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NETWORK PROBLEM THRESHOLD

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ABSTRACT

Network transmission errors such as collisions, CRC errors, misalignment, etc. are statistical in nature. Although errors can vary randomly, a high level of errors does indicate specific network problems, e.g. equipment failure. In this project, we have studied the random nature of collsions theoretically as well as by gathering statistics, and established a numerical threshold above which a network problem is indicated with high probability.

SUMMARY

In this report, we are concerned with the use of observed performance data on a CSMA/CD network, such as gathered by routine network monitoring equipment, for network fault detection. For this we need to understand the random nature of variations in network performance. Arrival of messages in a network is governed by random fluctuations in user demand. So network performance is statistical in nature, and network error levels can vary randomly. The goal of this project is to establish a threshold above which network error rates can be considered as indicative of unexpected network problems, such as equipment failure.

The approach we will take is described by three components of the project. One, we will study a theoretical probabilistic model for network collision rates. Two, we will gather statistics from channel 3/P of KSC's BCDS network. Three, we will correlate theory with actual data. Finally we will use the theoretical model to establish a usable network problem threshold.

In Sec. 2.2, a simple model for probabilities for success, collision and idle is developed for lightly loaded networks. For this the collision window is seen to be fundamental. The success probability can be written as the product of network traffic and collision window. The probability of collision per slot, increases as the square of the product of traffic and collision window, while the probability of collision per packet increases linearly with the same product. This model is extended for network utilization in Sec. 2.4. In Sec. 2.3, the theoretical model is adapted to relate its parameters to those observed from a network manager device, such as percentage of colliding transmissions.

Because of the importance of the collision window, an apparatus and method was developed to measure the network delay (Fig. 3-1). For the KSC network, the measured collision window was 80 μs . In Sec. 3.7, actual data taken from the network manager is analyzed. When we study individual data points corresponding to the default 10 s updates from the network manager, the collision rates vary from 0 to 10 percent over a traffic range of 30-250 pkts/s (Fig. 3-4). No obvious conclusion emerges. But, when points corresponding to nearly the same traffic are grouped, and we study average percentage of colliding transmissions versus network traffic, a linear relationship is observed, confirming the theoretical analysis.(Fig. 3-5)

In Sec. IV, we study the distribution of data on percentage of colliding transmissions for conditions of nearly constant network traffic. Based on the properties of exponential probability density function, a threshold level and an implementation rule is developed. The implementation rule states that if the observed collision percentage over a 10 s interval exceeds 0.037 times the network traffic in packets/s, then there is a 99% probability that an unusual condition such as equipment failure is indicated.

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LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS AND ACRONYMS

BCDS -- Broadband Communication Distribution System
CIF -- Central Instrumentation Facility
CRC -- Cyclic Redundancy Check
CSMA/CD -- Carrier Sense Multiple Access with Collision Detection
EDL -- Engineering Development Laboratory
HER -- Head End Remodulator
HQ -- Headquarters Building
KSC -- Kennedy Space Center
LAN -- Local Area Network
NMC -- Network Monitor Console
NRM -- Network Resource Monitor
RCV -- Receive
RX -- Receive
TX -- Transmit
XMT -- Transmit

I. INTRODUCTION

In this report, we are concerned with the use of observed performance data on a CSMA/CD network, such as gathered by routine network monitoring equipment, for network fault detection. For this we need to understand the random nature of variations in network performance. Arrival of messages in a network is governed by random fluctuations in user demand. As a result, network performance is statistical in nature, and network error levels can vary randomly.

How can error levels be used for diagnostics? From experience, we know that a "too-high" error level will indicate a network problem e.g. equipment failure. But how high is "too-high"?

Some of the types of data collected by network monitoring equipment are: collisions, CRC errors, and misalignments. Collisions occur when two users randomly happen to transmit at the same time. CRC errors are caused when part of the transmission is corrupted. This error is detected by the CRC code. Misalignment means that the length of the message did not follow standard rules. In this project we will focus on understanding and using collision performance data. This is not to say that collisions are undesirable *per se*. Collisions are unavoidable and generally not considered bad, because the network corrects for them. However, we are considering reported collision levels as indicators of other types of trouble with the network. For this, we ask what level of collisions are reasonable, and when we could conclude that an unreasonably high collsion rate is indicative of a network problem.

There is extensive prior literature on the theoretical performance analysis of CSMA/CD networks [1,2,3,4]. But the study of collision rates is generally not considered important in the literature for reasons given above. Rather, theoretical studies are more concerned with the maximum possible throughput and corresponding delay performance. So most theoretical analyses are concerned with modeling heavily loaded networks to understand their throughput delay characteristics. These analyses result in very general but quite complex models involving Markov queueing theory and matrix algebra. In practice, operational networks tend to be fairly lightly loaded and a complex model is not necessary. In this report, we show how a simple model for collision performance on a lightly loaded network can be used for network management purposes.

The approach we will take is described by three components of the project. One, we will study a theoretical probabilistic model for network collision rates. Two, we will gather statistics from channel 3/P of KSC's BCDS network. Three, we will correlate theory with actual data. Finally we will use the theoretical model to establish a usable network problem threshold.

II. THEORETICAL MODEL

2.1 COLLISION WINDOW

Central to the theoretical development is the concept of collision window. This is the time it takes on a CSMA/CD network from the instant of one station deciding to start a transmission, to the instant that *all* stations have "heard" the transmission, and decided to defer their own transmissions till the current transmission completes. This is the fundamental unit of time in developing the probabilistic event model in our work, and hence also referred to as a single slot.

Elements of the total delay and estimates are given below in Table 2-1. Precise knowledge is lacking due to lack of technical documentation availability from the manufacturer. These data are taken from IEEE STD 802.3 (supplement)[5]. The various delays are stated in terms of allowable bit periods. These have been converted to time units using 0.2 μs/bit corresponding to the BCDS 5 Mb/s transmission speed.

TABLE 2-1 Collision Window Elements

	BITS		μs
TX DATA to RF energy =	24	=	4.8
Propagation delay 1800m x 3.8ns/m =			6.8
H.E.R. RF to DATA =	75	=	15.0
H.E.R. DATA to RF =	24	=	4.8
Propagation delay 1800m x 3.8ns/m		=	6.8
RCV RF to RX DATA =	75	=	15.0
	Total	=	53.2

We will use a round figure of **60 μs** as our theoretical estimate to make allowances for taps, drop cables, amplifiers, etc. Later, in Sec. III, we will describe how the actual network delay was measured.

2.2 SUCCESS, IDLE AND COLLISIONS PER SLOT

Let us introduce the following notation:

λ -- Average packet arrival rate at any one station

T -- Collision window

n -- Number of stations

p -- For any one station, the probability of initiating a transmission within a slot.

P_s -- For a given slot of time T, the probability of initiating a successful transmission

P_I -- For a given slot, the probability of idle

P_c -- For a given slot, the probability of a collision

P_{CP} -- For a given packet, the probability of a collision. (Note that this is different from P_c)

OP_{CP} -- Observed probability of collision per packet

R -- Total network traffic in packets/s
D -- Average packet duration in sec
m -- Average packet length in units of T

The random nature of arrivals at a single station is governed by the Poisson distribution:

$$p_k = \frac{(\lambda T)^k e^{-\lambda T}}{k!}$$

where, p_k = Probability of k arrivals, k = 0,1,2,...

We will assume in our theoretical development that all stations are equally loaded, which is reasonable for the BCDS system, because each station is a bridge, which forwards traffic from a baseband ethernet LAN.

Then total traffic

$$R = n\lambda \text{ packets/s},$$

$$p = \lambda T,$$

and P_s = Pr(Exactly 1 packet at only 1 of n stations)
       $= np(1-p)^{n-1} \approx np = n\lambda T$.

Interestingly, P_s can be written as the product of network traffic and collsion window

$$P_s = RT. \tag{2-1}$$

Next,
$$P_I = \text{Pr(0 packets at all of n stations)}$$
$$= (1-p)^n.$$

Hence,
$$P_c = 1 - P_s - P_I = 1 - (1-p)^{n-1}[np + 1 - p]. \tag{2-2}$$

2.3 RELATE TO NRM DATA

Actual observations on the network are taken with a device called the NRM. The NRM reports the absolute number of collisions, from which it is easy to determine the proportion of transmitted packets that experience a collision. So we need to theoretically develop an equation for the proportion of packets that collide.

$$P_{CP} = \frac{\text{\# of collisions}}{\text{\# of xmt packets}} = \frac{\text{Pr(collision/slot)}}{\text{Pr(xmt success/slot)}}$$

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$$= P_C/P_S$$

For low traffic, p is small, and $P_I \approx 1$, so the above method of (2-2) is not accurate. For example, if

$$n = 33 ,$$
$$\lambda = 3 \text{ frames/s/station} ,$$
$$T = 25 \ \mu s,$$

then, p = 75E-6 = 0.000075 . Notice that p << 1. Next,

$$P_S = 25E-4 = 0.0025,$$
$$P_I = (1-.000075)^{32} = 0.997602787 \quad (\text{Notice, } \approx 1),$$

and

$$P_C = 1 - P_S - P_I = -1.028E-4 ,$$

which is impossible, since probability can never be negative.

A better way is to approximate $(1-p)^{n-1}$ as $(1-(n-1)p)$, since p is small, and write:

$$P_C = 1 - (1-(n-1)p)(np + 1 -p)$$
$$= [(n-1)p]^2.$$

Then

$$P_{CP} = P_C/P_S = [(n-1)^2/n]p \approx (n-1)p \text{ for } n >> 1 .$$

Comparing with $P_S = np$, we see that P_{CP} will increase linearly with traffic R. As for P_S in (2-1), P_{CP} can also be approximated as the product of network traffic and collision window

$$P_{CP} = RT. \tag{2-3}$$

It is interesting that the probability of collision per slot, P_C, increases as the square of the product RT, while the probability of collision per packet P_{CP} increases linearly with RT.

2.4 NETWORK UTILIZATION

Although not the primary concern of this work, the model developed above can be used to develop an equation for network utilization.

For this we introduce:

$$m = \text{Average packet size in units of } T = D / T$$

For example, if the average packet is 150 bytes long, it will take 150 x 8 x 0.2 = 240 µs at the BCDS transmission rate of 5 Mb/s. Now if T = 80 µs, then m = 240/80 = 3.

Considering the possible events during one slot, we see that the network will be idle for 1 slot with probability P_I, it will lead to a successful transmission, occupying on the average m slots, with probability P_S, and with probability P_C, it will lead to a collision. A collision will consume on the average, a certain number of time slots to resolve, which will depend on the backoff algorithm. But the resolution will require at least one additional slot, so we will optimistically assume a collision will consume on an average, 2 slots, one for the collision, one for the minimum backoff. We will see soon that this assumption is not very significant for lightly loaded networks. Then we can write the average network utilization as:

$$\rho = \frac{mP_s}{mP_s + P_I + 2P_C}.$$

Since $P_C \ll 1$ and $P_I \approx 1$, we can write approximately,

$$\rho \approx mP_s/ (1 + mP_s). \tag{2-4}$$

When $mP_s \ll 1$, we can simply approximate (2-4) as mP_s. Notice that from (2-1), $mP_s = mTR$, and hence,

$$\rho = mP_s = D\,R \tag{2-5}$$

$$= \text{Average Packet Duration X Network Traffic in pkts/s.}$$

For example, if the network traffic is 150 pkts/s and the average duration is 240 µs, then $\rho = 0.036$ or 3.6% average. The peak utilization can be much higher.

2.5 SIMPLER DERIVATION

A mathematically simpler derivation for the proportion of colliding packets is obtained by changing our argument approach slightly. Once a given packet starts transmitting, collision will occur if one of the remaining stations attempt to transmit within the collision window, and so

$$P_{CP} = \text{Pr(one or more of (n-1) stations will transmit)}$$
$$= 1 - \text{Pr(none of n-1 stations will transmit)}$$
$$= 1 - (1-p)^{n-1}$$
$$\approx 1 - [1-(n-1)p]$$
$$= (n-1)p,$$

which is the same as (2-3).

Since $p = \lambda T$ as seen in (2-1), we need to know the packet arrival rate and collision window to predict percent of colliding packets. In the next section we will discuss practical measurement of these quantities for the KSC BCDS network and relate them to observed collision rates.

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III. TEST RESULTS

3.1 COLLISION WINDOW MEASUREMENT

Fig. 3-1 shows the test setup used to measure the collision window. Note that the Head-end Remodulator is really part of the network equipment, and not part of the test equipment. The following equipment was used:

1 -	Tektronix type 7904 Oscilloscope
2 -	Tektronix 7A22 Differential Amplifier Vertical Modules
1 -	Tektronix 7B92A Dual Time Base
1 -	Network General SNIFFER Network Analyzer
2 -	Ungermann-Bass Buffered Repeaters
2 -	Black-Box (TM) Ethernet 4-port Direct Connects (Fan-out Boxes)

The test equipment is set up in the EDL building which is at the end of the BCDS cable. The HER is located in the CIF building, about 1800m distant. The SNIFFER is set up to generate a stream of 64-bit wide packets at 30 ms interval. Each packet must travel through the first fan-out box toward the cable. As it does so, a voltage signal appears on the RCV terminals of the first fan-out box. Then the packet travels through the buffered repeater and propagates along the cable to the HER. The 4/Q channel, which is a test channel, was used for the experiment to avoid interference with other users. At the HER, the packet is demodulated and remodulated on a different frequency and propagates back down the cable. It is then recieved by the second buffered repeater and sent to the second fanout box, causing a signal to appear on the RCV terminals of the second fanout box. The RCV terminals (pins 5 and 12) [6] of the two fanout boxes are connected to the left and right vertical channels of the scope respectively. By observing both signals simultaneously, we detected the relative delay between them. We note that the measured delay includes not only the network delay, but also the delay introduced by the two buffered repeaters.

3.2 EFFECT OF BUFFERED REPEATER PACKET PROCESSING LATENCY

The ethernet baseband speed = 10 Mb/s and the BCDS broadband speed = 5 Mb/s. Due to the speed difference, the buffered repeaters must store the packet and then forward it [7]. This introduces a delay which is equal to the packet duration. In going from baseband to broadband, the delay is 0.1 μs/bit, and from broadband to baseband it is 0.2 μs/bit. This gives a total delay of 0.3 μs/bit or 2.4 μs/byte. To account for the buffered repeater processing latency, total delay was measured for different packet sizes. The results are shown in Table 3-1.

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TABLE 3-1 Effect of Buffered Repeater Latency

Packet Size (Bytes) (x)	Total Delay (µs) (y)
64	230
96	310
128	390
160	470

Now let y represent the measured delay, and x represent the packet size in bytes. Fit a linear equation $y = mx + c$. Then m represents the processing delay per byte introduced by the buffered repeaters, and c is the fixed network delay that is independent of packet size.

Result: m = 2.4 µs/byte, c = 80 µs

The measured network delay **80 µs** is close to theoretical estimate of 60 µs. We will use the 80 µs figure as the best available value for the collision window.

3.3 PRACTICAL PREDICTION OF PERCENT COLLIDING TRANSMISSIONS

Using the theoretical model, we can predict the expected proportion of transmitted packets that will collide. Because we have identified a linear relation between P_{CP} and R in (2-3), the application of our theoretical model is extremely simple.

Let us use:

Network Traffic   =   125 packets/s
Collision Window   =   80 µs

Proportion of Colliding
            Transmissions =   125 x 80 x 10^-6
                                 =   0.01

or 1%

RULE OF THUMB :   Theory predicts a collision rate of 1% for a traffic level of about 125 pkts/s. This will change proportionally with traffic.

3.4 MEASUREMENT OF NETWORK PERFORMANCE

Two types of equipment were considered :

SNIFFER (TM)   : Made by Network General Corp.
NMC (TM)   : Made by Ungermann-Bass.

The NMC (Network Monitor Console) was selected for the project since it provides more suitable data than the SNIFFER. The SNIFFER attaches to the BCDS network through a device called a BUFFERED REPEATER. As part of its function, the Buffered Repeater discards transmitted packet fragments that normally result from a collision. Hence these packets are not passed to the SNIFFER. As a result the data analysis presented by SNIFFER is incomplete regarding information on BCDS collision rates.

Fig. 3-2 shows an example of a screen from the NRM, which is a functional part of the NMC. The A side of the screen refers to the BCDS and is of interest to us. The NRM was used to monitor channel 3/P of th e KSC BCDS system.

3.5 NETWORK PACKET ARRIVAL RATE AND COLLISION RATE FROM NRM DATA

In section II we saw that the network traffic R was a key parameter in determining collision performance. The total network packet arrival rate can be easily obtained from NRM data.

As seen in Fig. 3-2, each bridge keeps a running count of total XMT and RCV packets, which are then reported by the NRM. In Fig. 3-2, for example, we are observing the bridge located on the 2nd floor of the HQ building. The screen is updated every 10 second. Because cumulative counts are reported, two observations are necessary to get a picture of current activity.

For example:
Observation 1: XMTPKT = 209 ; RCVPKT = 25180 ;
After 10 s   : XMTPKT = 235 ; RCVPKT = 27101 .

Then, total Network Traffic in 10 s = 26 + 1921 = 1,947 ,

And,   Network Packet Arrival Rate = 195 pkts/s .

Observations indicate that the network packet arrival rate can vary from 50 to 500 pkts/s on BCDS 3/P channel.

A similar approach is needed to calculate the actual proportion of colliding packets.

For example:
Observation 1: XMTPKT = 629 ; COLLISN = 8 ;
After 10 s   : XMTPKT = 846 ; COLLISN = 11 .

Therefore there were 217 packets successfully transmitted by this bridge in the last 10 seconds. In addition, 3 transmission attempts resulted in collisions. Therefore the total number of attempts is 220 and the collsion rate over the last 10 s is

$$OP_{CP} = 3/220 = 0.0136 \text{ or about } 1.4\% .$$

3.6 DATA COLLECTION

Because it would be very difficult to analyze large quantities of data one screen at a time, we can use a log file to make the task simpler. An example log file is shown in Fig. 3-3. Each line in this file represents data from one 10 second update of the NRM screen. NMC data has been collected by taking 1,080 readings over a one day period. This represents 20 minutes worth of data, i.e. 120 points, every hour for 9 hours. The resulting log files can be analyzed using a spreadsheet program.

3.7 DATA ANALYSIS

Fig. 3-4 shows a sample data analysis of a log file. The method of Sec. 3.5 was applied to each line of a log file taken on June 17, 1992. The network traffic in packets/s and percentage of colliding transmissions was calculated for each 10 s update interval. The results are plotted in Fig. 3-4. As we can see, the raw data is somewhat confusing, with the collision percentage scattered anywhere from 0 to 10%, and traffic ranging from 30 to 250 pkts/s. There are two reasons for this confusion. One, the network traffic ranges over one order of magnitude, and from (2-3), so will P_{CP}, the collision probability per packet. Two, the theoretical development of Sec. II and (2-3) give us the expected or average value for the percentage of colliding transmissions. The actual data value will be a random value which is a sample taken from a certain probability distribution with the mean given by (2-3). So if we take many observations corresponding to a given traffic level, the average should tend toward the theoretical average of (2-3). With many data points for a given value of network traffic, we can study the shape of the probability distribution function by plotting occurrences of actual percent colliding transmission values.

Although we have many data points in Fig. 3-4, they do not all correspond to the same traffic level. Next, we group the data points into bins of approximately equal traffic. Thus all data points corresponding to network traffic of 25-50 packets/s are grouped together. Similarly, other groups are formed corresponding to traffic ranges of: 50-75, 75-100, 100-125 etc. packets/s. It is important to note that each group will have a different number of data points in it. We cannot control this, rather it is controlled by random fluctuations in the network traffic based on user demand. Then, for each group, we calculate the average traffic and average percentage of colliding packets. The average percent colliding packets versus average traffic is plotted in Fig. 3-5. Each point in Fig. 3-5 represents a group of data points of approximately equal traffic from Fig. 3-4, as described above. The points in Fig. 3-5 exhibit the expected linear trend. If we fit a straight line through these points, while forcing it through the origin, we obtain a slope of 0.0095. The regression equation then becomes:

$$OP_{CP} (\%) = 0.0095 R . \tag{3-1}$$

To compare with the results of Sec. 3.2, we note that substituting R = 125 in (3-1) leads to OP_{CP} = 1.2%. This agrees closely with the 1% collision level predicted by theory based on our measurement of the network collision window.

IV. THRESHOLD CALCULATION

4.1 PROBABILITY DENSITY FUNCTION FOR OCCURRENCES OF COLLISION PERCENTAGES

Let us focus on the data points belonging to just one of the bins mentioned in Sec. 3.7
We will study the data points corresponding to a traffic range of 75-100 pkts/s. We note from Fig. 3-4, that a large number of data points correspond to no collision or 0% collision rate. For higher collision rate values, the number of times they occur becomes progressively less. Fig. 4-1 plots the number of occurrences in the range 0-0.5, 0.5-1, etc. %, versus the lower limit of each range. Also shown is the shape of an exponential curve. Based on empirical observations, we will conjecture that the probability density function follows an exponential shape. A theoretical proof of the shape of the density function is still a question for further research.

4.2 95% AND 99% CONFIDENCE LIMITS FOR EXPONENTIAL DISTRIBUTION FUNCTION

The distribution function for an exponential density function with mean a^{-1} is

$$F_X(x) = Pr(X \leq x) = 1 - e^{-ax} .$$

(4-1)

For the 95% confidence level we solve (4-1) for x such that

$$F_X(x) = 0.95 ,$$

which yields

$$x = (-1/a) \ln(0.05) = 3 \, a^{-1}.$$

That is, at 95% confidence level, the sample value x is less than 3 times the mean. This is shown in graphical form in Fig. 4-2.

Similarly solving (4-1) for $F_X(x) = 0.99$ yields

$$x = 4.6 \, a^{-1}.$$

4.3 THRESHOLD DETERMINATION
From Sec. 3.3, we know that the expected or mean collision rate in % is

$$P_{CP}(\%) = 100*80*10^{-6}*R = 0.008 \, R$$

(4-2)

Combining this with the results of Sec. 4.2, we get the following thresholds:

At 95% confidence level

$$T_{h1} = 3 \times 0.008 \times R = 0.024 \, R .$$

(4-3)

At 99% confidence level

$$T_{h2} = 4.6 \times 0.008 \times R = 0.037 \, R \ . \tag{4-4}$$

4.4 RECOMMENDED IMPLEMENTATION

Procedure

1. Use NRM data to calculate traffic using the method described in Sec. 3.5, i.e.

$$R = \Delta(XMTPKTS+RCVPKTS) \, / \, \Delta T \ .$$

2. Calculate observed proportion of colliding packets using the method of Sec. 3.5, i.e.

$$OP_{CP} \ (\%) = \ 100 * \Delta(COLLISNS) \, / \, \Delta(XMTPKTS + COLLISNS).$$

3. Calculate thresholds T_{h1} and T_{h2} using formulas (4-3) and (4-4) given above.

4. If threshold T_{h1} is exceeded, there is >95% probability of a network hardware problem. If threshold T_{h2} is exceeded, there is >99% probability of a network hardware problem.

4.5 GRAPHICAL EXAMPLE

In Fig. 4-3, we see a spreadsheet analysis similar to Fig. 3-4, based on data taken on July 15. We can see that the data indicates higher levels of traffic as well as collision rates than Fig. 3-4. Application of the procedure of Sec. 4.4 shows that there are a considerable number of data points above the threshold. So we would conclude that this data indicates an unusually high collision rate, that would lead us to suspect some type of equipment problem.

V. CONCLUSIONS

We have presented an analysis of the collision probability in a CSMA/CD network with the idea of using our theoretical understanding in combination with observed collision performance data to draw conclusions about network problems. A simple theoretical model for this purpose has been developed which can be easily related to observed network data. From this model, we see that the percentage of colliding transmissions will increase in proportion to network load. The collision window was seen to be an important network property. An apparatus and methodology was developed to measure the network delay for KSC. The results of the theoretical model were in good agreement with actual collision performance data taken from the network during routine operation. A formula for the threshold and a recommended procedure for implementing it have been developed. The implementation rule states that if observed network collision rates exceed the threshold, a network problem is indicated with high probability.

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DELAY MEASUREMENT

Figure 3-1 Test Setup

```
+==============================================================================+
|      hq 2 east 2518            96396         DLL BRIDGE  1                    |
+-------------------------------------+----------------------------------------+
|        ETHERNET STATISTICS          |         ETHERNET STATISTICS            |
| XMTPKTS: 47696                      | XMTPKTS: 999918                        |
| RCVPKTS: 3464869                    | RCVPKTS: 361937                        |
| TXBYTES: 10005307                   | TXBYTES: 193588585                     |
| RXBYTES: 794548481                  | RXBYTES: 79632603                      |
| COLLISN: 4294                       | COLLISN: 46                            |
| ABORTED: 609                        | ABORTED: 0                             |
| CRC-ERR: 65535                      | CRC-ERR: 0                             |
| ALGNMNT: 65535                      | ALGNMNT: 0                             |
| OVERRUN: 12                         | OVERRUN: 43                            |
| LOSTPKT: 0                          | LOSTPKT: 0                             |
| OUTBUFS: 0                          | OUTBUFS: 0                             |
| THRUPUT: 148                        | THRUPUT: 6959                          |
| 586HUNG: 3                          | 586HUNG: 0                             |
|                                     |                                        |
| FORWARD: ACTIVE   STATE: ENABLED    | FORWARD: ACTIVE    STATE: ENABLED      |
+=====================================+========================================+
```

```
F1=Prev Menu   F2=Write a File  F3=RDB Tables   F4=Monitor All
               F7=Help          F8=Port Monitor F9=Clear Stats F10=Choices
```

Figure 3-2. Example NRM screen.

```
Name: hq 2 east 2518          Address: 96396
Type: DLL BRIDGE              NetID: 1
Wed Jun 17 08:27:39 19  Update 0:00:10
Time       XMTPKTS A  RCVPKTS A  TXBYTES A  RXBYTES A  COLLISN A  CRC-ERR A
08:28:58   4          7268       1700       1166270    0          1
08:29:08   5          8397       2152       1336310    0          1
08:29:18   6          9387       2604       1556375    0          1
08:29:28   7          10368      3056       1760815    0          1
08:29:38   8          10967      3508       1864166    0          1
08:29:48   10         11830      4358       1973602    0          1
08:29:58   11         12361      4810       2067351    0          1
08:30:08   54         13194      8370       2182999    0          2
08:30:18   97         14153      11930      2314550    0          2
08:30:28   168        14984      17562      2428938    0          2
08:30:38   169        15991      18014      2573177    0          3
08:30:48   171        16988      18864      2782542    0          3
08:30:58   179        18489      19834      2999141    0          3
08:31:08   215        19314      22876      3111832    0          3
08:31:18   272        20088      27472      3219796    0          3
08:31:28   399        20958      37248      3335106    1          3
08:31:38   414        21745      38736      3469666    1          3
08:31:48   416        22565      39586      3636555    1          3
08:31:58   417        23299      40038      3755670    1          5
08:32:08   418        25022      40490      4029934    1          5
08:32:18   419        26079      40942      4218496    1          5
08:32:28   434        27742      42430      4502791    3          5
08:32:38   435        28954      42882      4714739    3          5
```

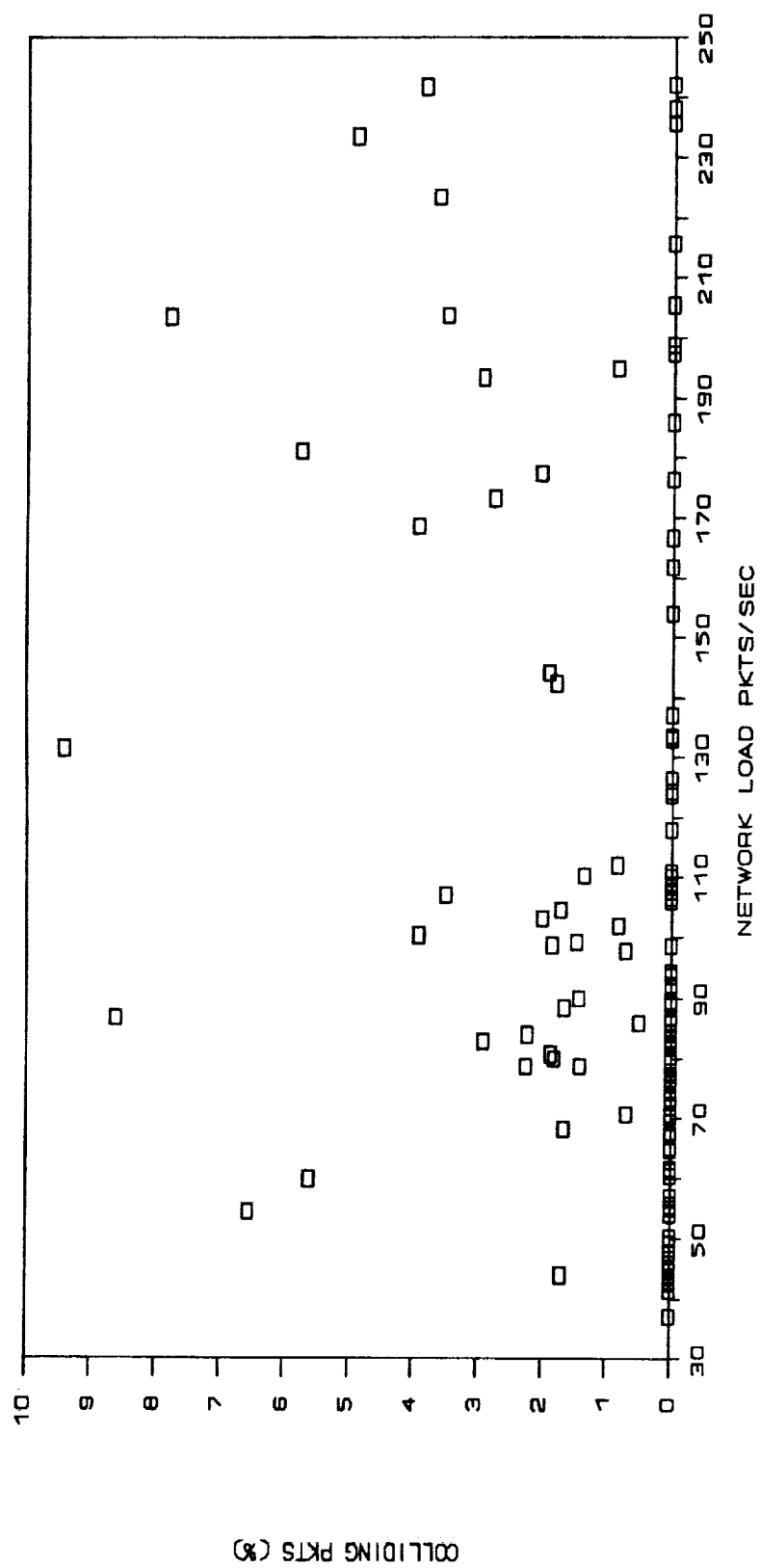Figure 3-3. Example Log file from NRM.

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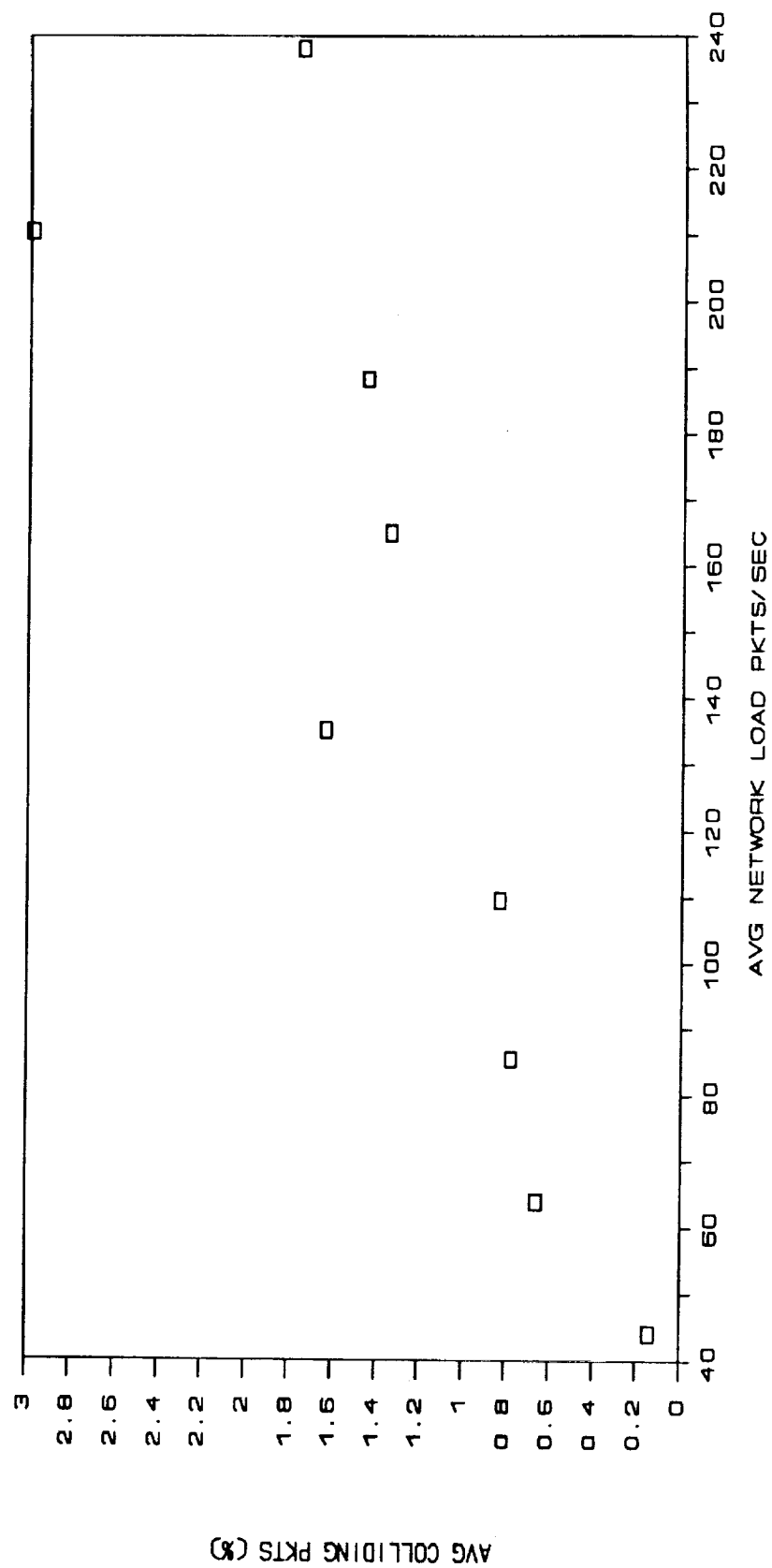Figure 3-4 Analysis of 10 second update data points.

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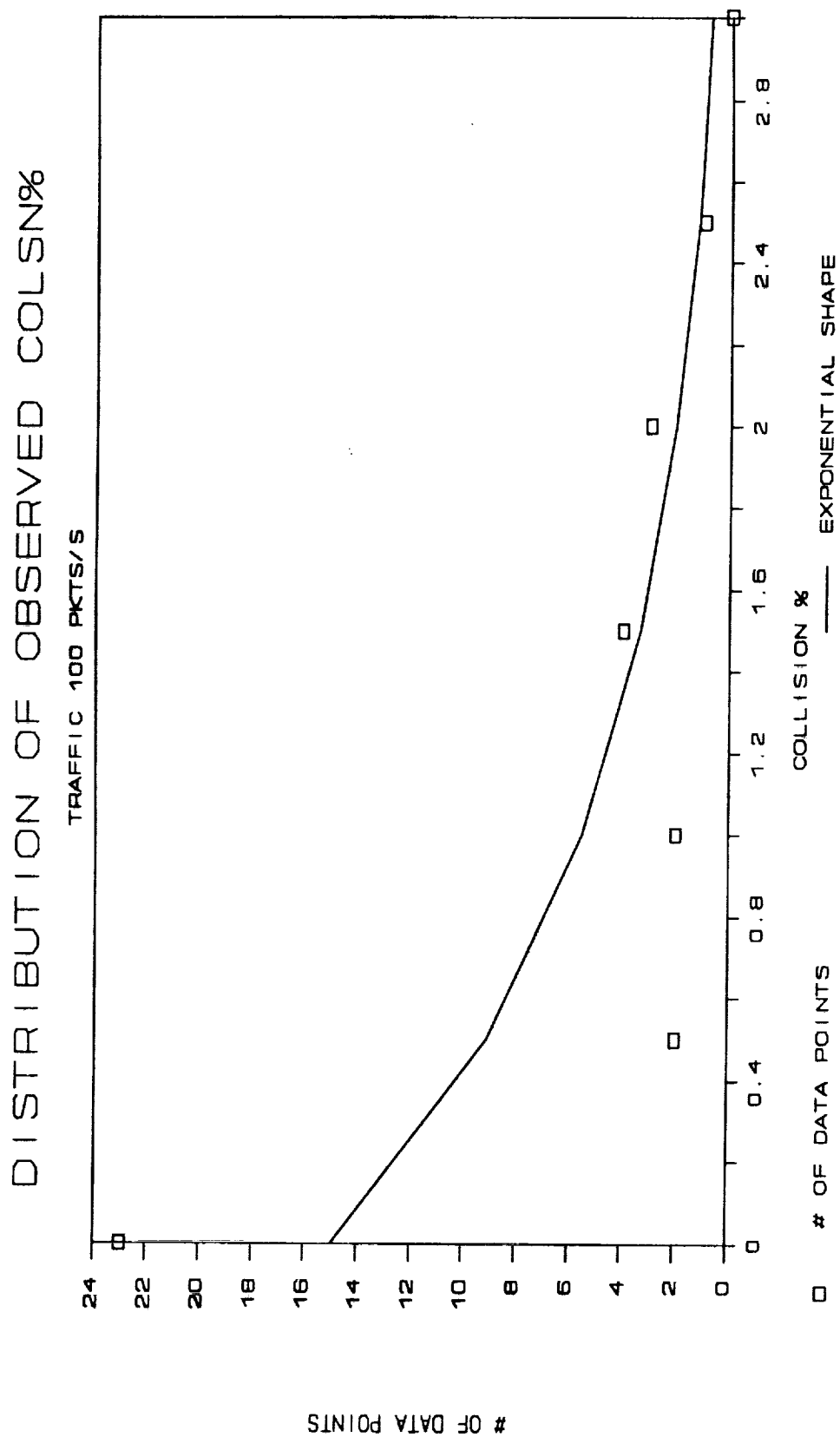Figure 3-5. Analysis after grouping data points by traffic.

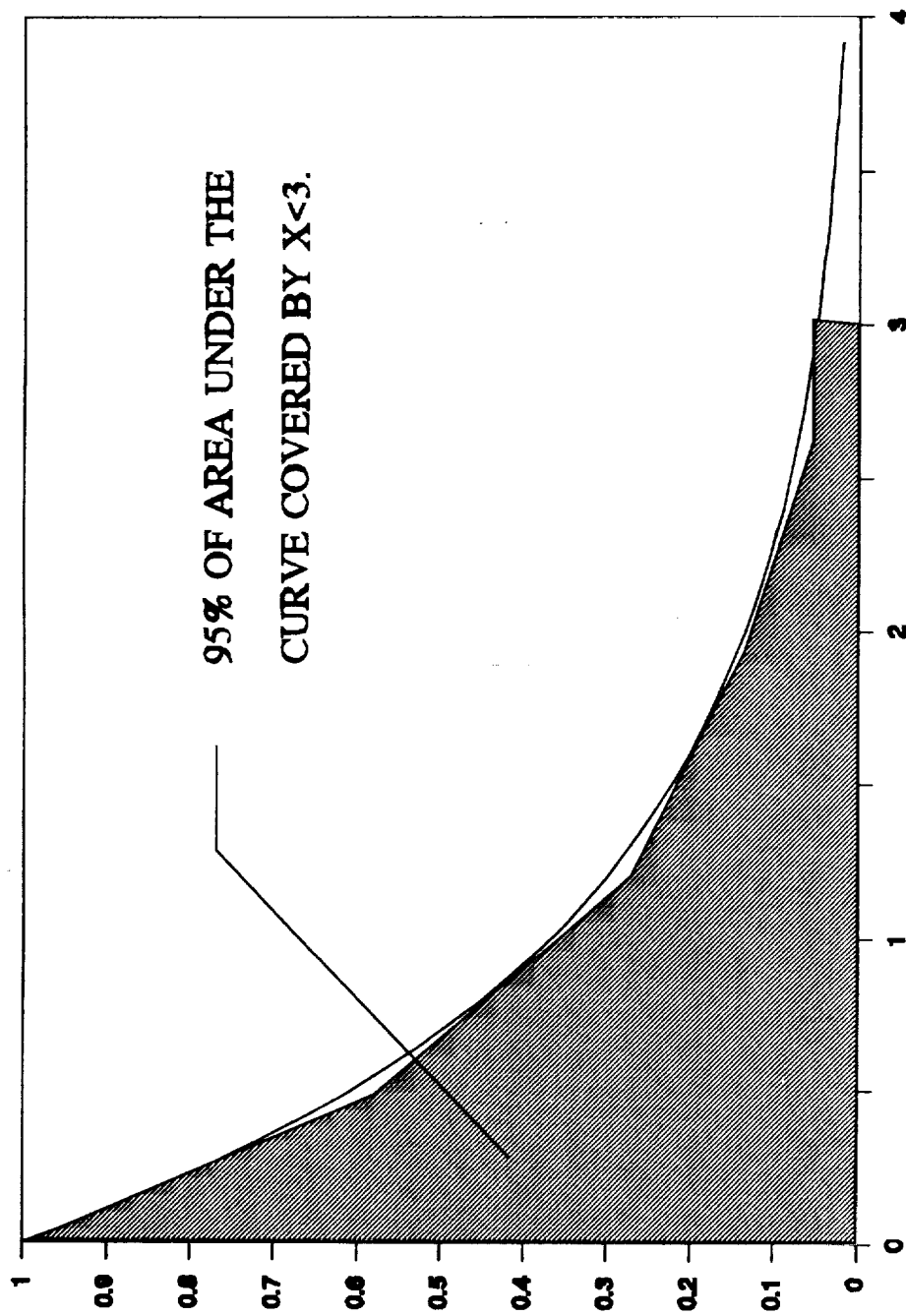Figure 4-1. Number of occurrences vs percentage colliding packets, for fixed traffic.

95% OF AREA UNDER THE
CURVE COVERED BY X<3.

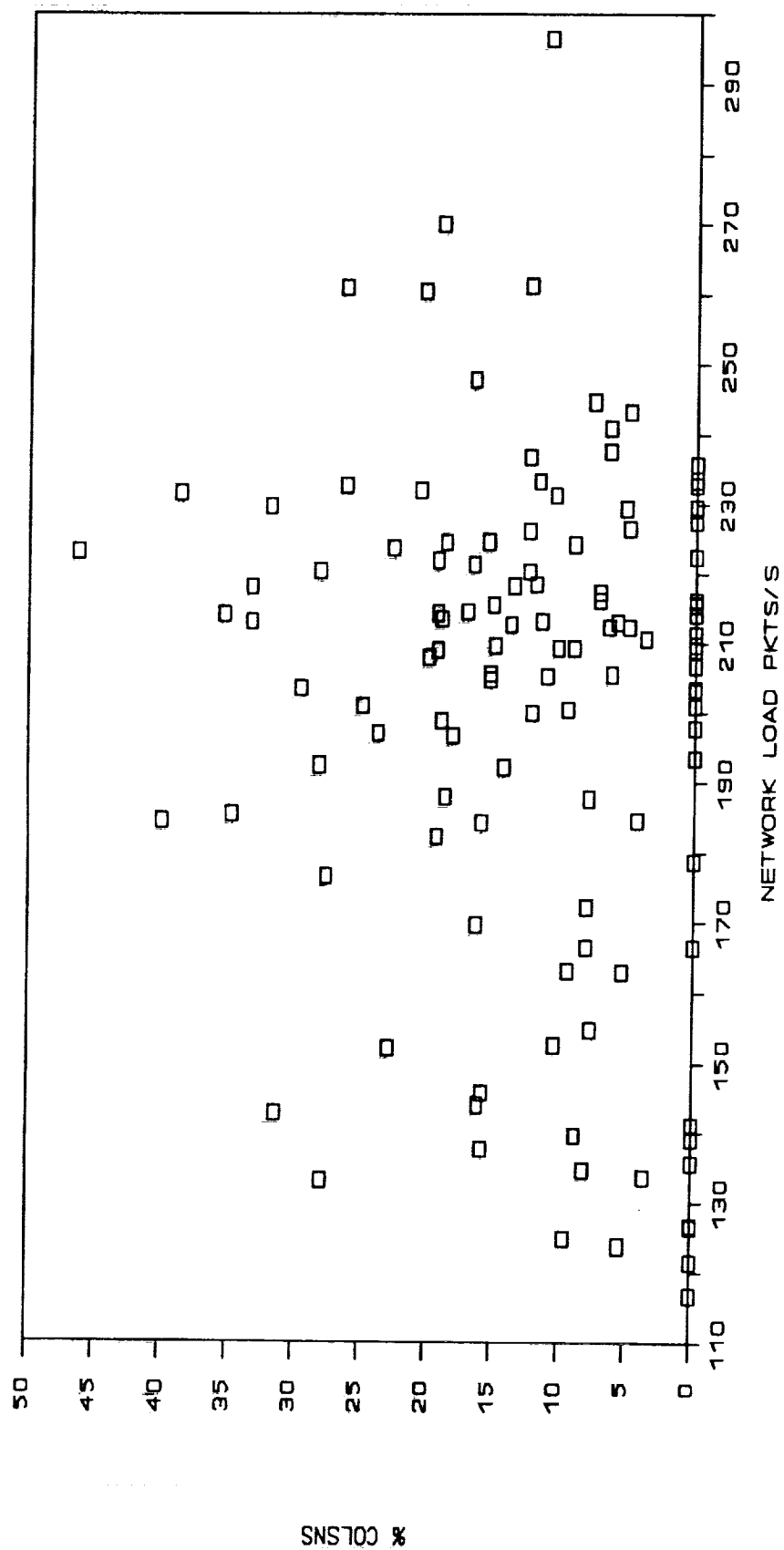Figure 4-2. 95% confidence limit from exponential density function.

Figure 4-3. Example of data with collision percent exceeding threshold.