i. interfering cell traffic rate with a Bernoulli distribution, for cell interleaving.

1.2 Background

In order to get into the intricacies of the study, it is imperative that a brief overview be described.

1.2.1 ATM Layer

ATM (Asynchronous Transfer Mode) is a connection-oriented form of data transfer. ATM is the underlying technology that makes B-ISDN (Broadband Integrated Services Network) possible. The basic concept behind ATM is to transfer information in the form of fixed-size packets called cells. The cells are 53 bytes long, of which 5 bytes are of header and 48 bytes are payload. The delivery of the information is not guaranteed but the order in which they reach the destination is guaranteed.

1.2.2 AAL type2

The AAL type 2 (ATM Adaptation Layer type 2) is used to multiplex more than one low bit rate user stream on an ATM virtual connection. AAL type 2 provides bandwidth efficient transmission for short and variable length packets. The AAL type 2 is subdivided into a Common Part Sublayer (CPS) and a Service Specific Convergence Sublayer (SSCS). Multiple AAL type 2 connections may utilize a single underlying ATM connection. With regards to the model which is under consideration, the information to be transmitted is compressed voice samples with a Constant Bit Rate (CBR) of transmission during talkspurts. Based on the size of the packets which are created in the AAL type 2 layer the cells are arranged in the ATM layer and transmitted from the transmitter to the receiver.

1.2.3 Specifics

Coming back to the objectives of this study, the simulations are carried out with the view of finding the losses/delays occuring in the model developed, as follows:

1. Cell Loss Rate (CLR): This is the ratio of the total number of discarded cells to the total number of cells produced during the simulation.

2. Packet Loss Rate (PLR): This is the ratio of the total number of discarded packets to the total number of packets produced during the simulation.

3. In addition to this, we calculate the ratio of PLR/CLR which is a ratio of ratios, in order to express the relationship between PLR and CLR.

4. Also the mean delay and its standard deviation (a measure of jitter) is measured in the cells produced as well as in the corresponding packets.

Chapter 2

System Model Description

The system model gives a clear picture as to where the different components of the simulation model fit in the system. The simulations are performed considering only homogeneous (statistically identical) sources.

2.1 The Transmitter

The transmitter adds a 3-byte header to the CPS_SDU (user data segment) to form a CPS_Packet. The CPS_Packet Payload (CPS_SDU) essentially has a size of 1 to 44 or 64 bytes, so the CPS_Packet-Payload + 3 bytes is the CPS_Packet size. Now the CPS_Packets are combined to form 47-byte CPS_PDU Payloads. To each CPS_PDU Payload is added a 1-byte Start Field (STF) header to form a CPS_PDU of 48 bytes. The transmitter then adds a 5-byte header to create an ATM cell of 53-bytes. In addition to this, there are certain parameters in the transmitter which influence the transmission, line rate, and the coding rate of the cells and the network. These parameters are listed below. With respect to the current model which is being used, except for the CPS_Packet Size and Number of Users, all other parameters are kept constant with values as indicated in parentheses.

1. CPS_Packet Size in bytes (variable).
2. Number of Users (variable).
3. Voice Bit Rate in kbps (32).
4. Mean On Time in secs (0.42).
5. Mean Off Time in secs (0.58).
6. Peak Cell Rate of the VCC in kbps (1536).
7. Silence detection [1 if Yes, 0 if No] (1).
8. Timer Expiration in secs [if ATC type is Non_DBR] (0.01)
9. ATC Type [1 if DBR, 0 if Non_DBR] (0)
10. Wireless/Trunking [1 if Trunking] (1)

2.2 The Receiver

The AAL2 layer receiver receives data from the ATM layer in the form of 48 byte CPS-PDUs from which the CPS-packets are re-assembled. The receiver model implements all of the error-recovery procedures specified for AAL2 [1]. The parameter used in the receiver is the Max_SDU_Deliver_length. This parameter indicates the maximum size CPS_SDU, in octets. Here the Max_SDU_Deliver_length is given as 45 bytes.

2.3 The Network

This component simulates two network related effects which cells and packets encounter:

i. Loss: which simulates the discarding of cells and packets.

ii. Delay Variations: which simulates the variable delay (jitter) encountered by cells and packets.

The network used for receiver testing [2] was an error network which executed a deterministic type of distribution for cell discard. The present loss network executes a probabilistic type of distribution for cell discard as well as for delay variation. Implementation details of the network model are given in the following subsections.

Based on the basic three components viz. the transmitter, the receiver, and the network, the top level of the system model is as shown in Figure 2.1.

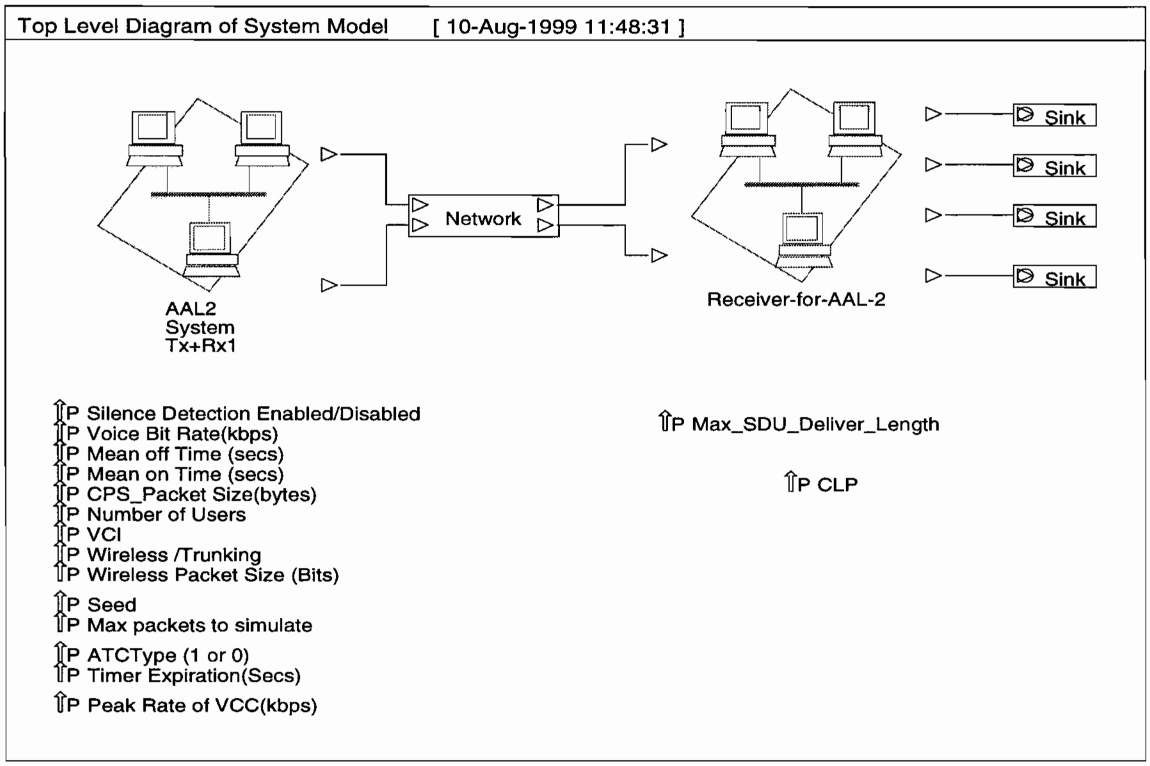

Figure 2.1: Top Level Diagram of System Model

2.3.1 The Loss Network

The loss network deals with the discarding of cells. This model uses two different methods of discarding cells.

2.3.1.1 Using a Bernoulli Distribution of Cell Loss

The first model is based on a random Bernoulli distribution of discarding cells as compared to the deterministic model executed before. As seen from Figure 2.2 the following blocks are incorporated in the system model:

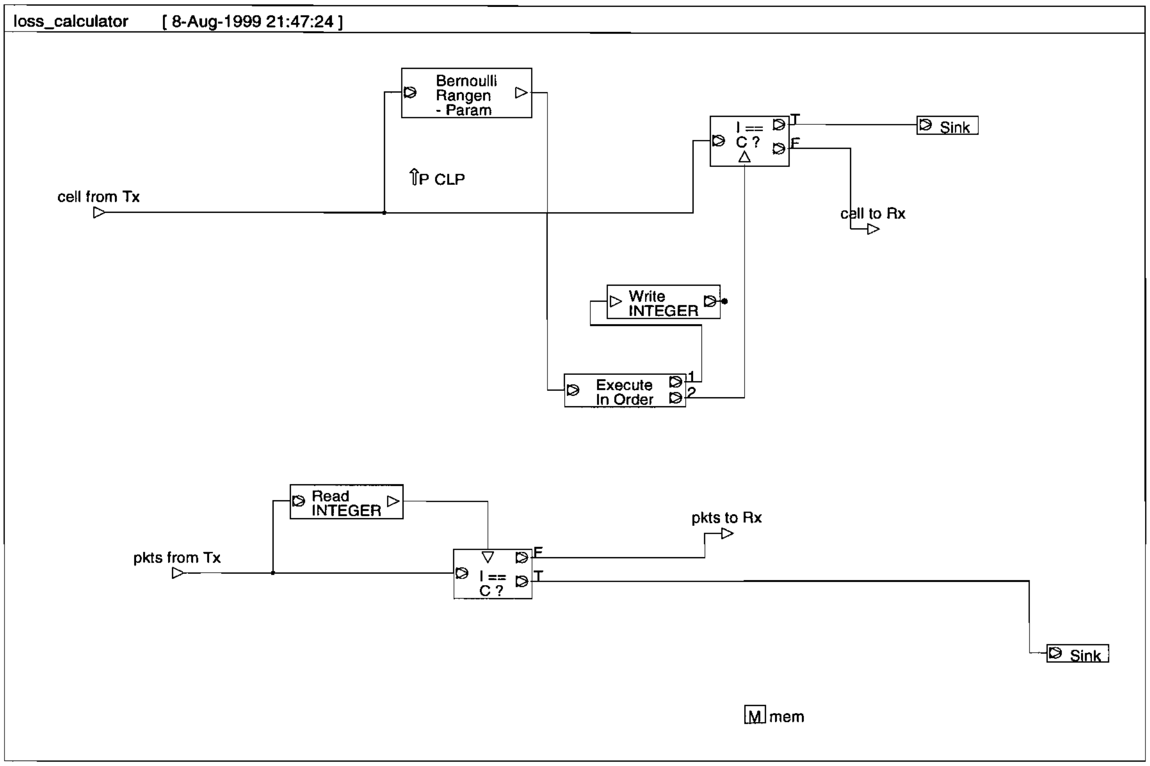

Figure 2.2: Component Model Diagram of Loss Network Block

1. Bernoulli Rangen-Param Block: This generates either a 0 or 1 as an output based on a probability specified as a parameter (CLP).
2. Switch Block: This block is actually a conditional block which when the condition is satisfied allows the data structure (cell) to go to the output port.

On triggering the Bernoulli Rangen-Param Block at the arrival of a cell, the output of this block is an integer (I) which is either a one or zero depending on the sample of a random number. This integer value is compared with the value given to the constant (C) in the Switch Block. If satisfied then the cell is discarded; if not then it reaches the receiver. An important aspect of this model is that the event of a cell getting discarded (1) or reaching the receiver (0) is saved in the memory with the help of the Write Integer block which writes the value of the Bernoulli Block output in memory. This value is read by the Read Integer block and based on the functions of another Switch

Block, the packets associated with the respective cell meet the same fate as the cell in which they were assembled.

2.3.1.2 Loss Network for Bursty Cell Losses

The second model is based on a two-state discrete time Markov chain (DTMC), which remains in the No-Error state with probability P_{nn} and transitions from the Error state to the No-Error state with probability P_{en}. A cell that arrives with the block in the No-Error state is allowed to reach the receiver, and a cell that arrives with the block in the Error state results in discarding the cell. This system model makes it possible to discard cells in successive blocks producing bursty cell losses.

With respect to Figure 2.3, we use a Binomial Rangen block which has the number of trials (N) and the probability of success in each trial (P) as inputs. Based on values for N (always 1 here) and P (which is either P_{nn} or P_{en} depending on the previous state of the block), this block outputs the number of successes (either a 0 or a 1 when N=1). After this block is a Switch block (more or less like the previous conditional block) that forwards the cell to the receiver or discards it, according to its input. It is to be seen here that whether passed to the receiver or discarded (indicating current state of the block), the cell intializes an expression block which provides a new expression for P, either P_{nn} if passed or P_{en} if discarded.

The expressions for the values of P_{nn} and P_{en} are given with the help of two parameters viz. Cell Loss Ratio (CLR), which is the probability of being in the Error state, and Mean Burst Length (Mn_bur_ln), which is the mean length of an error burst. From an analysis of the DTMC, we obtain:

$$P_{en} = \frac{1}{Mn\_bur\_ln} \tag{2.1}$$

$$P_{nn} = \frac{(1 - CLR) - \frac{(CLR)}{(Mn\_bur\_ln)}}{(1 - CLR)} \tag{2.2}$$

As an example, supposing on specifying the CLR and the Mn_bur_ln, the first cell is transmitted. We initialize the value of P to 1, so this cell reaches the receiver. On its way it triggers the expression block which is connected to the T port of the switch to give P the value of P_{nn} above. When some later cell exits from the F port of the switch (is discarded), the associated expression block assigns the value of P_{en} above to P.

Also the cell to packet co-ordination with regards to discarding and reaching the receiver is done in the same manner as the Bernoulli loss network described previously.

2.3.2 The Delay Network

This type of a network system model is used to create delay variation (jitter) in the cell traffic by simulating interfering traffic. The delay variation is created using a Bernoulli distribution to model bursty interfering traffic, as discussed in the following subsection.

2.3.2.1 Delay Network Using the Bernoulli Distribution

This delay network (Figure 2.4) involves a Simple FIFO block to create a delay. The variation in the delay is created by the Bernoulli block. The cells enter the delay network with a peak VCC rate of 1.536 Mbps and immediately enter the FIFO queue. A cell at the head of the FIFO queue is

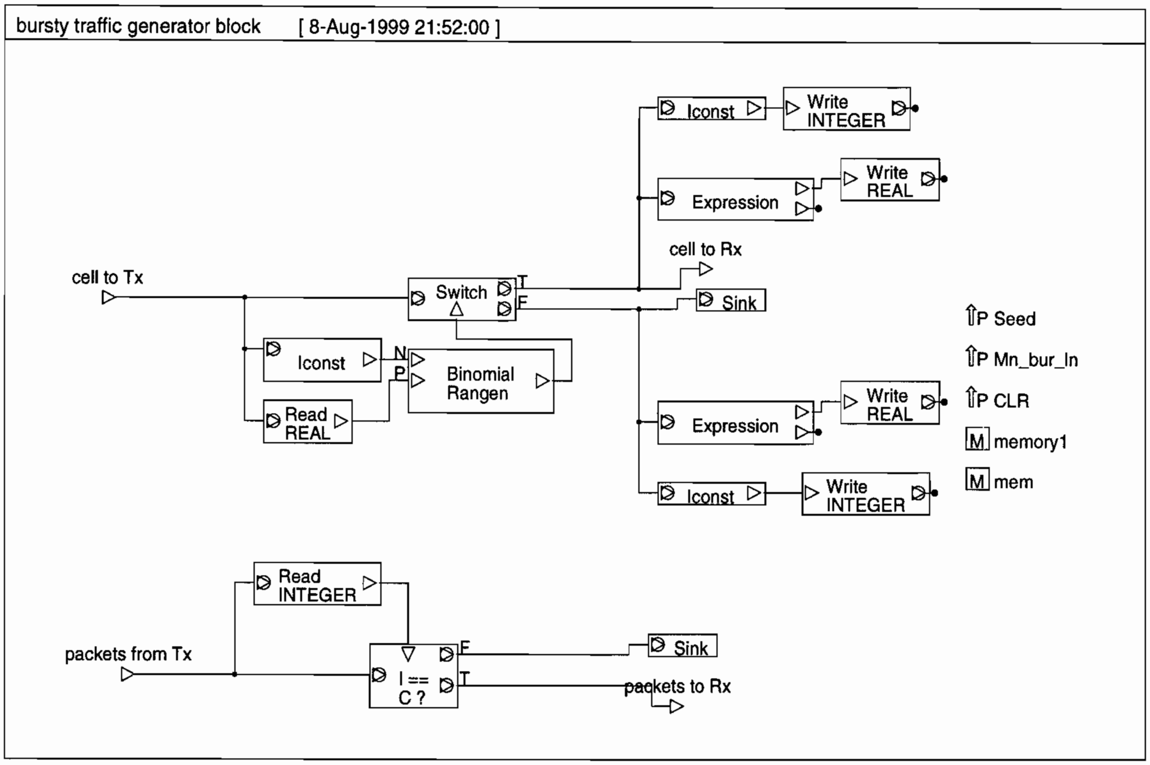

Figure 2.3: Component Model Diagram of Bursty Cell Losses

allowed to pass through only if the FIFO is triggered at its trigger input port. The FIFO is triggered with the help of a Uniform Pulse Generator that creates pulses at ten times the rate of the peak VCC rate. Thus the potential service rate of the FIFO is ten times the peak arrival rate. However, to create the delay variation, the pulses from the generator are filtered or gated by the combination of a Bernoulli block with success probability 'p' and a comparison block. The combination triggers the FIFO with probability 'p' for each input pulse, thereby creating a random trigger pulse train and hence cell delay variation. The comparator to the right of the FIFO allows the FIFO to be triggered only if it is not empty.

The effective mean service rate of the FIFO is (p)(10)(Peak_VCC_rate). Any value of 'p' that makes this rate larger than the mean arrival rate will result in finite delays.

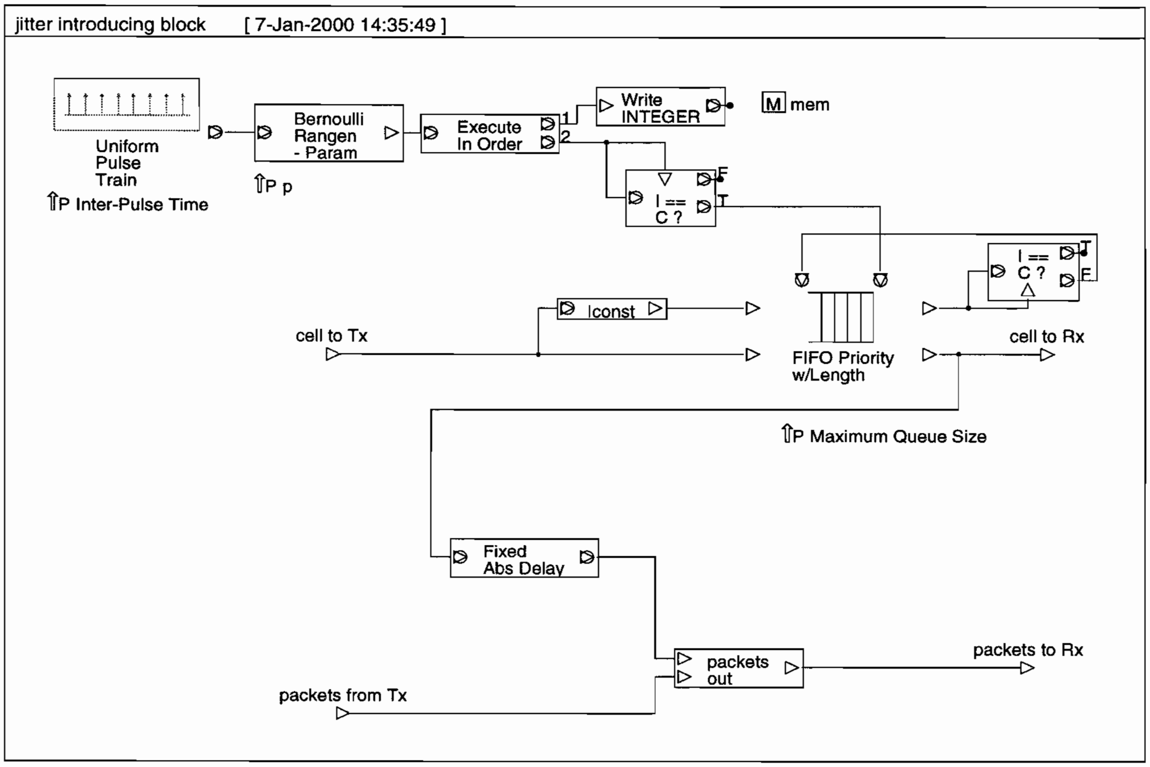

Figure 2.4: Component Level Diagram of System Model for introducing Delay Variation using Bernoulli Distribution

Chapter 3

Simulation Results for Cell Losses

3.1 Bernoulli Cell Losses

The simulation models were executed to run under certain conditions. These conditions were created by varying the Cell Loss Probability (CLP), the CPS_Packet Size and the corresponding Number of Sources (Users).

3.1.1 Scenarios and Results

The simulations were carried out with different CLPs i.e. 10^{-2}, 10^{-3}, 10^{-4}, & 10^{-5}, and they were simulated for a total number of 100/CLP packets in order to obtain a significant number of cell and packet loss events. The normalized effective source load (relative to the 1.536 Mb/s Peak VCC rate) was kept constant at approximately 0.66. Because the AAL2 overhead is influenced by the packet size, the number of sources must be adjusted for each packet size, as follows:

$$N \times 32k \times 0.42 \times \frac{P+3}{P} \times \frac{53}{47} = \mathrm{ArrivalRate} \tag{3.1}$$

and,

$$\frac{\mathrm{ArrivalRate}}{1.536\mathrm{Mbps}} = 0.66 \tag{3.2}$$

where N stands for Number of Sources, P stands for Packet size, 32k is the Voice Bit rate in kbps, and 0.42 is the speech activity factor.

The following abbreviations are used in the figures and tables:

1. CLP stands for Cell Loss Probability (Target)

2. CLR stands for Cell Loss Rate (Measured).

3. PLR stands for Packet Loss Rate (Measured).

In the next few pages, tables and plots of results are given. The plots portray the CLP on the X-axis and the PLR/CLR ratio on the Y-axis.

It can be seen from all of the tables that the Target CLR and the measured CLR are very close in value. Furthermore, the plots clearly illustrate that, for a given packet size, the PLR/CLR ratio for all the different Target CLRs does not vary much. The PLR/CLR ratio is always larger than 1.1 and usually less than 1.5, but approaches 2.0 for a packet size of 24 bytes.

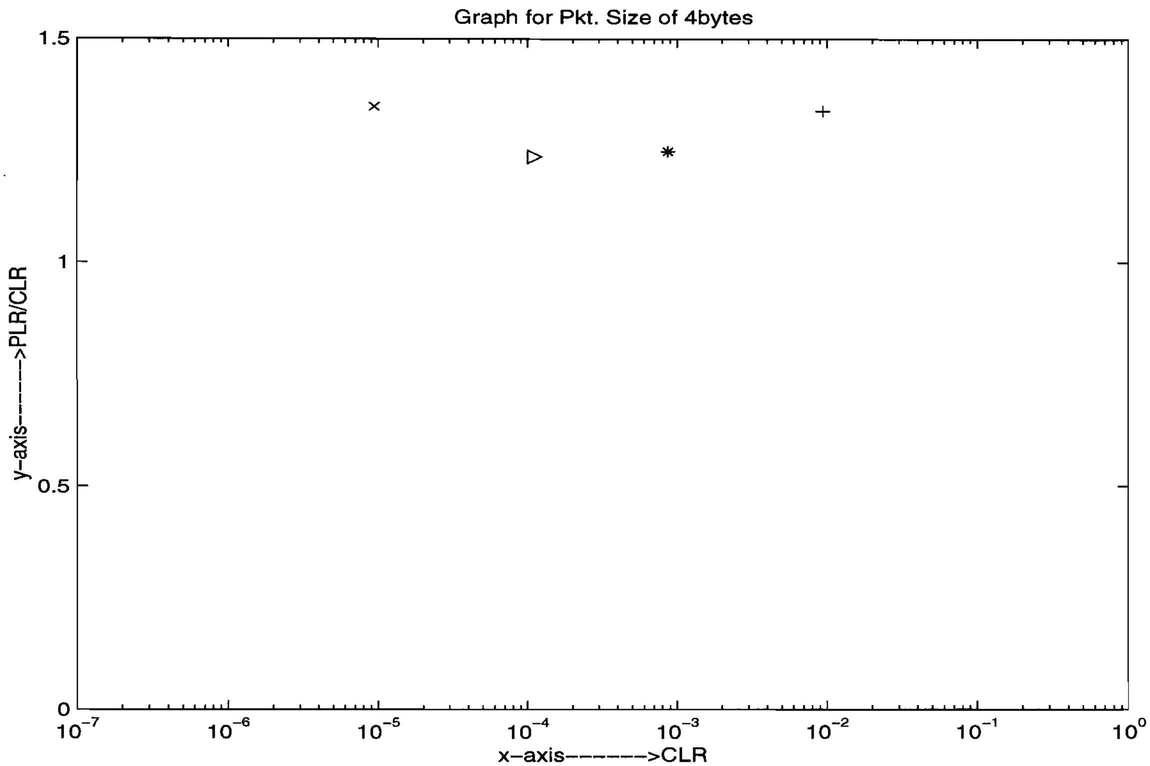

Figure 3.1: **Simulation Results for Packet Size 4 bytes and 38 sources**

Target CLR	$\mathbf{10^{-2}}$	$\mathbf{10^{-3}}$	$\mathbf{10^{-4}}$	10^{-5}
Lost Cells	14	13	16	14
Total Cells	1.487 X 10^{3}	1.4884 X 10^{4}	1.487 X 10^{5}	1.487 X 10^{6}
Measured CLR	9.414 X 10^{-3}	8.7342 X 10^{-4}	1.07599 X 10^{-4}	9.4149 X 10^{-6}
Lost Pkts (Net)	104	95	112	102
Lost Pkts (Rcv)	21	14	21	25
Lost Pkts (Tot)	126	109	133	127
Total Packets	10^{4}	10^{5}	10^{6}	10^{7}
Measured PLR	1.26 X 10^{-2}	1.09 X 10^{-3}	1.33 X 10^{-4}	1.27 X 10^{-5}
PLR/CLR	1.338432	1.24796	1.23607	1.34892

Table 3.1: **Simulation Results for Packet Size 4 bytes and 38 sources.**

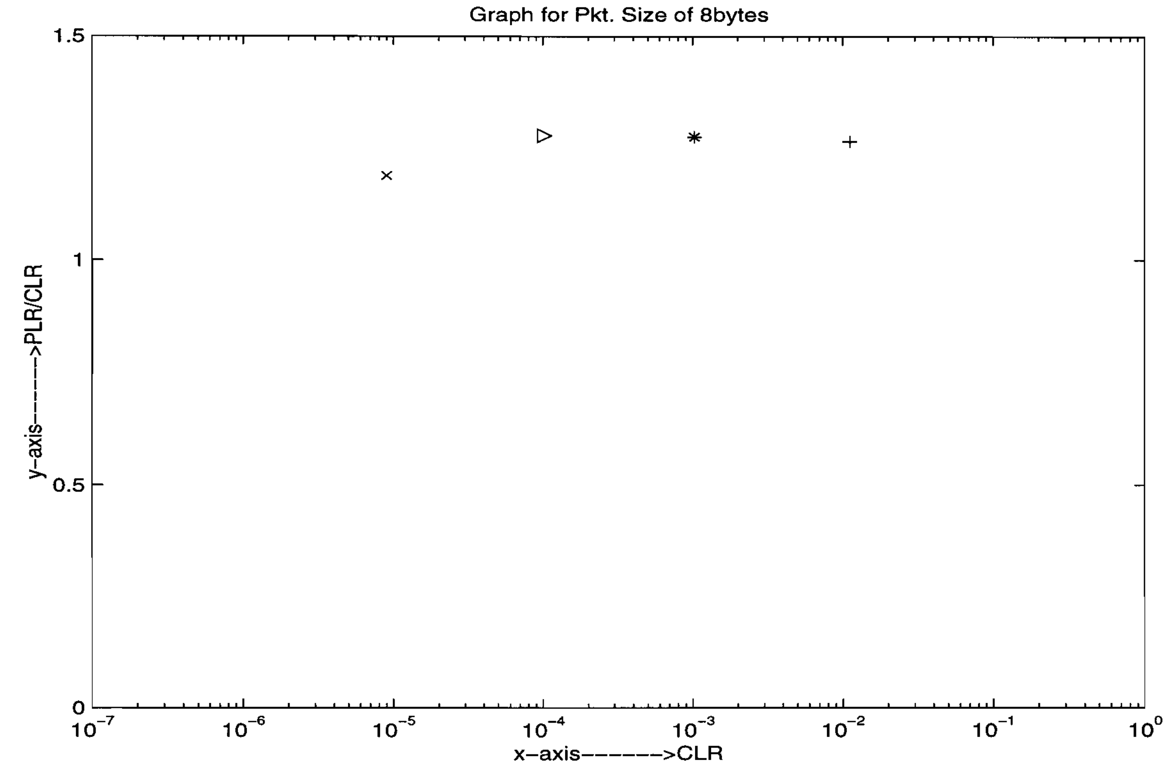

Figure 3.2: **Simulation Results for Packet Size 8bytes and 48 sources**

Target CLR	10^{-2}	10^{-3}	10^{-4}	10^{-5}
Lost Cells	26	24	23	21
Total Cells	2.333×10^3	2.333×10^4	2.333×10^5	2.333×10^6
Measured CLR	1.11444×10^{-2}	1.0272×10^{-3}	9.8585×10^{-5}	9.00×10^{-6}
Lost Pkts (Net)	117	107	103	95
Lost Pkts (Rcv)	24	24	23	22
Lost Pkts (Tot)	141	131	126	107
Total Packets	10^4	10^5	10^6	10^7
Measured PLR	1.41×10^{-2}	1.31×10^{-3}	1.26×10^{-4}	1.07×10^{-5}
PLR/CLR	1.2652	1.275311	1.278084	1.1888

Table 3.2: **Simulation Results for Packet Size 8bytes and 48 sources.**

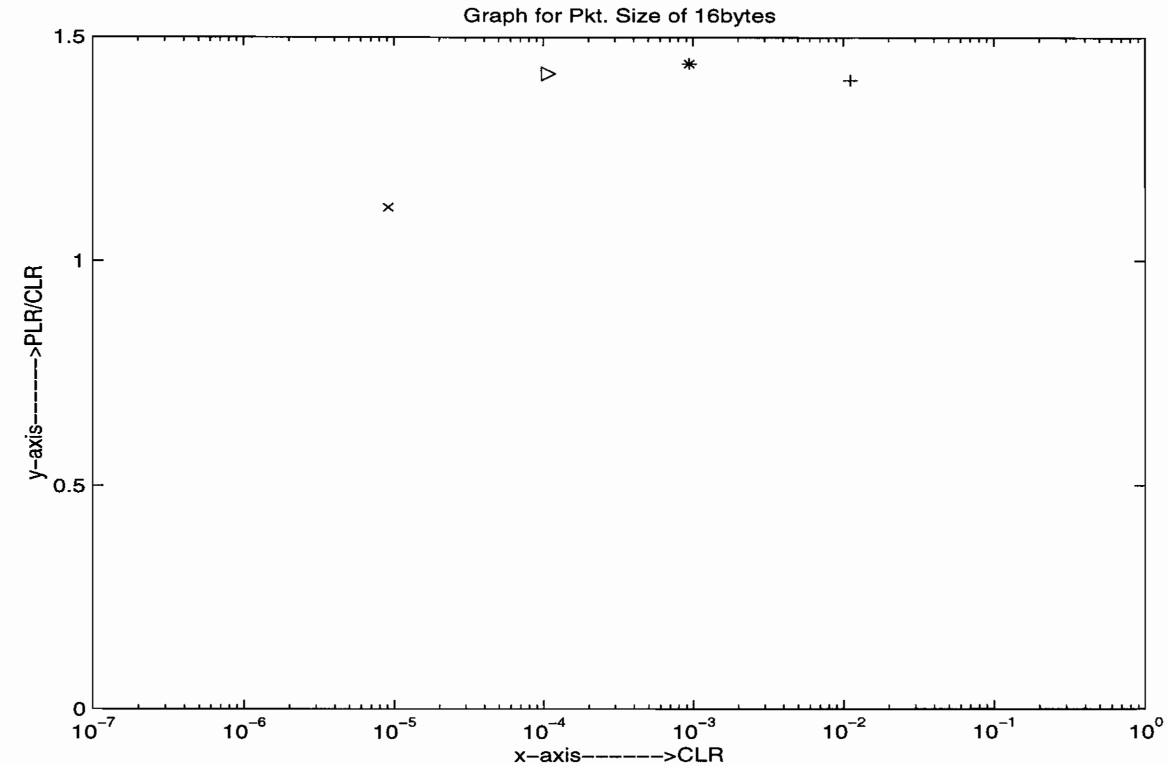

Figure 3.3: **Simulation Results for Packet Size 16bytes and 56 sources**

Target CLR	10^{-2}	10^{-3}	10^{-4}	10^{-5}
Lost Cells	45	38	42	37
Total Cells	4.025 X 10^{3}	4.0259 X 10^{4}	4.0259 X 10^{5}	4.0259 X 10^{-6}
Measured CLR	1.1180 X 10^{-2}	9.4388 X 10^{-4}	1.043244 X 10^{-4}	9.19049 X 10^{-6}
Lost Pkts (Net)	112	100	110	96
Lost Pkts (Rcv)	45	36	38	37
Lost Pkts (Tot)	157	136	148	103
Total Packets	10^{4}	10^{5}	10^{6}	10^{7}
Measured PLR	1.57 X 10^{-2}	1.36 X 10^{-3}	1.48 X 10^{-4}	1.03 X 10^{-5}
PLR/CLR	1.40429	1.44086	1.41865	1.12072

Table 3.3: **Simulation Results for Packet Size 16bytes and 56 sources.**

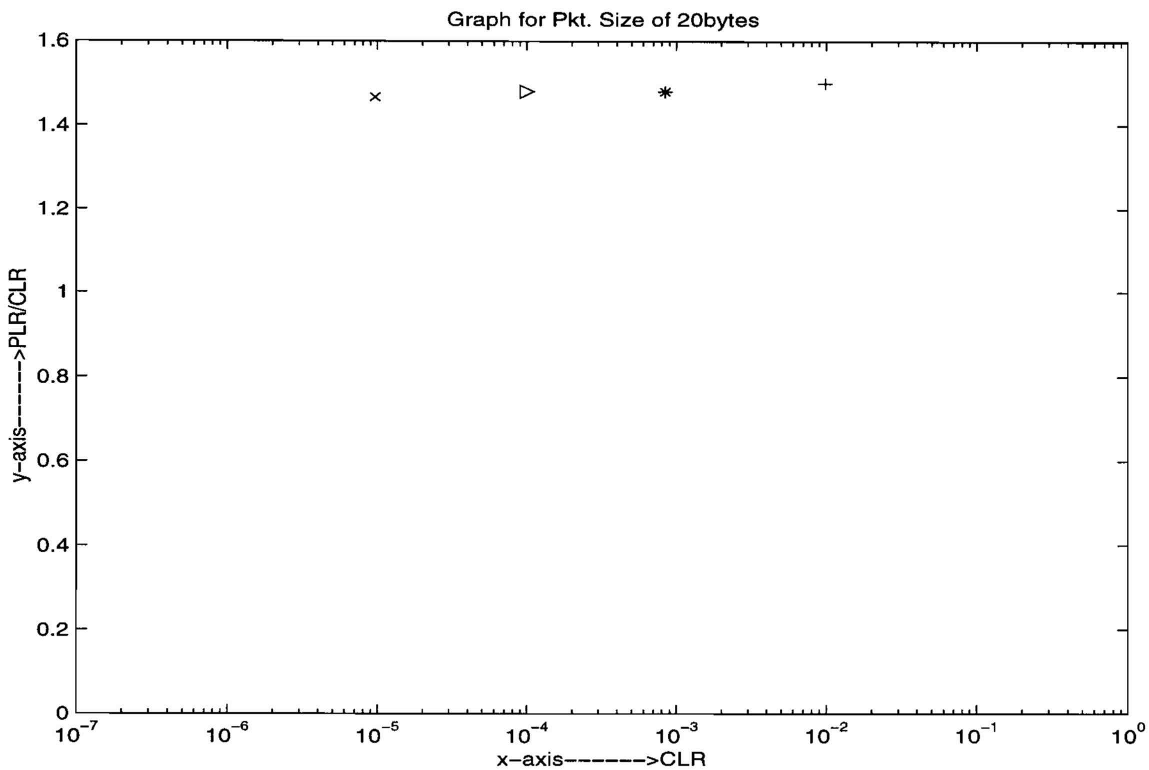

Figure 3.4: **Simulation Results for Packet Size 20bytes and 58 sources**

Target CLR	10^{-2}	10^{-3}	10^{-4}	10^{-5}
Lost Cells	48	41	47	47
Total Cells	4.865×10^3	4.865×10^4	4.865×10^5	4.865×10^6
Measured CLR	9.86639×10^{-3}	8.42754×10^{-4}	9.660842×10^{-5}	9.6787×10^{-6}
Lost Pkts (Net)	103	88	96	95
Lost Pkts (Rcv)	45	37	47	37
Lost Pkts (Tot)	148	125	143	142
Total Packets	10^4	10^5	10^6	10^7
Measured PLR	1.48×10^{-2}	1.25×10^{-3}	1.43×10^{-4}	1.42×10^{-5}
PLR/CLR	1.50	1.483	1.4802	1.467139

Table 3.4: **Simulation Results for Packet Size 20bytes and 58 sources.**

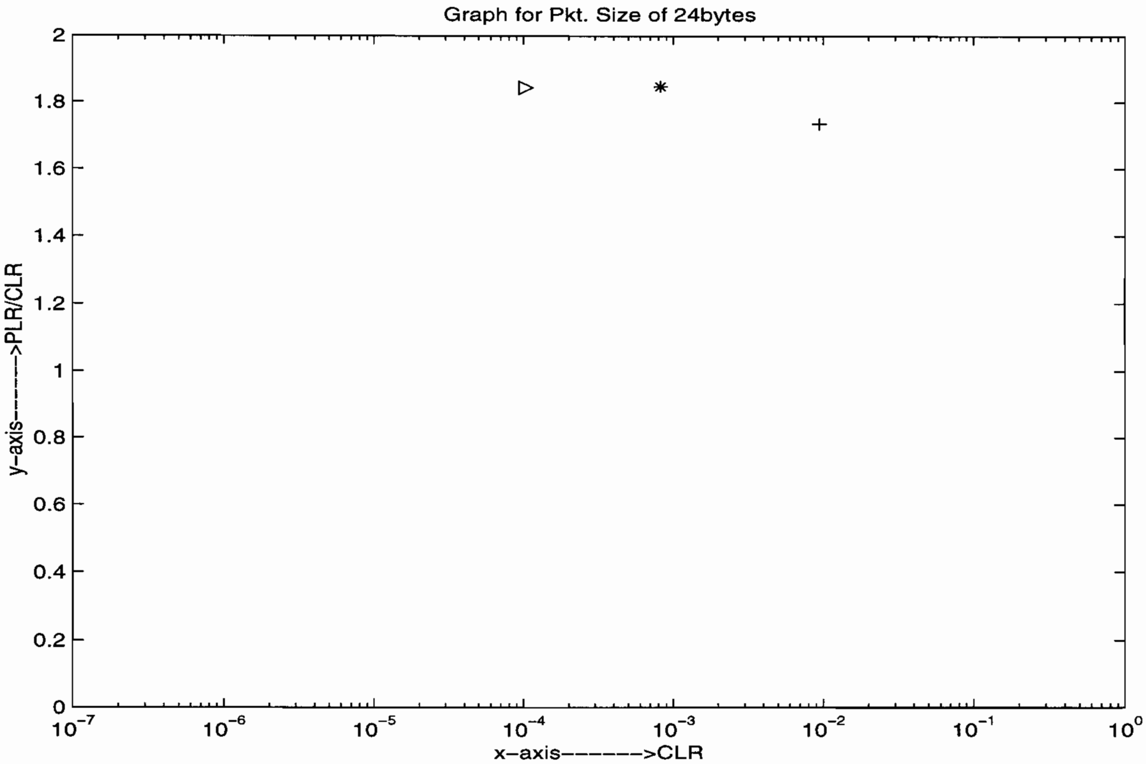

Figure 3.5: **Simulation Results for Packet Size 24bytes and 59 sources**

Target CLR	10^{-2}	10^{-3}	10^{-4}
Lost Cells	54	47	57
Total Cells	5.70987 X 10^3	5.70987 X 10^4	5.70987 X 10^5
Measured CLR	9.473 X 10^{-3}	8.23136 X 10^{-4}	9.982714 X 10^{-5}
Lost Pkts (Net)	93	88	103
Lost Pkts (Rcv)	71	64	81
Lost Pkts (Tot)	164	152	184
Total Packets	10^4	10^5	10^6
Measured PLR	1.64 X 10^{-2}	1.52 X 10^{-3}	1.84 X 10^{-4}
PLR/CLR	1.734110	1.84659	1.843186

Table 3.5: **Simulation Results for Packet Size 24bytes and 59 sources.**

3.2 Bursty Cell Losses

The Loss Network based on binomial distribution producing bursty cell losses was executed under various scenarios and the results were noted down.

3.2.1 Scenarios and Results

With bursty cell losses, another parameter (mean burst length) is introduced in addition to the parameters in the Bernoulli loss case. We used values of 1, 5, 10 and 15 for mean burst length. In these simulations, we omitted the 10^{-5} CLR condition and used packet sizes of 16, 20 and 24 bytes. This results in 9 combinations of CLR and packet size, and there is one table and one figure for each combination.

The following abbreviations are used in the tables and figures:

1. CLR′ stands for the Measured Cell Loss Rate.

2. PLR stands for Packet Loss Rate.

3. M_B_L stands for Mean Burst Length.

From the tables and figures that follow it can be seen that, just as in the previous case, the Target CLR is nearly equal to the measured CLR value i.e. CLR′. Also note that the PLR/CLR′ values consistently decrease toward 1.0 as the Mean Burst Length increases. This behavior can be understood with an example.

Consider a packet size of 16 bytes which, with the 3-byte overhead forms a CPS_Packet of 19 bytes. For a consecutive string of cells, the ratio of packets produced to cells produced approaches 47/19 = 2.47. Now consider the effect of an isolated cell loss. At worst, this could produce 4 packet losses since the cell could hold the trailing edge of one packet, two more complete packets, and then the leading edge of a fourth packet. So, at worst, the ratio of packets lost to cells lost is 4.0 in this case. Now note that PLR/CLR is identical to the ratio of packets lost to cells lost divided by the ratio of packets produced to cells produced. So for isolated cell losses and 16-byte packets, the PLR/CLR can be approximated by 4.0/2.47 = 1.62.

Now consider a string of 10 consecutive cell losses. In this case, there can be at most int(470/19) = 24 complete packets plus portions of two more (a leading edge and a trailing edge). Thus the ratio of packets lost to cells lost is upper-bounded by 26/10 = 2.6 and the PLR/CLR can be approximated by 2.6/2.47 = 1.05. Clearly, the PLR/CLR will approach 1.0 in the limit as the length of the cell loss burst approaches infinity.

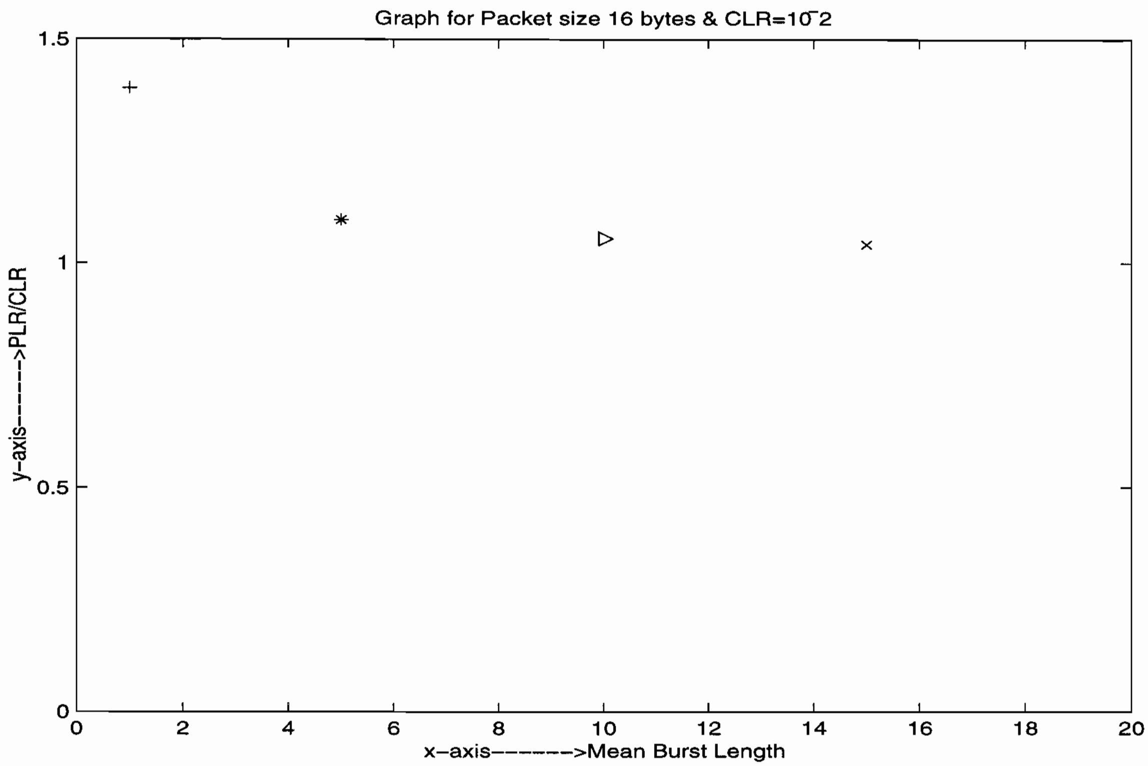

Figure 3.6: **Simulation Results for Packet Size 16bytes and 56 sources with CLR= 10^{-2}**

M_B_L	1	5	10	15
Target CLR	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Lost Cells	418	440	395	386
Total Cells	40271	40271	40271	40271
CLR′	1.0379×10^{-2}	$1.0925976 \times ^{-2}$	$9.80854709 \times 10^{-3}$	9.585061×10^{-3}
Lost Pkts (Net)	1044	1086	977	956
Lost Pkts (Rcv)	399	111	57	42
Lost Pkts (Tot)	1433	1197	1034	998
Total Packets	99997	99997	99997	99997
PLR	1.44304×10^{-2}	1.1970359×10^{-2}	1.034031×10^{-2}	9.98029×10^{-3}
PLR/CLR′	1.390345	1.0955871	1.05421426	1.041234

Table 3.6: **Simulation Results for Packet Size 16 bytes and 56 sources with CLR= 10^{-2}**

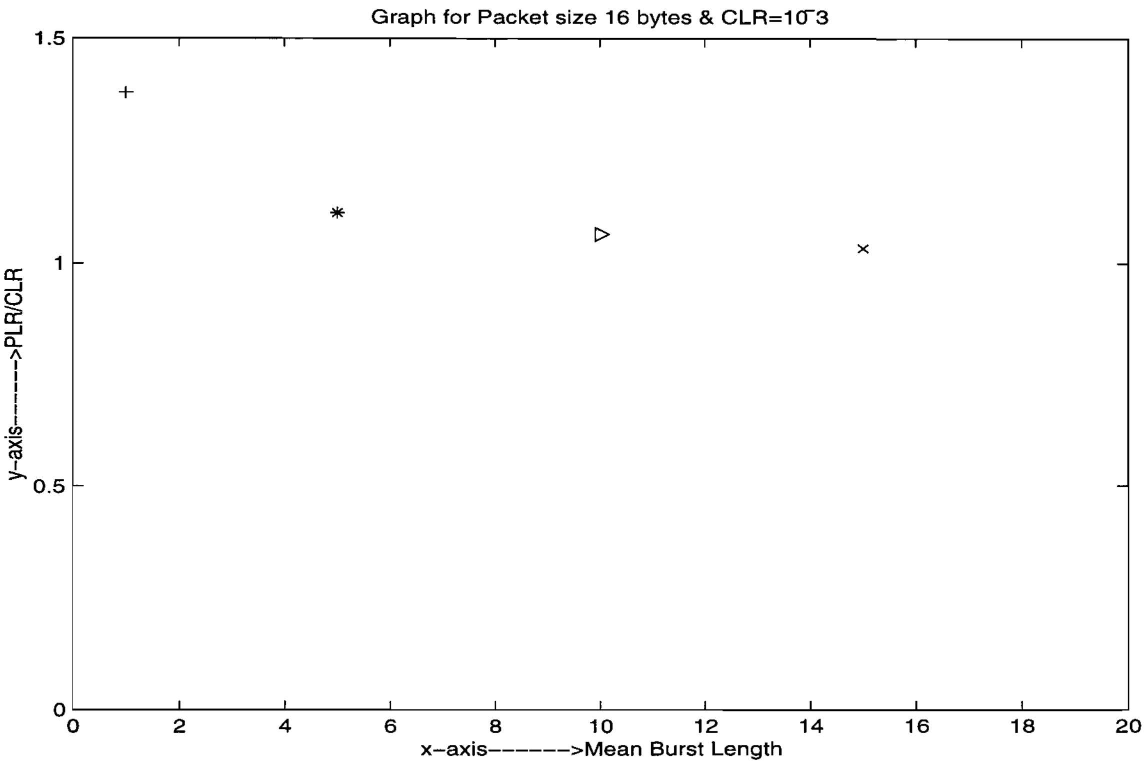

Figure 3.7: **Simulation Results for Packet Size 16bytes and 56 with CLR 10^{-3}**

M_B_L	1	5	10	15
Target CLR	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Lost Cells	411	380	371	486
Total Cells	402737	402737	402737	402737
CLR′	1.020517×10^{-3}	9.42543×10^{-4}	9.211967×10^{-4}	1.2067428×10^{-3}
Lost Pkts (Net)	1016	948	923	1210
Lost Pkts (Rcv)	390	101	58	37
Lost Pkts (Tot)	1406	1049	981	1247
Total Packets	999996	999996	999996	999996
PLR	1.4060056×10^{-3}	1.0490041×10^{-3}	9.810039×10^{-4}	1.247004×10^{-3}
PLR/CLR′	1.377738	1.11177	1.0649234	1.0333643

Table 3.7: **Simulation Results for Packet Size 16bytes and 56sources with CLR=10^{-3}**

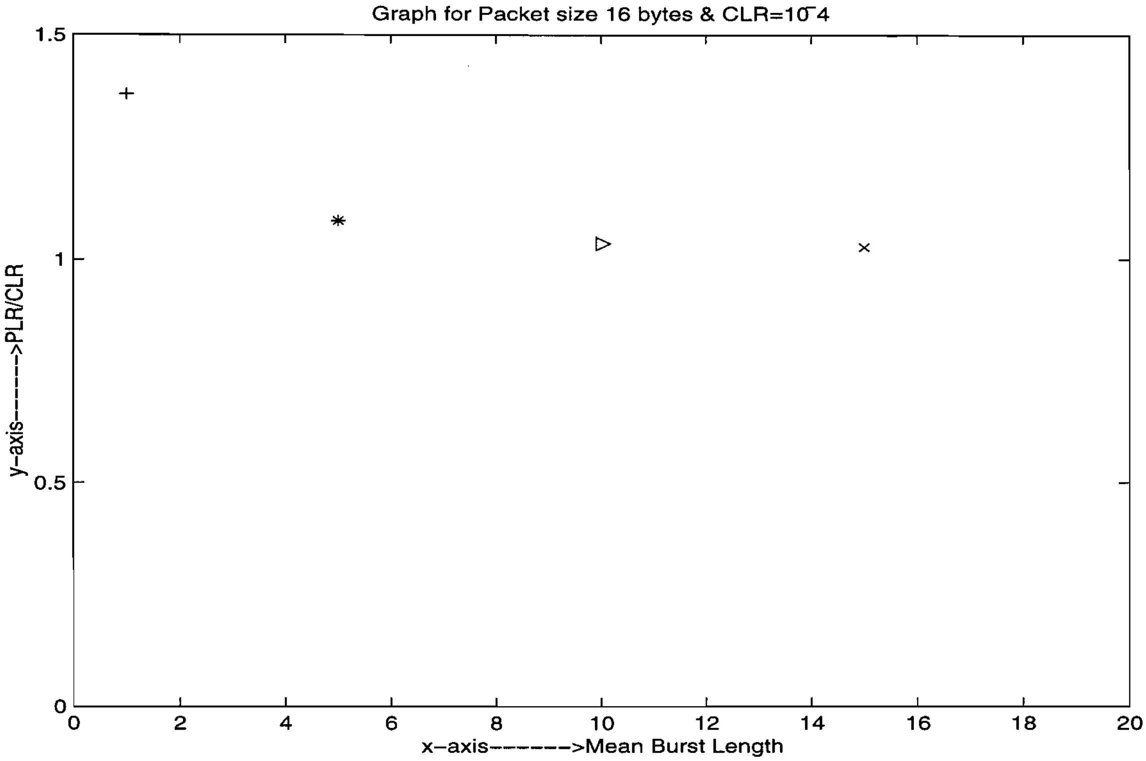

Figure 3.8: **Simulation Results for Packet Size 16bytes and 56 with CLR 10^{-4}**

M_B_L	1	5	10	15
Target CLR	10^{-4}	10^{-4}	10^{-4}	10^{-4}
Lost Cells	116	435	657	569
Total Cells	1167093	4027391	4027391	4027391
CLR′	9.93922 X 10^{-5}	1.0801037 X 10^{-4}	1.631329 X 10^{-4}	1.412825 X 10^{-4}
Lost Pkts (Net)	280	1082	1630	1414
Lost Pkts (Rcv)	114	93	60	38
Lost Pkts (Tot)	394	1175	1690	1452
Total Packets	2898961	999995	999995	999995
PLR	1.359107 X 10^{-4}	1.17500 X 10^{-4}	1.6900 X 10^{-4}	1.45200 X 10^{-4}
PLR/CLR′	1.36741897	1.0878585	1.035965673	1.02772

Table 3.8: **Simulation Results for Packet Size 16bytes and 56sources with CLR=10.$^{-4}$**

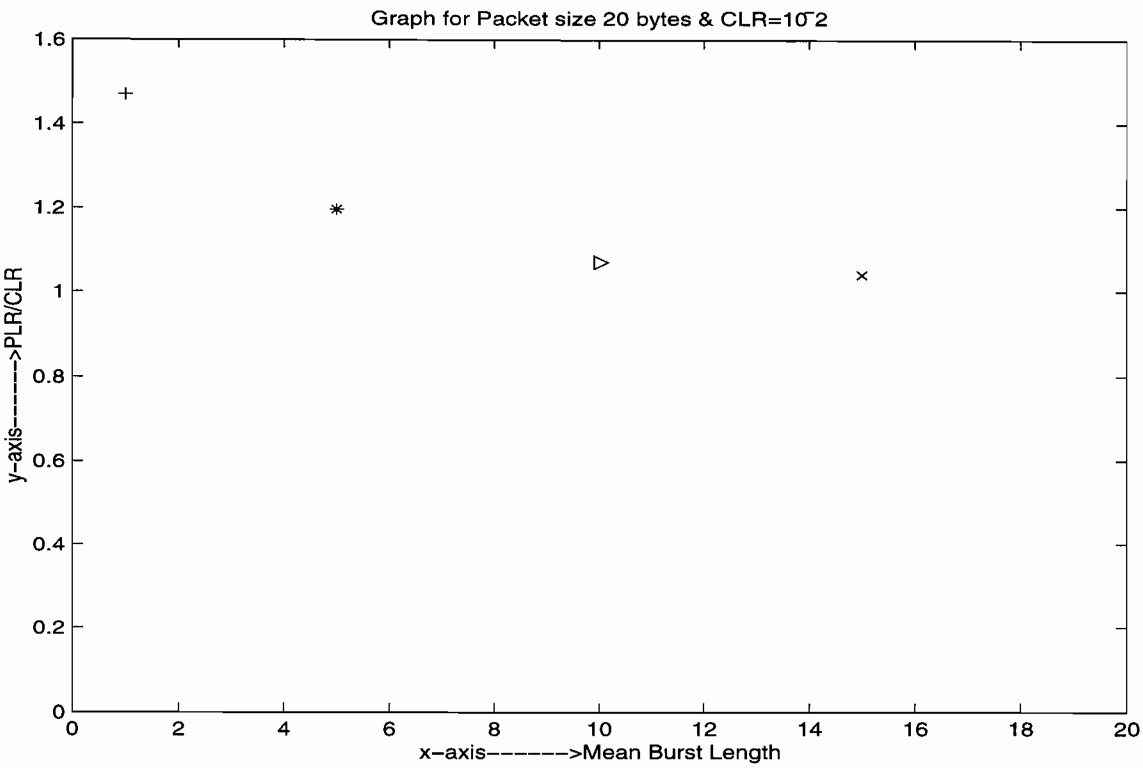

Figure 3.9: **Simulation Results for Packet Size 20bytes and 58 Sources with CLR 10^{-2}**

M_B_L	1	5	10	15
Target CLR	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Lost Cells	504	538	521	480
Total Cells	48697	48697	48697	48697
CLR′	1.034971 X 10^{-2}	1.1047908 X 10^{-2}	1.0698811 X 10^{-2}	9.85687 X 10^{-3}
Lost Pkts (Net)	1049	1105	1072	990
Lost Pkts (Rcv)	472	217	73	35
Lost Pkts (Tot)	1521	1322	1145	1025
Total Packets	99998	99998	99998	99998
PLR	1.52103 X 10^{-2}	1.32202 X 10^{-2}	1.145022 X 10^{-2}	1.0250205 X 10^{-2}
PLR/CLR′	1.469635	1.196630566	1.0702337	1.039904656

Table 3.9: **Simulation Results for Packet Size 20bytes and 58sources with CLR=10.$^{-2}$**

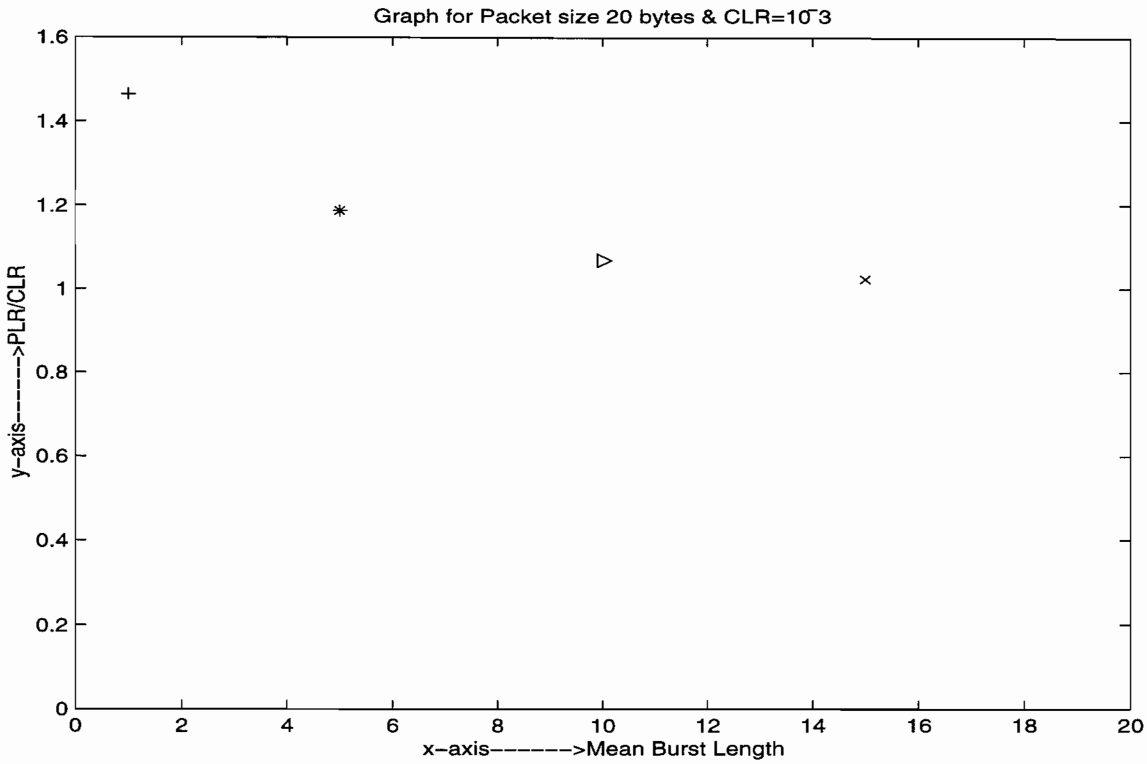

Figure 3.10: **Simulation Results for Packet Size 20bytes and 58 sources with CLR=10^{-3}**

M_B_L	1	5	10	15
Target CLR	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Lost Cells	493	480	462	554
Total Cells	486971	486971	486971	486971
CLR′	1.01238 X 10^{-3}	9.85684 X 10^{-4}	9.48721 X 10^{-4}	1.137644 X 10^{-3}
Lost Pkts (Net)	1012	986	950	1138
Lost Pkts (Rcv)	470	185	64	37
Lost Pkts (Tot)	1482	1171	1014	1165
Total Packets	999998	999998	999998	999998
PLR	1.482002 X 10^{-3}	1.17100 X 10^{-3}	1.014002 X 10^{-3}	1.16500 X 10^{-3}
PLR/CLR′	1.46388	1.188009	1.0688087	1.0240482

Table 3.10: **Simulation Results for Packet Size 20bytes and 58sources with CLR=10.$^{-3}$**

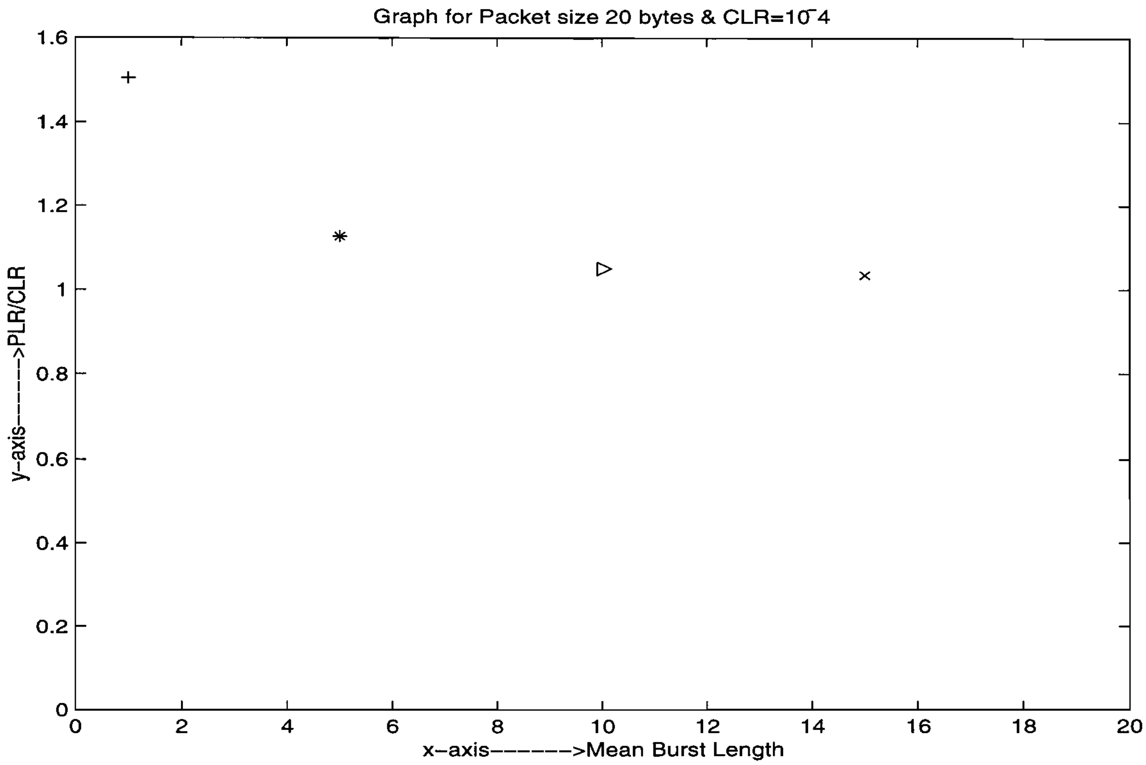

Figure 3.11: **Simulation Results for Packet Size 20bytes and 58 sources with CLR 10^{-4}**

M_B_L	1	5	10	15
Target CLR	10^{-4}	10^{-4}	10^{-4}	10^{-4}
Lost Cells	45	530	756	747
Total Cells	467563	4670823	4670823	4670823
CLR′	9.62437×10^{-5}	1.1347036×10^{-4}	1.61855×10^{-4}	1.59928×10^{-4}
Lost Pkts (Net)	94	1088	1550	1533
Lost Pkts (Rcv)	45	140	83	56
Lost Pkts (Tot)	139	1228	1633	1589
Total Packets	960146	9600869	9600869	9600869
PLR	1.44769×10^{-4}	1.279050×10^{-4}	1.700887×10^{-4}	1.655058×10^{-4}
PLR/CLR′	1.5044	1.127214	1.050871274	1.034877267

Table 3.11: **Simulation Results for Packet Size 20bytes and 58sources with CLR=10.$^{-4}$**

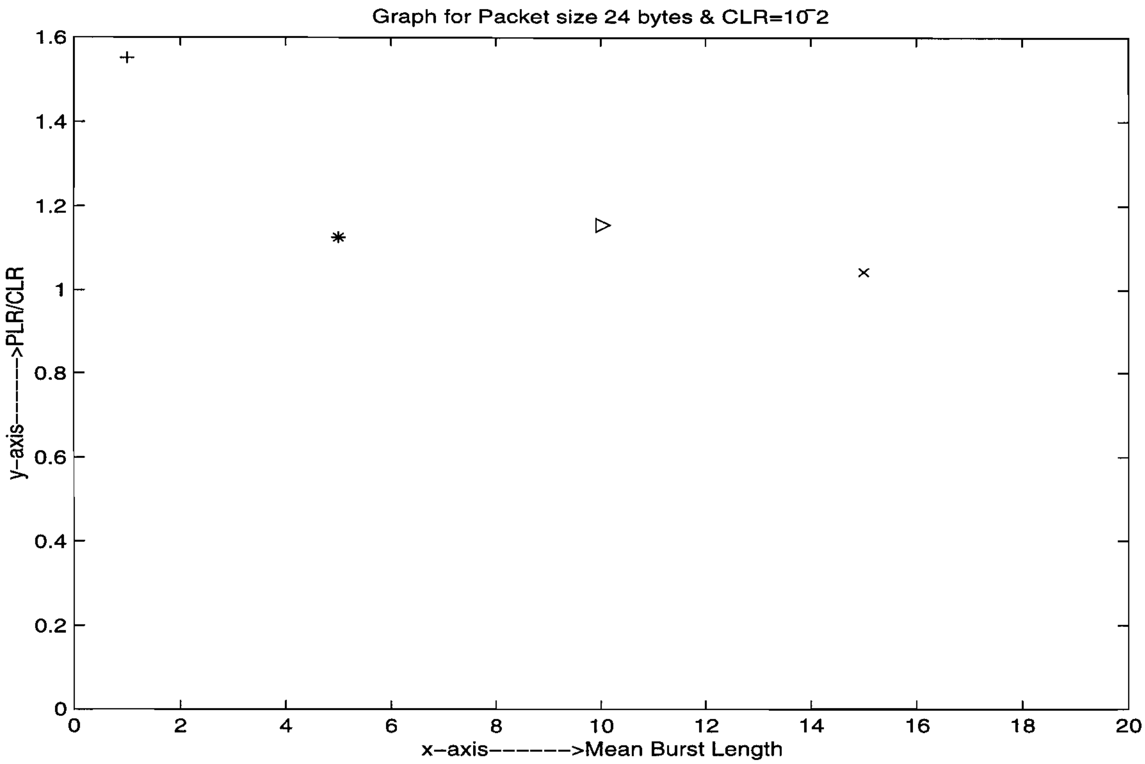

Figure 3.12: **Simulation Results for Packet Size 24bytes and 59 sources with CLR 10^{-2}**

M_B_L	1	5	10	15
Target CLR	10^{-2}	10^{-2}	10^{-2}	10^{-2}
Lost Cells	5727	5795	6040	5629
Total Cells	570982	570982	570982	570982
CLR′	1.0030 X 10^{-2}	1.014918 X 10^{-2}	1.0578266 X 10^{-2}	8.931980 X 10^{-3}
Lost Pkts (Net)	10032	10152	10568	9842
Lost Pkts (Rcv)	5525	1285	660	441
Lost Pkts (Tot)	15557	11437	12228	10283
Total Packets	999997	999997	999997	999997
PLR	1.555570 X 10^{-2}	1.1437034 X 10^{-2}	1.22280 X 10^{-2}	1.028303 X 10^{-2}
PLR/CLR′	1.5510515	1.12689233	1.155955	1.043067285

Table 3.12: **Simulation Results for Packet Size 24Bytes, 59Sources with CLR=$10.^{-2}$**

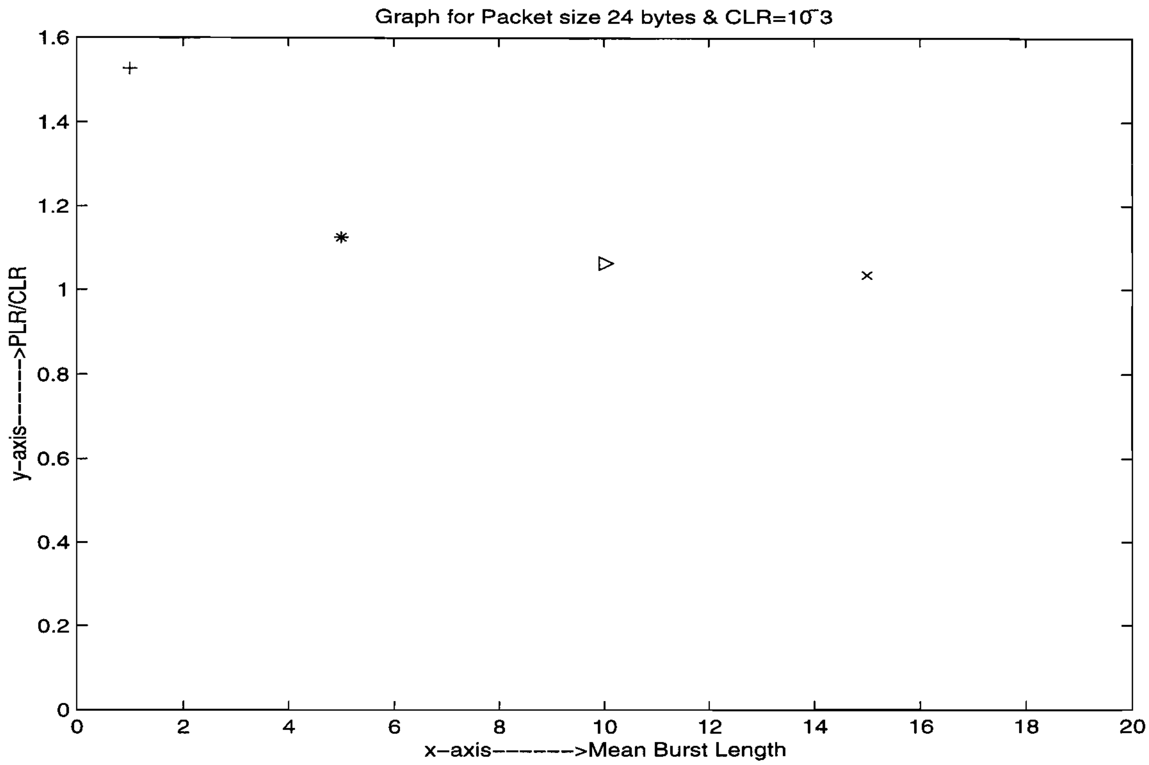

Figure 3.13: **Simulation Results for Packet Size 24bytes and 59 sources with CLR 10^{-2}**

M_B_L	1	5	10	15
Target CLR	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Lost Cells	584	549	503	618
Total Cells	570982	570982	570982	570982
CLR′	1.022799×10^{-3}	$9.61501413 \times 10^{-4}$	8.809384×10^{-4}	1.0823458×10^{-3}
Lost Pkts (Net)	1017	960	881	1080
Lost Pkts (Rcv)	545	122	56	40
Lost Pkts (Tot)	1562	1082	937	1120
Total Packets	999997	999997	999997	999997
PLR	1.562004×10^{-3}	1.0820032×10^{-3}	9.370028×10^{-4}	1.1200033×10^{-3}
PLR/CLR′	1.5271863	1.1253267	1.06364169	1.03479254

Table 3.13: **Simulation Results for Packet Size 24Bytes, 59Sources with CLR=$10.^{-3}$**

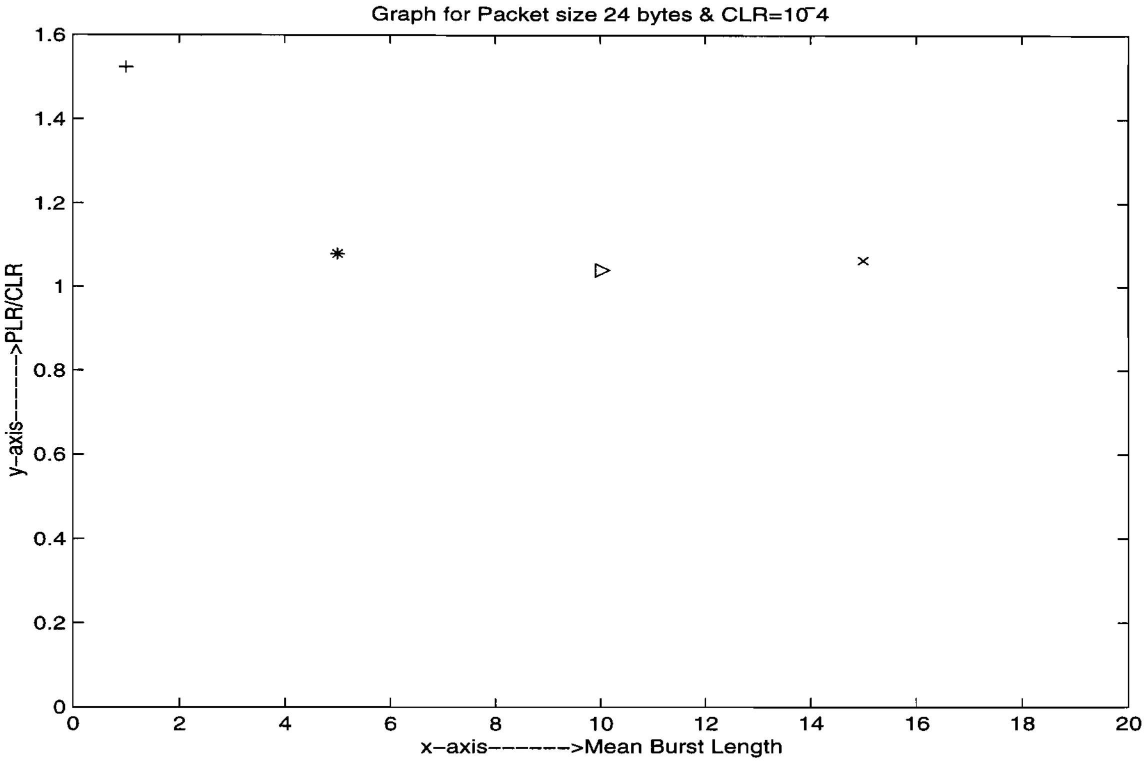

Figure 3.14: **Simulation Results for Packet Size 24bytes and 59sources with CLR 10^{-4}**

M_B_L	1	5	10	15
Target CLR	10^{-4}	10^{-4}	10^{-4}	10^{-4}
Lost Cells	57	64	124	51
Total Cells	570982	570982	570982	570982
CLR′	9.9828×10^{-5}	1.120875×10^{-4}	2.1716971×10^{-4}	8.931980×10^{-5}
Lost Pkts (Net)	95	109	217	90
Lost Pkts (Rcv)	57	12	9	5
Lost Pkts (Tot)	152	121	226	95
Total Packets	999997	999997	999997	999997
PLR	1.52×10^{-2}	1.21000×10^{-4}	2.2600067×10^{-4}	9.5000×10^{-5}
PLR/CLR′	1.5226	1.0795170	1.040663903	1.063597

Table 3.14: **Simulation Results for Packet Size 24 Bytes, 59 Sources with CLR=10.$^{-4}$**

Chapter 4

Simulation Results for Cell Delays

4.1 Scenarios and Results

For the delay simulations, we again use packet sizes of 16, 20 and 24 bytes. In addition, we vary the cell delay control parameter 'p'. With the source load held at approximately 0.66, we have an input rate to the network queue of approximately (0.66)(1.536 Mb/s) = 1.014 Mb/s. Since the mean output rate of the queue is (p)(100)(1.536 Mb/s), we must have 'p' larger than 0.0066. We allowed 'p' to take 7 values between 0.007 and 1.0.

We measured four different delay metrics in the simulations:

1. The Mean value of the delay for cells.
2. The Standard Deviation of the delay for cells.
3. The Mean value of the delay for packets.
4. The Standard Deviation of the delay for packets.

The results are given in the tables that follow. Note first that when 'p' is high, an arriving cell will almost always have to wait only until the beginning of the next "cell slot" (since the queue does not trigger unless there is something in it). Since the arrival instants are reasonable independent, we would expect the mean delay in this case to be about half of a cell slot, or (0.5)(53)(8)/[(100)(1.536 Mb/s)] = 1.38 microseconds, which agrees well with the measured values in the tables.

We also see from the mean delay results that the difference between the mean packet delay and the mean cell delay is very nearly a constant for a given packet size. This implies that the mean packet delay is always the sum of the mean cell delay and a network-independent mean packet delay (which is approximately 320 microseconds for a packet size of 16 bytes, 345 microseconds for 20 byte packets, 390 microseconds for 24 byte packets). The network-independent delay is a function of the AAL2 and source parameters and represents time spent waiting for the AAL2 transmitter to form an ATM cell. Above this basic delay, any given packet's delay will be increased by the delay of the cell carrying the final portion of the packet.

The situation is not quite as simple for delay variance (standard deviation), but we again see a similar relationship between cell and packet delay variance. Specifically, for small cell delay variance (light network loads), the packet delay variance is nearly constant, and for large cell delay variance (heavy network loads), the packet delay variance is approximately the same as the cell delay variance.

Finally, for a fixed network load, cell and packet delays are nearly independent of packet sizes, as one would expect.

p	Approx Load (%)	Mean Pkt Delay (s)	Mean Cell Delay (s)	Delay Difference (s)
1.0	0.66	3.20e-04	1.13e-06	3.19e-04
0.1	6.6	3.45e-04	2.60e-05	3.19e-04
0.02	33	4.78e-04	1.60e-04	3.18e-04
0.01	66	8.59e-04	5.43e-04	3.16e-04
0.009	73	1.13e-03	8.17e-04	3.16e-04
0.008	82	3.13e-03	2.81e-03	3.15e-04
0.007	94	2.76e-02	2.72e-02	3.20e-04

Table 4.1: **Mean Delays for Packet Size 16 Bytes, 56 Sources**

p	Approx Load (%)	Pkt Delay SD (s)	Cell Delay SD (s)
1.0	0.66	2.46e-04	9.10e-07
0.1	6.6	2.48e-04	2.65e-05
0.02	33	2.87e-04	1.62e-04
0.01	66	5.51e-04	5.21e-04
0.009	73	9.14e-04	9.07e-04
0.008	82	4.96e-03	4.98e-03
0.007	94	3.74e-02	3.74e-02

Table 4.2: **Standard Deviation of Delays for Packet Size 16 Bytes, 56 Sources**

p	Approx Load (%)	Mean Pkt Delay (s)	Mean Cell Delay (s)	Delay Difference (s)
1.0	0.66	3.45e-04	1.06e-06	3.44e-04
0.1	6.6	3.70e-04	2.57e-05	3.44e-04
0.02	33	5.05e-04	1.61e-04	3.44e-04
0.01	66	9.07e-04	5.63e-04	3.44e-04
0.009	73	1.20e-03	8.55e-04	3.45e-04
0.008	82	3.49e-03	3.14e-03	3.46e-04
0.007	94	3.07e-02	3.03e-02	3.52e-04

Table 4.3: **Mean Delays for Packet Size 20 Bytes, 58 Sources**

p	Approx Load (%)	Pkt Delay SD (s)	Cell Delay SD (s)
1.0	0.66	2.56e-04	9.36-07
0.1	6.6	2.58e-04	2.61e-05
0.02	33	2.95e-04	1.63e-04
0.01	66	5.83e-04	5.48e-04
0.009	73	9.76e-04	9.60e-04
0.008	82	5.51e-03	5.52e-03
0.007	94	3.85e-02	3.85e-02

Table 4.4: **Standard Deviation of Delays for Packet Size 20 Bytes, 58 Sources**

p	Approx Load (%)	Mean Pkt Delay (s)	Mean Cell Delay (s)	Delay Difference (s)
1.0	0.66	3.94e-04	9.61e-07	3.93e-04
0.1	6.6	4.19e-04	2.59e-05	3.93e-04
0.02	33	5.56e-04	1.64e-04	3.92e-04
0.01	66	9.54e-04	5.66e-04	3.88e-04
0.009	73	1.21e-03	8.23e-04	3.87e-04
0.008	82	3.00e-03	2.61e-03	3.87e-04
0.007	94	2.68e-02	2.64e-02	3.92e-04

Table 4.5: **Mean Delays for Packet Size 24 Bytes, 59 Sources**

p	Approx Load (%)	Pkt Delay SD (s)	Cell Delay SD (s)
1.0	0.66	3.02e-04	9.47-07
0.1	6.6	3.02e-04	2.63e-05
0.02	33	3.34e-04	1.65e-04
0.01	66	5.88e-04	5.39e-04
0.009	73	8.58e-04	8.32e-04
0.008	82	4.31e-03	4.32e-03
0.007	94	3.42e-02	3.42e-02

Table 4.6: **Standard Deviation of Delays for Packet Size 24 Bytes, 59 Sources**

Chapter 5

Conclusions

Here we summarize the conclusions of this study. All references to packets should be understood as AAL2 CPS_packets.

5.1 Conclusions Regarding Bernoulli Cell Losses

1. Packet loss ratios are always larger than cell loss ratios by a factor of 1.1 to 1.9.
2. The factor by which packet loss ratios are larger than cell loss ratios is moderately dependent on the CPS_packet size.
3. The factor by which packet loss ratios are larger than cell loss ratios is weakly dependent on the cell loss ratios.

5.2 Conclusions Regarding Bursty Cell Losses

1. Again, packet loss ratios are always larger than cell loss ratios.
2. Packet loss ratios approach cell loss ratios as the mean cell loss burst length increases.

5.3 Conclusions Regarding Cell Delays

1. Mean packet delays are the sum of a network-independent mean packet delay and the mean cell delay.
2. The network-independent mean packet delay increases with increasing packet size.
3. In similar fashion, packet delay variance is unaffected by cell delay variance when cell delay variance is small (light network loads), but packet delay variance is dominated by cell delay variance when cell delay variance is relatively large (heavy network loads).
4. Cell delays are largely independent of packet sizes, for given AAL2 and network load.

Bibliography

[1] *B-ISDN ATM Adaptation layer specification: Type 2 AAL,* ITU-T Recommendation I.363.2, September 1997.

[2] A. Iyengar, R. R. Vatte, D. W. Petr, *AAL2 Receiver Simulation Model,* Technical Report ITTC-FY99-TR-13110-04, September 1998.