ABSTRACT

Title of Thesis: Simulation of Voice and Data Integration

Urmila S. Patel, Master of Science, 1991

Thesis directed by: Professor Irving Wang

A simulation model of integrated voice and data is developed. The data packets are transmitted during voice inactivity (i.e. silence duration). A statistical model of voice (talkspurt) and silence duration is generated. Inter–arrival time between data packets is modeled using geometrical distribution. The data traffic statistics is simulated for a given voice activity model and various data packet arrival rates. Four important results are obtained by performing this simulation: 1. Average data packet delay versus arrival rate. 2. The optimal ratio of data packet arrival rate to average data packet delay. 3. Probability of wait time for various data packet arrival rates. 4. Probability of zero waiting time versus arrival rate. These results can be utilized to optimally select the data traffic intensity. Several plots have been generated to provide more insight of the voice and data integration.

Simulation of Voice and Data Integration

by

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To my husband Kartik and
brother Kumud

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CHAPTER 1

INTRODUCTION

In the last ten years, there has been a great deal of activity in integrated telecommunication networks. Public telephone and telecommunications networks are rapidly evolving from analog technology to the exclusive use of digital technology. The Integrated Digital Network (IDN) will combine the extensive geographic coverage of the telephone network with the data carrying capacity of digital data networks in a structure called the Integrated Service Digital Network (ISDN).

ISDN will become a worldwide public telecommunications network that will service a wide variety of user needs. ISDN will support a variety of services related to voice communications (telephone calls) and nonvoice communications (digital data). These services are to be provided in conformance with standards (CCITT recommendations) that specify a small number of interfaces and data transmission facilities.

Many different types of services will be available from this system, such as an ISDN data transmission service that will allow users to connect their ISDN terminal or computer to another one anywhere in the world. A new communication service called Videotex is expected to become widespread with ISDN. Videotex provides an interactive access to a remote database by a person at a distant terminal.

Simultaneous voice and data transmission is another application being considered for ISDN.

The movement toward digital technology has been pushed by the competitive desire to lower cost and improve quality of voice transmission and networking services. In an analog network, signals may pass through one or more intermediate switching centers before reaching the destination. At each switching center, the incoming FDM carrier has to be demultiplexed and demodulated by an FDM channel bank before being switched by a space–division switch. After switching, the signals have to be multiplexed and modulated again to be transmitted. This repeated process results in an accumulation of noise, as well as high cost. Whereas, in a digital network, incoming voice signals are digitized using PCM and multiplexed using TDM, so Time–division digital switches along the way can switch the individual signals without decoding. Furthermore, separate multiplex/demultiplex channel banks are not needed at the intermediate offices, since that function is incorporated into the switching system.

A number of small–scale ISDN facilities have been developed, but the promised extension of ISDN to encompass worldwide public telecommunication is not yet a reality. Also, digital service has not yet been extended to the end user. Telephones are still sending analog data to the end office where they must be digitized. Lower–speed (<56 kbps) end–user digital service is commonly available via leased lines at present, and higher–speed leased services are being introduced.

This thesis describes and analyzes transmission of data packets (nonvoice) during voice communication.

The main objectives of this simulation project are:

1. To obtain Voice and Data statistics, for use in simulation program.
2. To obtain data packet delay statistics.
3. To achieve or to select the optimal ratio of data packet arrival rate to average time delay per packet.
4. To obtain waiting statistics for data packets.
5. To provide a general scheme for integrated voice and data modeling which can be used in mobile voice/data communication or CATV networks.

Chapter 2 provides protocol and model description. Chapter 3 gives a detailed description and analysis of generating talkspurt and silence duration used in simulation design. Simulation results are discussed in chapter 4.

CHAPTER 2

PROTOCOL AND MODEL DESCRIPTION

This chapter presents the description of a model on which voice/data integration protocol is tested. It also provides an overview of protocol and defines the assumptions used to develop the protocol.

2.1 SYSTEM MODEL:

2.1.2 MODEL DESCRIPTION:

The system considered here has one voice source and one data packet source sharing one voice channel for transmission purpose. As shown in figure 2.1 two types of traffic arrive at a transmission link. The voice traffic is digitized. It can be PCM, ADPCM or any other compressed voice. A voice detection unit may be embedded into the controller. A controller is used to schedule the traffic on arrival. The controller would know each user`s frame bandwidth requirement and would decide whether to immediately transmit an arriving data packet or schedule it for later transmission. Figure 2.1 conceptually explains how voice and data integration is modelled.

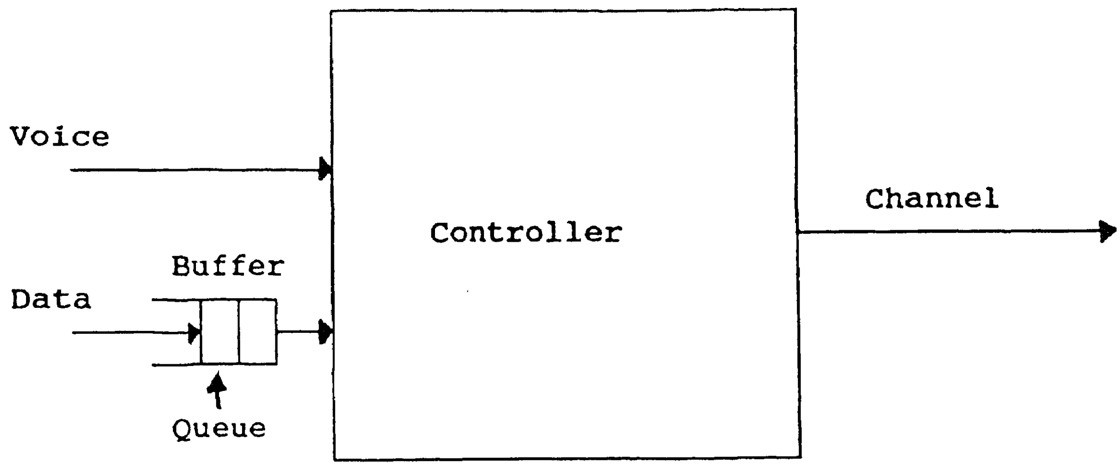

Figure 2.1 Integration of Voice and Data Traffic

Data packets arrive at rate λ packets/sec with inter-arrival time geometrically distributed. During voice inactivity, data packets are placed for transmission. The key to combining voice and data onto a common channel is the concept that speech can be modelled as short bursts of vocal energy (talkspurt) separated by gaps contain no vocal energy (silence duration). Thus, voice detection is a crucial part of the system since it determines when to start and stop transmitting data packets.

The model described here is a representation of (1) Collocated voice and data sources using a single channel and (2) Two stations, one transmitting voice and the other transmitting data through a common node in a network using the same channel.

A. Voice Model:

Speech first passes through a speech detector which generates an on–off speech pattern. Figure 2.2 depicts a functional block diagram of the speech detector. Incoming digital speech signals are used to compute speech energy (amplitude). A threshold detector is set at this point to detect the presence of an amplitude above some fixed value. The threshold detector triggers a flip–flop between clock pulses. A pulse will be output synchronously with a frame clock. This pulse indicates that speech energy crossed the threshold, which indicates an "on interval." The absence of a pulse indicates an "off interval." A spurt is an unbroken sequence of on intervals. A gap is an unbroken sequence of off intervals. Using this method, speech can be transformed into a spurt gap pattern.

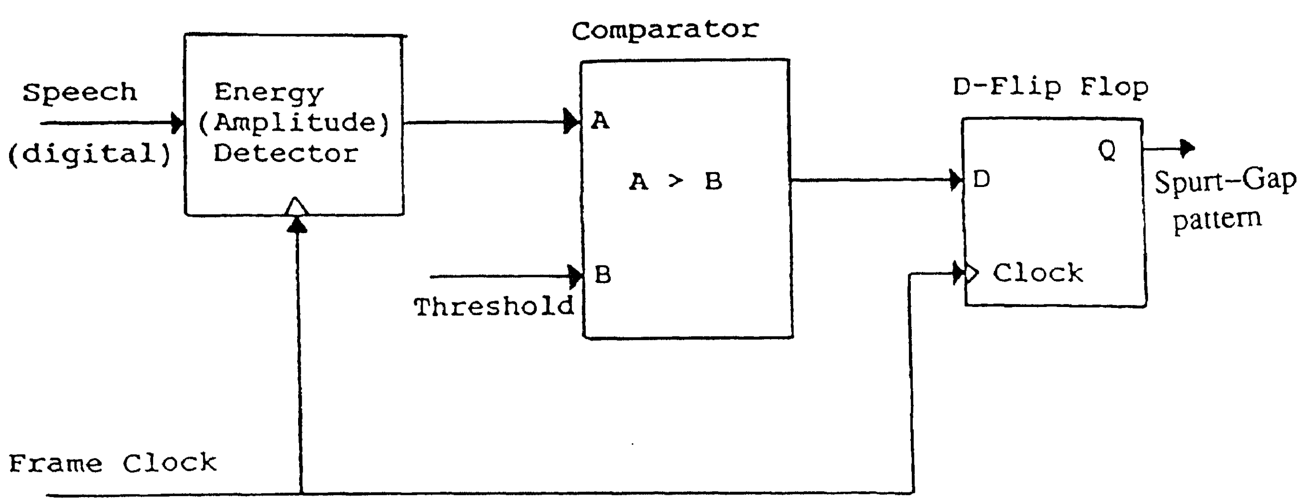

Figure 2.2 Speech Activity Detector.

Talkspurt:

Speech waveform is divided into fixed–size frames. This is accomplished by use of a frame clock to sample the speech detector. It ensures that on/off intervals will be an integral multiple of frame lengths. The pattern obtained corresponds to talkspurt and silence duration. Talkspurt is a time period that contains a sequence of speech sounds unbroken by pauses [1]. Each frame is evaluated for energy content, and if total energy content falls above a certain threshold, the frame is taken as a talkspurt. Here we consider 1 frame to be 22.5 milliseconds. The length of the talkspurt is described by a geometric distribution.

Silence Period:

A silence period can occur between syllables and between words, as well as between phrases and sentences. Silence gap detection is accomplished by dividing the speech waveform into fixed–size frames. Each frame is evaluated for energy content, and if total energy content falls below a certain threshold, the frame is taken as a silence. Here we consider 1 frame to be 22.5 milliseconds.

B. Data Model:

Poisson arrival is most often used to characterize random arrival of the data packets at the node. It can also be expressed by exponential inter–arrival time. The system model considered here is discrete. The discrete geometric distribution is the closest fit to the exponential distribution. Thus the geometric distribution for inter–arrival time of data packets is considered. The data packet length is 1 frame (22.5 milliseconds). The inter–arrival is an integral multiple of frame periods.

Longer data packets (n frames long) can be represented as n packets with an inter–arrival time of 1 frame.

2.1.2 ASSUMPTIONS:

* All variables are measured using a frame as an unit.
* A frame clock is the heart of the simulation.
* A frame length is 22.5 millisecond long.
* The voice talkspurt length (in terms of frame length) is geometrically distributed with average length of 7.54 frames [4].
* Talkspurt is an integral multiple of frame length.
* The silence duration (in terms of frame length) has weighted geometric distribution [4]. An average silence duration is 5.95 frames long.
* Silence is an integral multiple of frame lengths.
* An inter–arrival time between two data packets is assumed to be geometrically distributed. The parameter RHO is equal to 1.0 – (Ar. rate * .0225).
* All data packets are one frame long.
* The detector/controller is assumed to be ideal such that the voice detection is instantaneous.
* Buffer capacity for data packets is infinite.
* Probability of having zero inter–arrival time (simultaneous arrival) is zero.

* The length of one talkspurt and silence duration is independent of another talkspurt or silence duration.
* Talkspurt and silence duration are always alternated.
* Average talkspurt or silence rate is 1/(Ave. talkspurt time + Ave. silence duration) = 1/ .0225*(7.54+5.95) = 3.29 /sec.
* Channel capacity is fixed C bits/second.
* The service time of data packets depends on length of the packet, since data packet length is one frame, the service time is 1 frame period long.

2.2 PROTOCOL DESCRIPTION:

A protocol for data transmission over a digital voice channel is explained here. Data packets arrives randomly and inter–arrival time follows geometric distribution. When voice is active (during talkspurt), all data packets are stored in the queue. After that talkspurt silence duration follows. During the silence period, the packets are transmitted. The packets are served on First Come First Serve (FCFS) basis. During the data packet transmission period, if any more packets arrive, they are placed in the queue and remain there until service is available. The service availability depends on average silence duration as well as data packet arrival rate. If during the silence period, there is nothing in the queue and a data packet arrives, it is transmitted immediately.

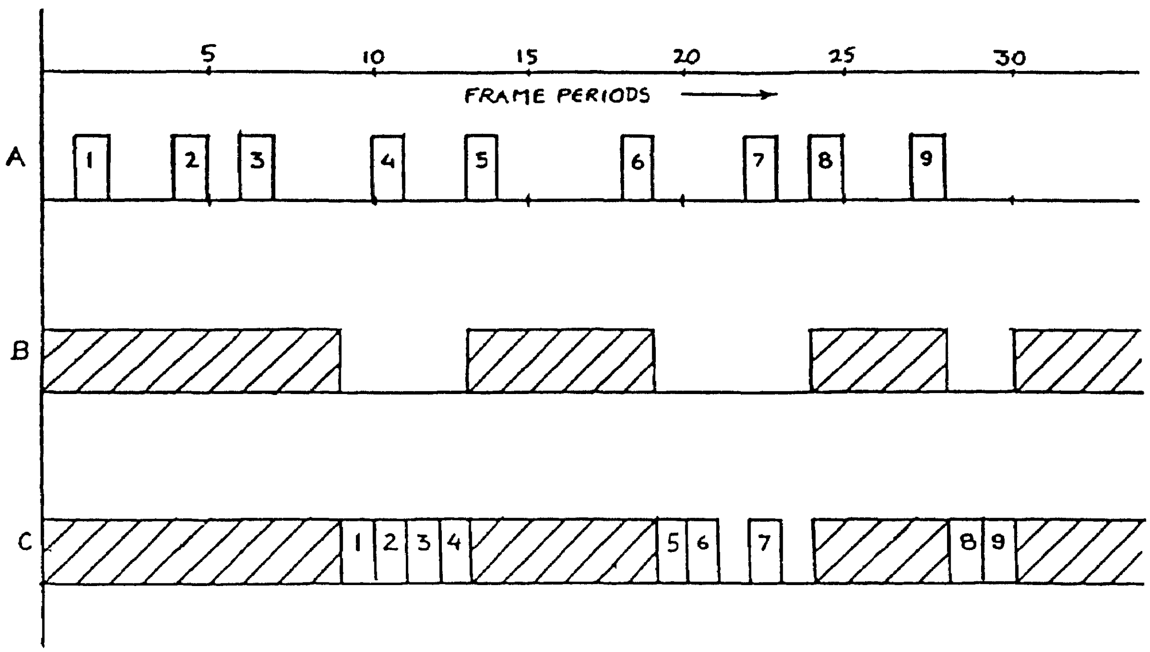

Figure 2.3 Voice/Data Integration Protocol
A) Arriving data packet B) Voice activity
C) Integration of voice and data.

Figure 2.3 above depicts the voice/data integration protocol. The first talkspurt is 9 frames long. That is followed by silence duration of 4 frames. The next talkspurt is 6 frames long followed by silence duration of 5 frames. The third talkspurt is 4 frames long followed by silence duration 2 frames long. A total of 9 data packets arrived during this period. They arrived at the end of 1st, 4th, 6th, 10th, 13th, 18th, 22nd, 24th and 27th frame. Data packets numbered 1, 2 and 3 arrived during a talkspurt so they were placed in the queue. At the end of the first talkspurt (9^{th} frame), the transmission of the queued packets began. The 1^{st}, 2^{nd}, and 3^{rd} packets were transmitted during frames 10, 11 and 12 respectively. During transmission of these three packets, another packet arrived. Since there was one frame worth of silence duration available, the 4^{th} packet was transmitted during the 13^{th} frame. The fifth data packet arrived at the beginning of the next talkspurt and sixth one during the talkspurt. Both were placed in the queue until a silence period was available at the end of the 18^{th} frame. Both packets were transmitted during the 19^{th} and 20^{th} frame leaving an empty queue. The 7^{th} data packet came in at the beginning of the 22^{nd} frame. It was transmitted immediately since the queue was empty. The eighth data packet arrived at the beginning of third talkspurt and ninth one during the talkspurt. Both were placed in the queue until a silence period was available at the end of the 27^{th} frame. Both packets were transmitted during the 28^{th} and 29^{th} frame.

CHAPTER 3

SIMULATION DESIGN AND EXPERIMENTS

This chapter discusses the simulation design used in the experiment performed. FORTRAN is used for the implementation of the model and simulation. Simulation codes are given in Appendix A. Three different process models were developed: 1. Speech activity or talkspurt length. 2. Silence duration and 3. Data packet inter–arrival time. The voice/data integration process model is generated using a protocol in conjunction with three process models.

3.1 VOICE (TALKSPURT) PROCESS GENERATION:

3.1.1 ALGORITHM

To obtain statistical data for a voice (talkspurt), an algorithm to generate random numbers with a geometric probability distribution function was developed. Theoretical values were also calculated. Collected results are: average talkspurt length in frames, and probability distribution curves for simulated and calculated values.

Derivation of talkspurt:

The measured talkspurt length can be modelled by a geometric distribution with a probability density:

$$f_x(k) = (1-r)\, r^{k-1} \qquad k = 1,2,3,4.....\text{frames} \qquad ....(1)$$

Where $f_x(k)$ is the probability that the talkspurt is k frame long and r=0.8674[4].

Random numbers of the geometric variable G:p can be computed from the set of uniformly distributed random numbers U. Before we proceed to simulate the geometric random variable, we will first look at the general algorithm for simulating X [2]. X is a random variable that takes the values: 1,2,3,.... and with

$$p_i = P_r(X=i) \qquad \text{for} \qquad i \geq 0.$$

Select a uniform random variable U (0,1).

$$\text{Set } X=0 \qquad \text{if} \qquad 0 \leq U < p_0 , \qquad \text{and}$$

$$\text{Set } X=j \qquad \text{if} \qquad \sum_{i=0}^{j-1} p_i \leq U < \sum_{i=0}^{j} p_i \qquad \text{for } j \geq 1$$

Now it is easy to see that this algorithm works by selecting a value U and observing in which probability interval U lands.

e.g take j=3

$$\text{Now check} \qquad \sum_{i=0}^{2} p_i \leq U < \sum_{i=0}^{3} p_i$$

If U lands in this range than set X=3.

Now based on this algorithm we will go to simulate the geometric random variable X, which is one of the keys to generating a talkspurt.

$$p_i = P_r(X=i) = r\ (1-r)^{i-1} \qquad \text{for} \quad i \geq 1, \quad 0 < p < 1$$

To operate the above algorithm we need successive cumulative sums of the $\{p_i\}$. Because p_i is of a simple geometric form, cumulative sums are also of a simple form. Here,

$$\sum_{i=1}^{j} p_i = \frac{p(1-(r)^j)}{1-r} = 1-r^j \qquad \text{for } j \geq 1$$

Thus the algorithm becomes:

Set $X=j$ if $1-r^{j-1} \leq U < 1-r^j$ for $j \geq 1$

$$-r^{j-1} \leq U-1 < -r^j$$

$$r^{j-1} \geq (1-U) > r^j \qquad \text{.................(2)}$$

It is intuitively clear that if U is a U (0,1) random variable, then so is (1-U) , Hence we can reduce the labor of arithmetic slightly.

$$r^{j-1} \geq U > r^j \qquad \text{...(3)}$$

The random variable X resulting from using (2) will have the same geometric distribution as the random variable resulting from using (3).

We set $X = j \geq 1$ if, and only if

$$(j-1)\log_e(r) \geq \log_e U > j \log_e(r)$$

We have $X = j$ if

$$(j-1) <= \frac{\log_e U}{\log_e(r)} < j \qquad \text{for } j >= 1 \text{ ...(4)}$$

Finally , we note that we can express (3) very simply by setting

$$X = 1 + \frac{\log_e U}{\log_e(r)} \qquad \text{...(5)}$$

Random variable X will take an integer value of the expression in eq.(5). This geometrically random variable X is used to generate the length of talkspurt.

The average talkspurt duration is 7.541 frames or 169.7 milliseconds. An expression for expected value of talkspurt duration is derived in appendix B equation (6).

3.1.2 PROGRAM

The FORTRAN source code is given in appendix A.1.

3.2 VOICE INACTIVITY (SILENCE DURATION) PROCESS GENERATION:

3.2.1 ALGORITHM

Weighted geometric distribution is used to generate the silence duration statistics. The user inputs the seed value and the amount of total numbers to be generated. Using the geometric probability density function, a theoretical value is calculated. Calculated and simulated probability distribution curves, and average silence duration length are collected

Derivation of Silence Duration:

Silence duration length can be modeled as the truncated sum of two suitable weighted geometric distributed probability density function [4]:

$$f_I\ (k) = C_1\ (1-r_1)\ r_1^{k-1} + C_2\ (1-r_2)\ r_2^{k-1} \qquad k = 1,2,3,\ldots \text{ frames } \ldots(6)$$

As we have seen in a previous derivation, the successive cumulative sum of

$\{p_i\} = 1-r^j$ for $j \geq 1$

therefore,

$$\sum_{k=1}^{j} f_i(k) = C1\ (1-r_1^{j-1}) + C2\ (1-r_2^j)$$

Set X=j if $C_1\ (1-r_1^{j-1}) + C_2\ (1-r_2^{j-1}) \leq U < C_1\ (1-r_1^j) + C_2\ (1-r_2^j)$....(7)

Now, by generating the uniform random number U, and observing which probability interval U lands in, the length of the silence duration is generated. The average silence duration is 6.659 frames or 149.8 milliseconds. Refer to appendix B for Expected value derivation.

3.2.2 PROGRAM

The FORTRAN source code is given in appendix A.2.

3.3 DATA PACKET ARRIVAL PROCESS GENERATION:

3.3.1 ALGORITHM

Geometric probability distribution is used to find inter–arrival time. The arrival rate is a parameter. An algorithm is developed to generate geometrically distributed random numbers using equation (5). It computes theoretical as well as simulated probability distribution for four different arrival rates (4,8,12,16).

3.3.3 PROGRAM

The FORTRAN source code is given in appendix A.3.

3.4 VOICE/DATA INTEGRATION STATISTICS GENERATION:

3.4.1 FLOWCHART

The voice data integration simulation flowchart is given in figure 3.1(a), 3.1(b) and 3.1(c).

List of variable used in flowchart and simulation.

IS : Seed value to generate Uniform Random Number

N : Total number of data packets generated (counter)

Q : Total number of data packets in Queue

TV : Talkspurt length

TS : Silence duration

TT : Total TV + TS

TQS : TV + Q

TTV : TT + TV

TA(n) : Arrival time of nth data packets (in terms of frame number)

TD(n) : Departure time of nth data packets (in terms of frame number)

V : Counter for total number of talkspurt / silence duration.

TMAX : Maximum simulation time

LAMBDA : Data packets arrival rate

3.4.2 ALGORITHM

This simulation program provides flexibility to choose the desired value for total simulation time and data packet arrival rate. It prompts for seed value simulation time in seconds and data packet arrival rate in packets/second. Actual simulation time is expressed as an integer multiple of 10000 frames, i.e. 10000 seconds is equals to 444,444 frames. The actual simulation time will be 450,000 frames. Data packets are generated by calling the subroutine Arrival(). The total arrival time is the sum of inter–arrival. The program stops and calculates the final results only if total arrival time is greater than or equal to maximum simulation time. The subroutines Voice() and Silence() are called to generate talkspurt and silence

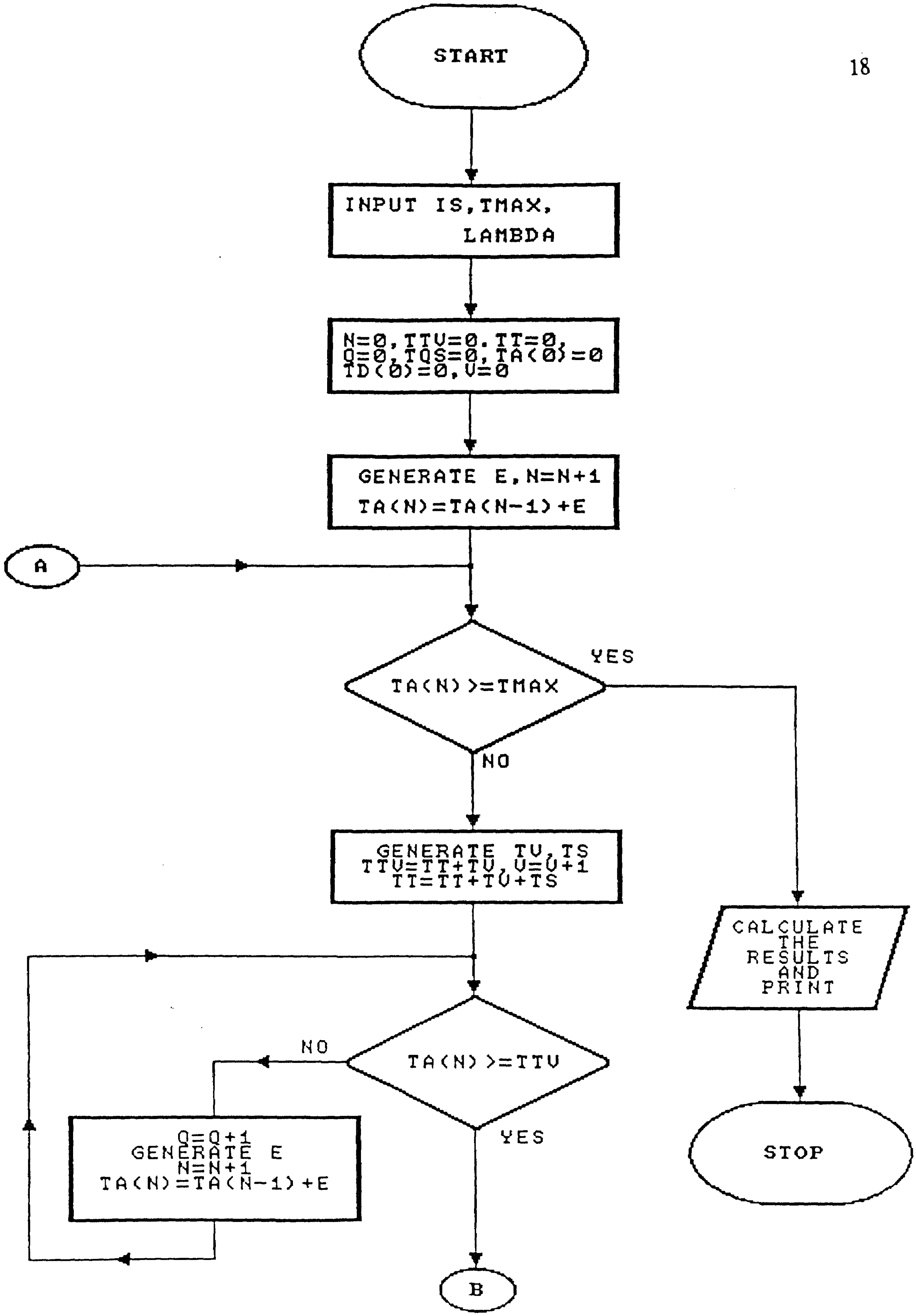

Figure 3.1(a) Voice/Data Integration Flowchart

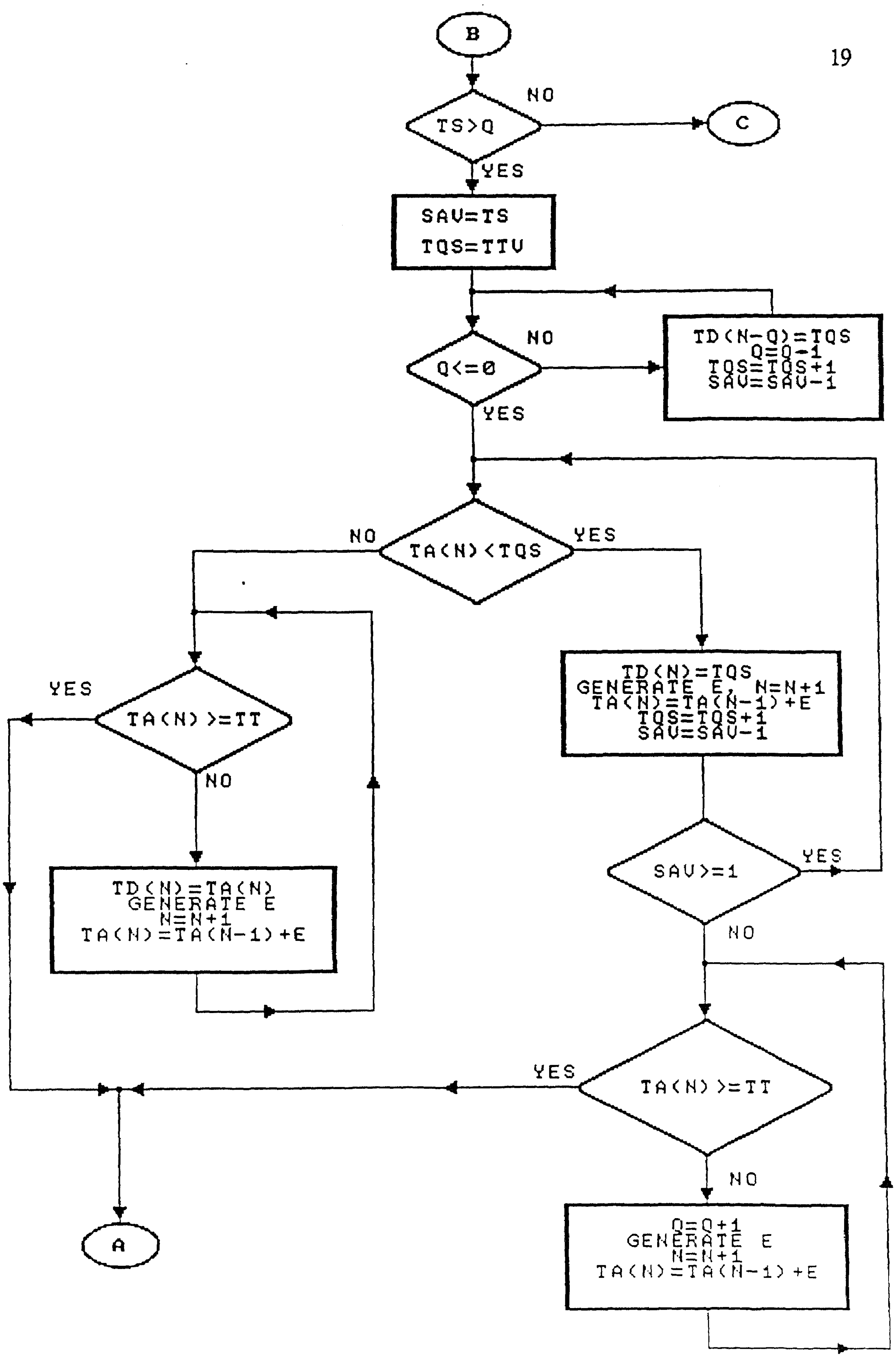

Figure 3.1(b) Voice/Data Integration Flowchart

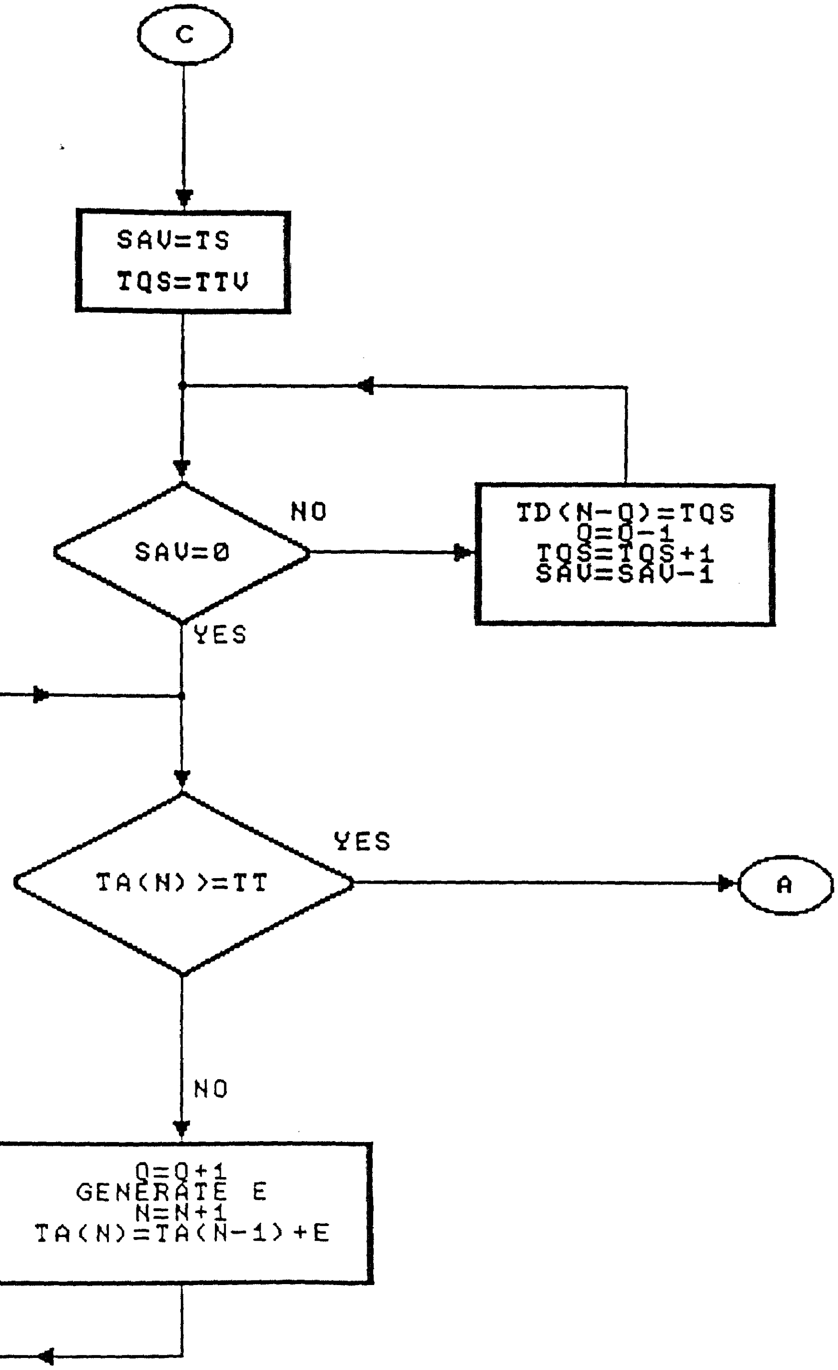

Figure 3.1(c) Voice/Data Integration Flowchart

duration. The arrival time of a packet is checked against talkspurt. If it has arrived during the talkspurt than it cannot be transmitted until the silence duration and therefore it is placed in the queue. All data packets arriving during talkspurt are placed in the queue and served in a First Come First Serve (FCFS) discipline during the a silence period. If a data packet arrives during silence period and if no data packet is waiting in queue, then that data packet is immediately served.

The primary statistical measurements, collected at the end of the simulation are average packet inter–arrival time, average talkspurt rate, probability of zero waiting time, and average data packet delay for different arrival rates.

3.4.3 PROGRAM

The FORTRAN source code is given in Appendix A.4.

CHAPTER 4

SIMULATION RESULTS

This chapter presents simulation results of various stochiastic processes including voice/data integration service. A comparison is made between simulation and theoretical values. Experiments for voice, silence duration and data packet arrival rate were run for 100,000 samples.

4.1 VOICE (TALKSPURT) SIMULATION RESULT

The voice (talkspurt) statistics, theoretical, and simulation results are shown in figure 4.1(a) and 4.1(b). Figure 4.1(a) presents the talkspurt length versus its corresponding probability of occurrence on a log scale. Figure 4.1(b) shows the same on a linear scale. The simulation curves are pretty much the same as the theoretical curves. A calculated average talkspurt length is 7.541 frames, where the simulated average talkspurt length is 7.547 frames.

4.2 VOICE INACTIVITY (SILENCE DURATION) SIMULATION RESULT

Silence duration statistics are presented in Figure 4.2(a) and 4.2(b), on a log scale and a linear scale respectively. Calculated and simulated values are nearly equal. This proves the validity of simulated silence duration statistics. As silence duration increases, the probability of silence duration (abscissa) exponentially decreases.

The value of simulated average silence duration is 5.953 frames while the calculated expected value is 6.659 frames.

One can see from figure 4.2(a) that the slope of the curve is different at lower values (< 8 frames) of silence duration and higher values (> 20 frames) of silence duration. Silence durations of less than 8 frames represent a silence periods between syllables and words while larger durations represent silence periods between phrases and sentences.

4.3 DATA PACKET ARRIVAL SIMULATION RESULTS

Results of the experiment with data packet arrival rates 4, 8, 12, and 16 packets/sec. are shown in figure 4.3 through figure 4.6. It is clearly seen from the figures that as arrival rate increases, the slope (negative) of probability versus inter–arrival time increases, which is expected. As arrival rate increase, packets are generated faster, therefore the time between two adjacent packets obviously decreases. For example, take a look at figure 4.6. We notice that at an arrival rate of 16 packets/sec, the probability of having the distance greater than 47 frames between the two adjacent data packets (inter–arrival time) is zero. Again, theoretical and simulation curves match very well.

Theoretical expected values of inter–arrival time are 11.11, 5.55, 3.709 and 2.77 frames for arrival rate of 4, 8, 12, 16 packets/second respectively. Corresponding values of simulated inter–arrival times are 11.12, 5.56, 3.707 and 2.78 frames.

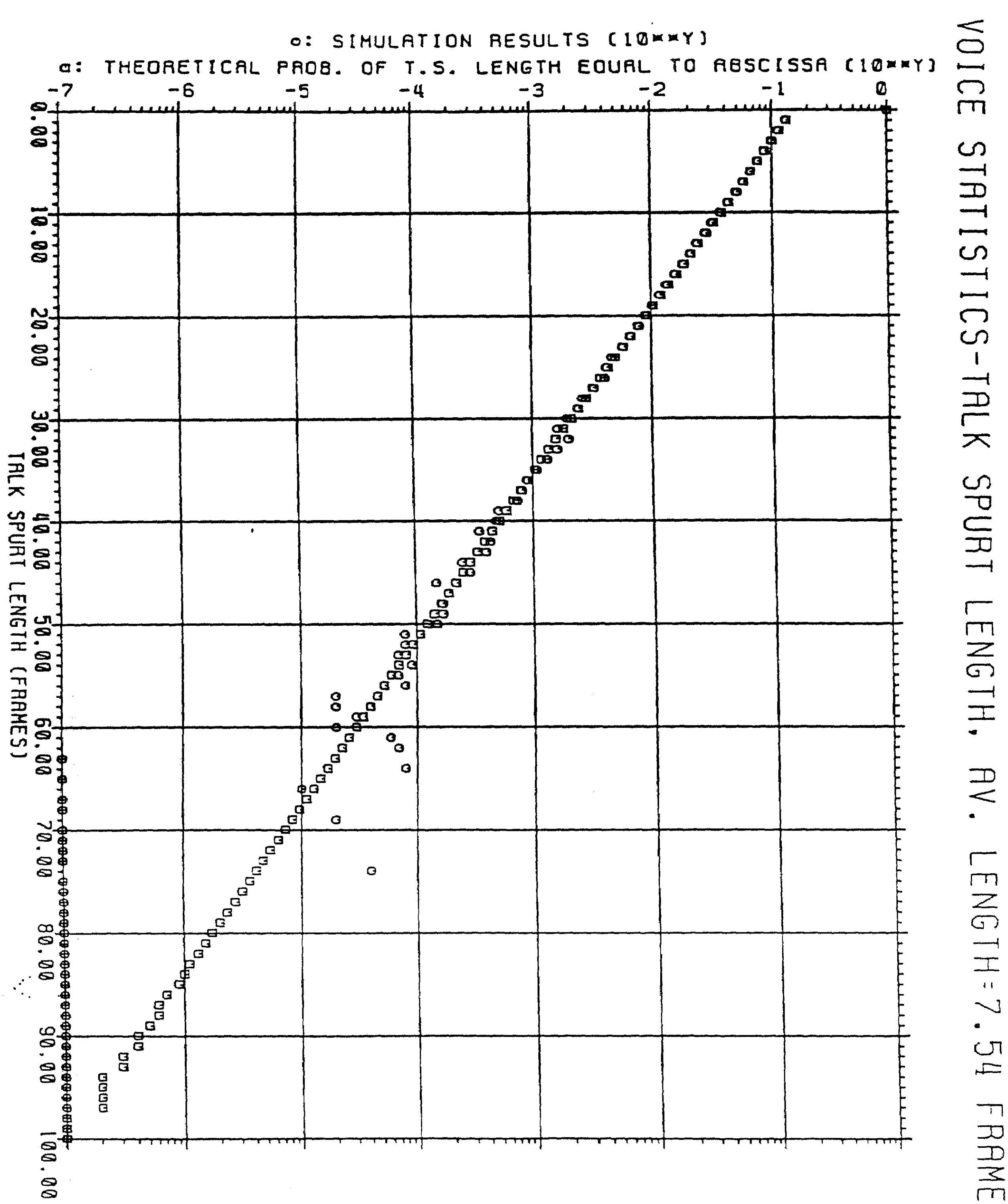

Figure 4.1(a) Voice Statistics (log scale)

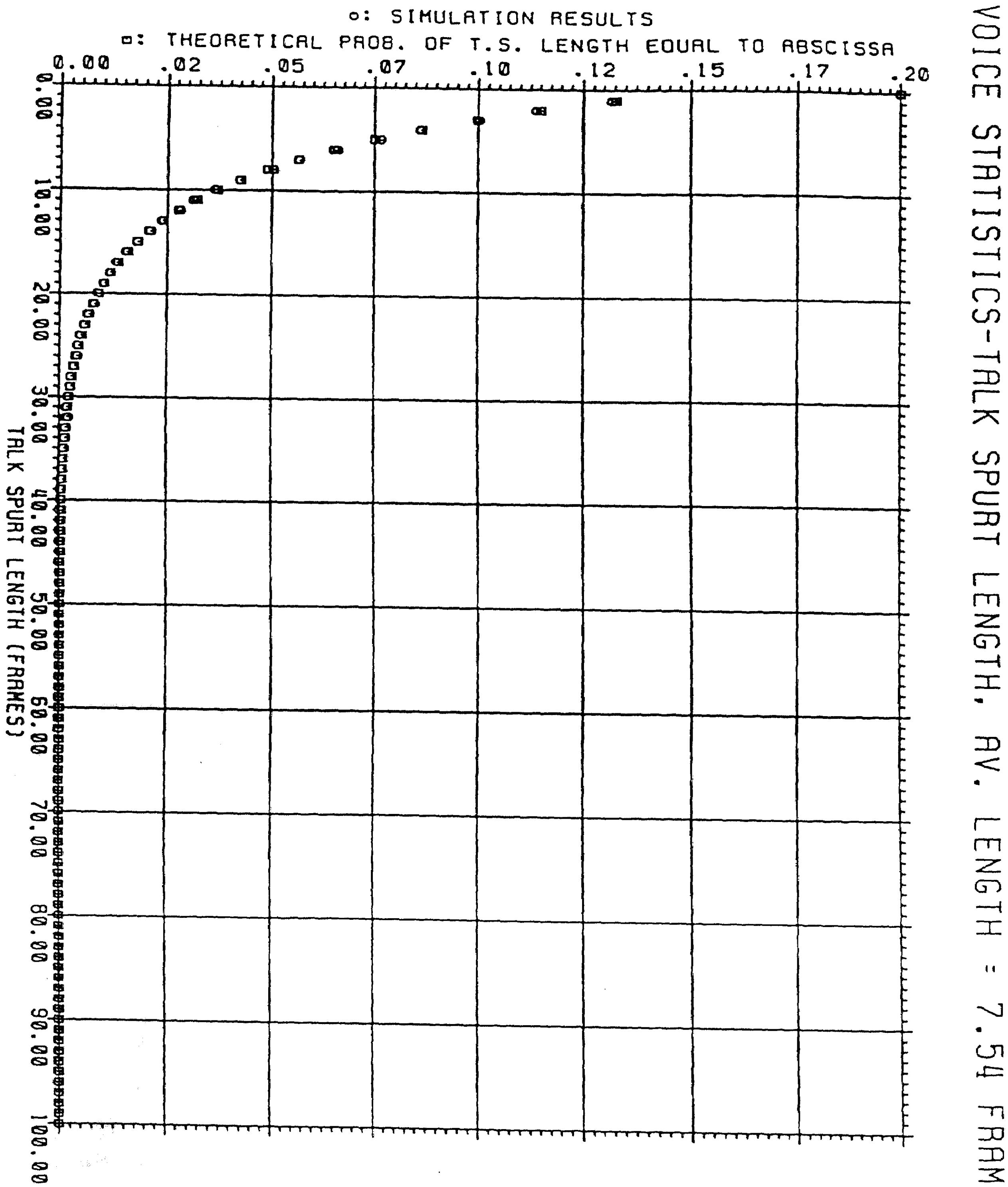

Figure 4.1(b) Voice Statistics (linear scale)

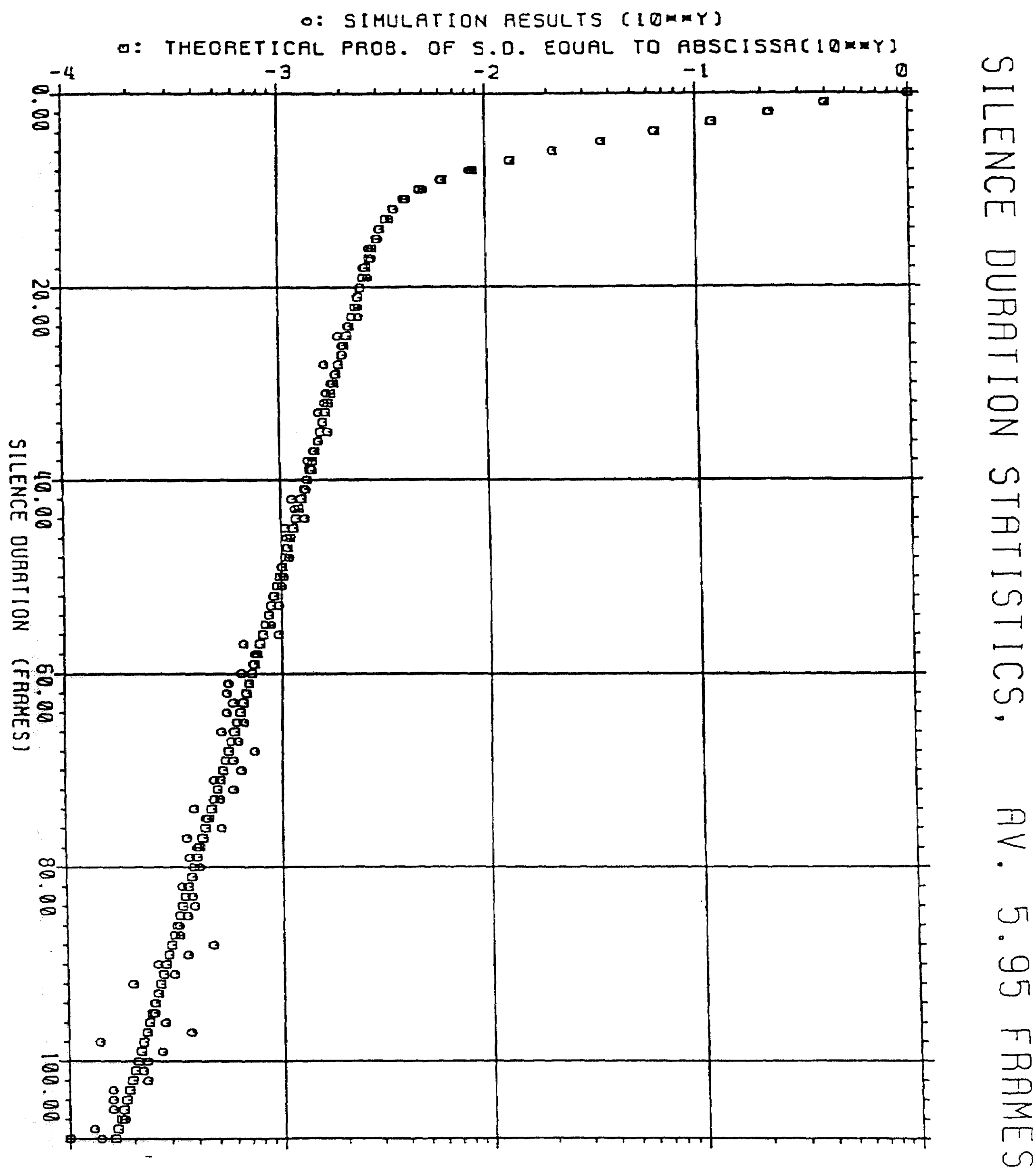

Figure 4.2(a) Silence Duration Statistics (log scale)

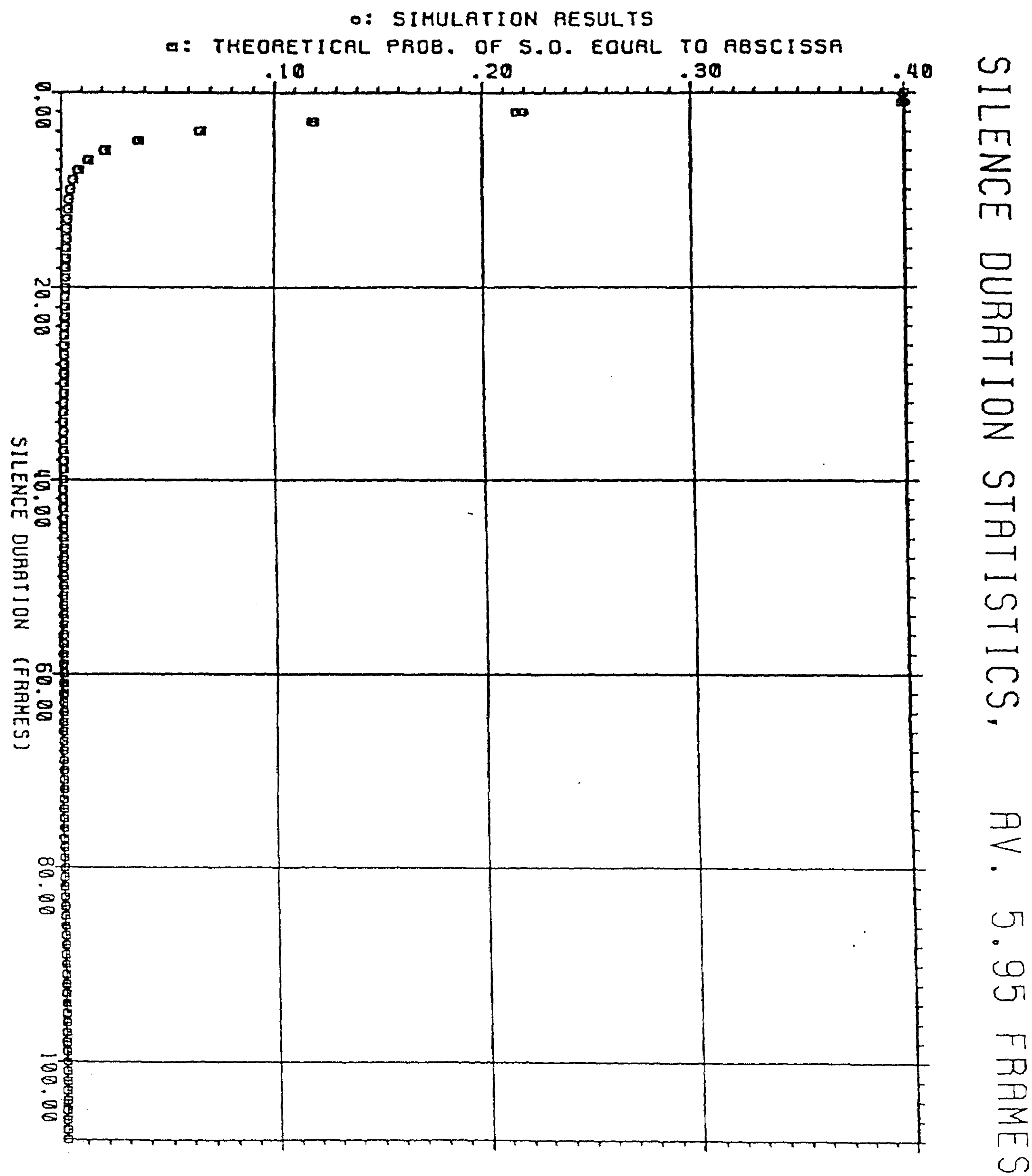

Figure 4.2(b) Silence Duration Statistics (linear scale)

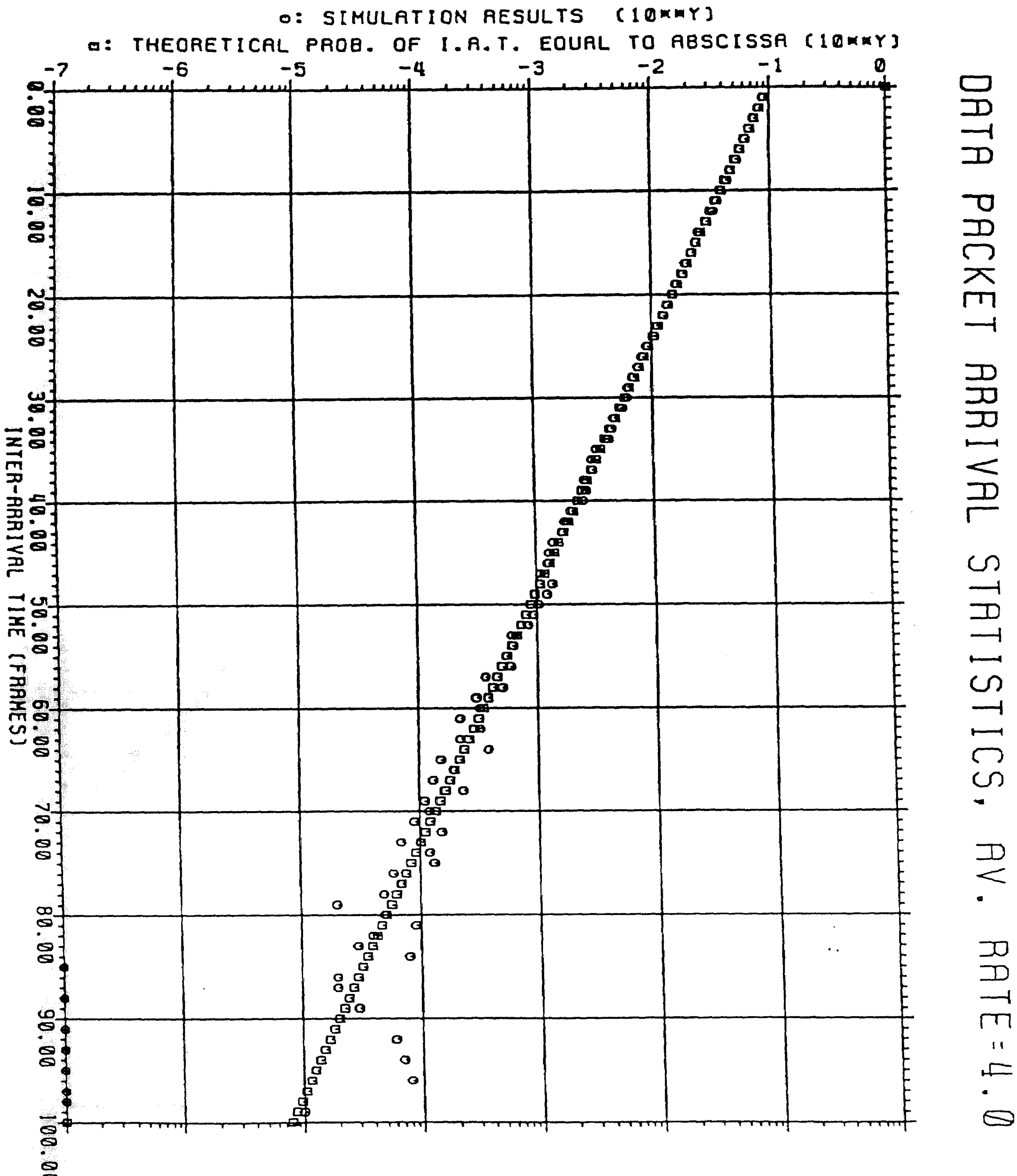

Figure 4.3 Data Packet Arrival Statistics at rate 4 packets/sec.

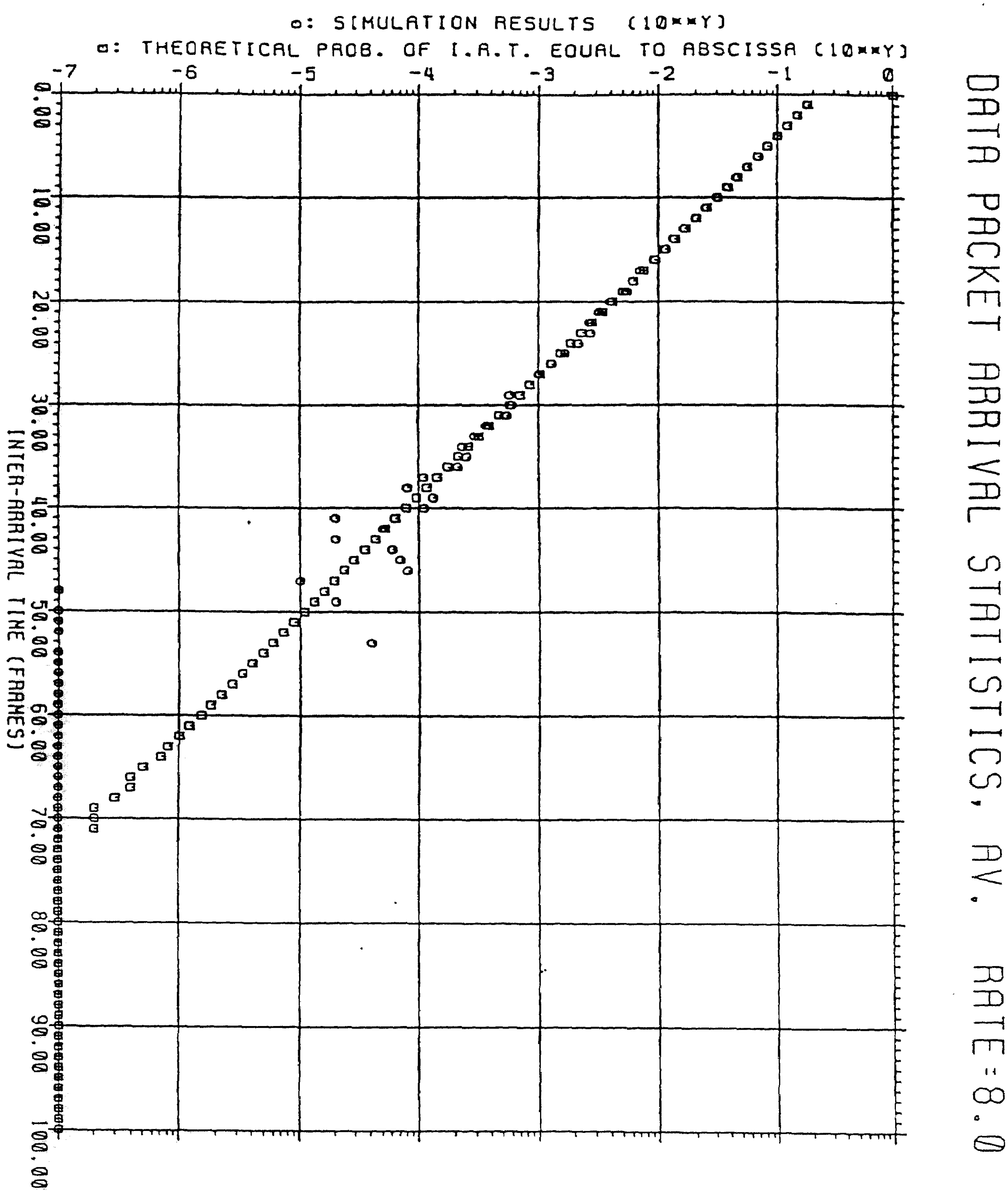

Figure 4.4 Data Packet Arrival Statistics at rate 8 packets/sec.

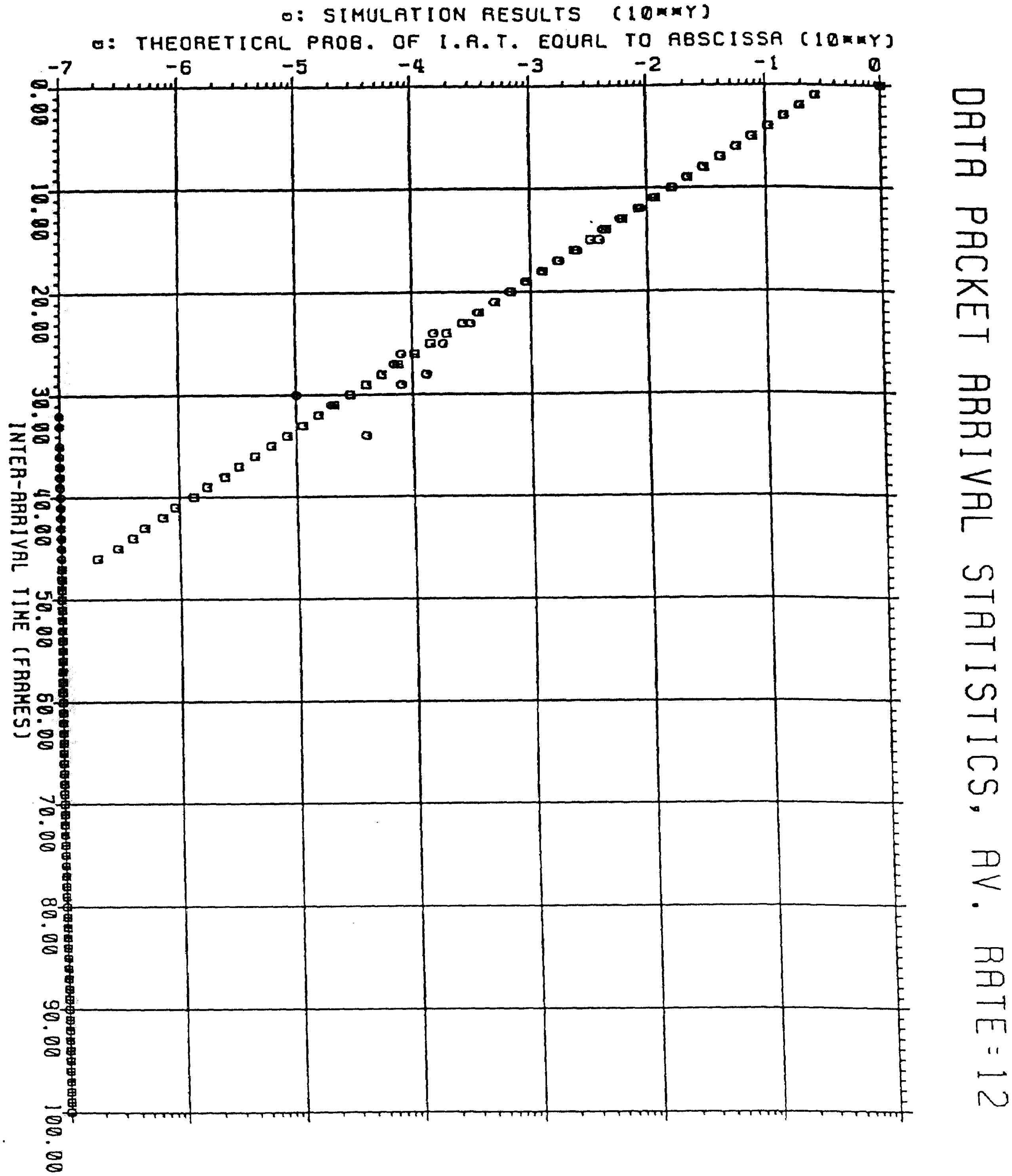

Figure 4.5 Data Packet Arrival Statistics at rate 12 packets/sec.

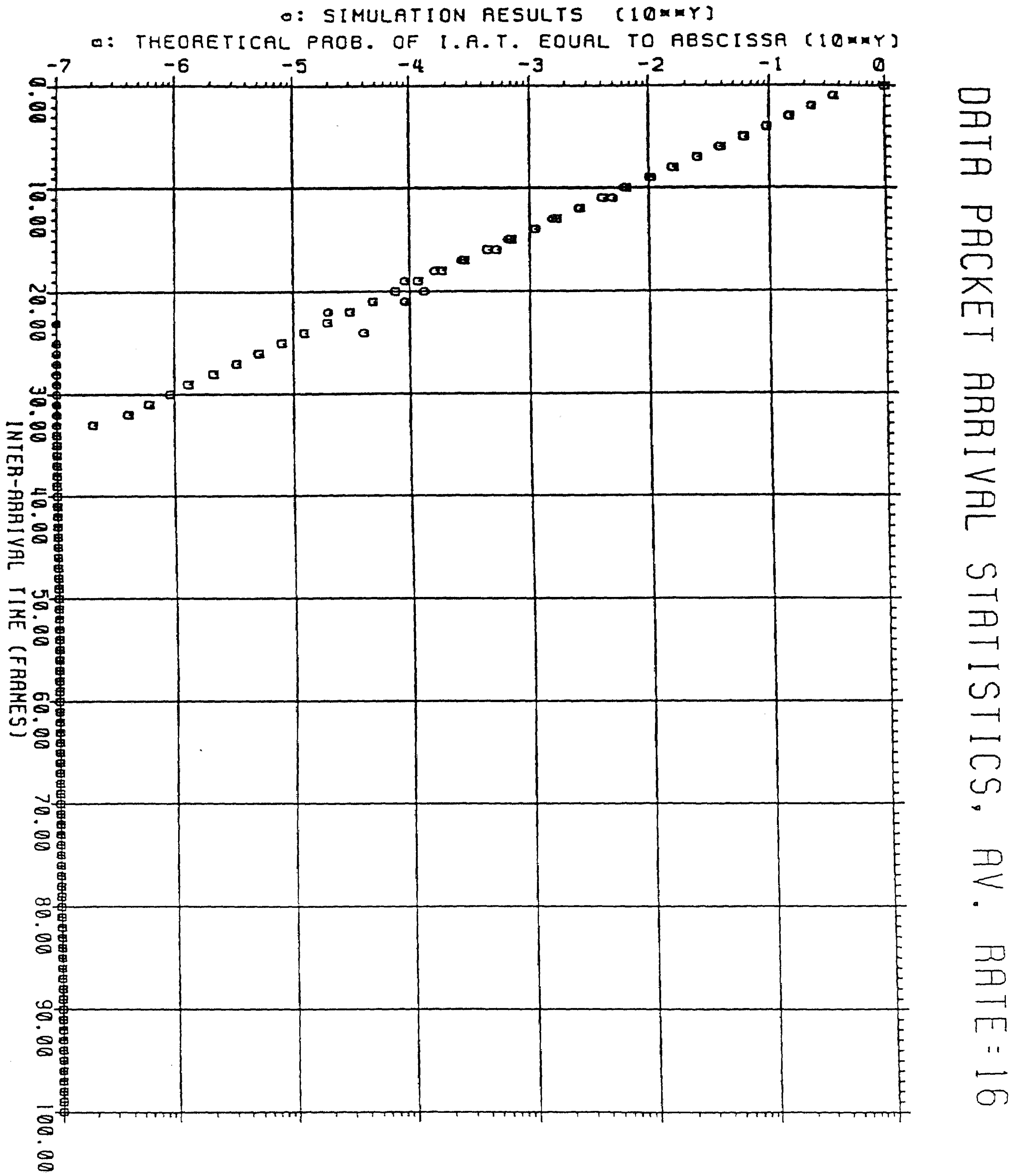

Figure 4.6 Data Packet Arrival Statistics at rate 16 packets/sec.

4.4 VOICE/DATA INTEGRATION SIMULATION RESULTS

The voice/data integration experiments were ran for 10,000 seconds (approximately 450,000 frames), and for various data arrival rate. Data arrival rates from 1 packet/second to 20 packets/second were used for simulation purpose. The following statistics were obtained for each case.

1. Total number of data packets generated.
2. Total number of data packets serviced.
3. Data packet arrival rate as per simulation.
4. Packet inter–arrival time (sec.).
5. Average talkspurt/silence rate (per sec.)
6. Probability of zero wait time.
7. Average data packet delay (frames).
8. Probability of wait time (0–200 frames).

The result of the sample run of this experiment is presented in appendix A.4. The seed value was 16807 for all experiments. Theoretical average talkspurt rate/silence rate is given by 1/(talkspurt + silence duration) = 3.13 /second. The simulated result is of 3.29 /second.

4.5 AVERAGE DATA PACKET DELAY VS. ARRIVAL RATE

The prime results of simulation are based on the above statistics. Simulation results of average data packet delay with different data packet arrival rates are shown in Table 4.1. Data packet delay is the time each packet spent waiting before being serviced. This table shows the results for arrival rate from 1 packet/sec. to 20 packets/second. We can see, from the table as well as from figure 4.7 that average data packet delay increases with the arrival rate. Figure 4.7 shows that during the arrival rate 1 to 14 packets/second, average delay increases steadily. For an arrival rate of 15 packets/second and above, the average delay increases sharply, since it approaches data packet transmission capacity.

As the arrival rate increases, a greater amount of data packets come into the system. The service of these packets depends upon a silence duration statistic that has fixed capacity. The theoretical capacity for data packet transmission is: (Average silence duration)/[frame time*(Average talkspurt + Average silence duration)] = 6.659/[.0225*(6.659+7.541)] = 20.8 packets/second. The simulated data transmission capacity is: = 5.953/[.0225*(5.953+7.547)] = 19.6 packets/second. Therefore, all data packets cannot be served on their arrival, so they are placed in a queue. The packets in the queue wait until the silence duration occurs. As figure 4.7 states, when the arrival rate increases, the queue will increase and as well as the average data packet delay.

4.6 RATIO OF AVERAGE ARRIVAL RATE TO AVERAGE DELAY

Table 4.2 presents the data used to find the optimum arrival rate. The ratio of average arrival rate to average delay is considered as one of the performance measures. The performance curve is shown in figure 4.8. From this curve, optimum data packet arrival is 6 packets/second. There is not much performance degradation

TABLE : 4.1

VOICE/DATA INTEGRATION STATISTICS

SEED VALUE = 16807 TOTAL SIM. TIME (SEC) = 10000.00
AVERAGE TALK SPURT RATE (PER SEC) = 3.29

AVERAGE DATA PACKET ARRIVAL RATE (PACKETS/SEC)	AVERAGE DATA PACKET DELAY (FRAMES)
1.000000	4.656875
2.000000	5.154598
3.000000	5.783758
4.000000	6.493093
5.000000	7.396003
6.000000	8.433848
7.000000	9.964211
8.000000	11.48726
9.000000	13.80577
10.00000	16.44546
11.00000	19.84325
12.00000	24.65047
13.00000	29.90484
14.00000	36.81536
15.00000	47.94444
16.00000	59.00859
17.00000	83.01635
18.00000	133.3712
19.00000	211.0172
20.00000	329.2377

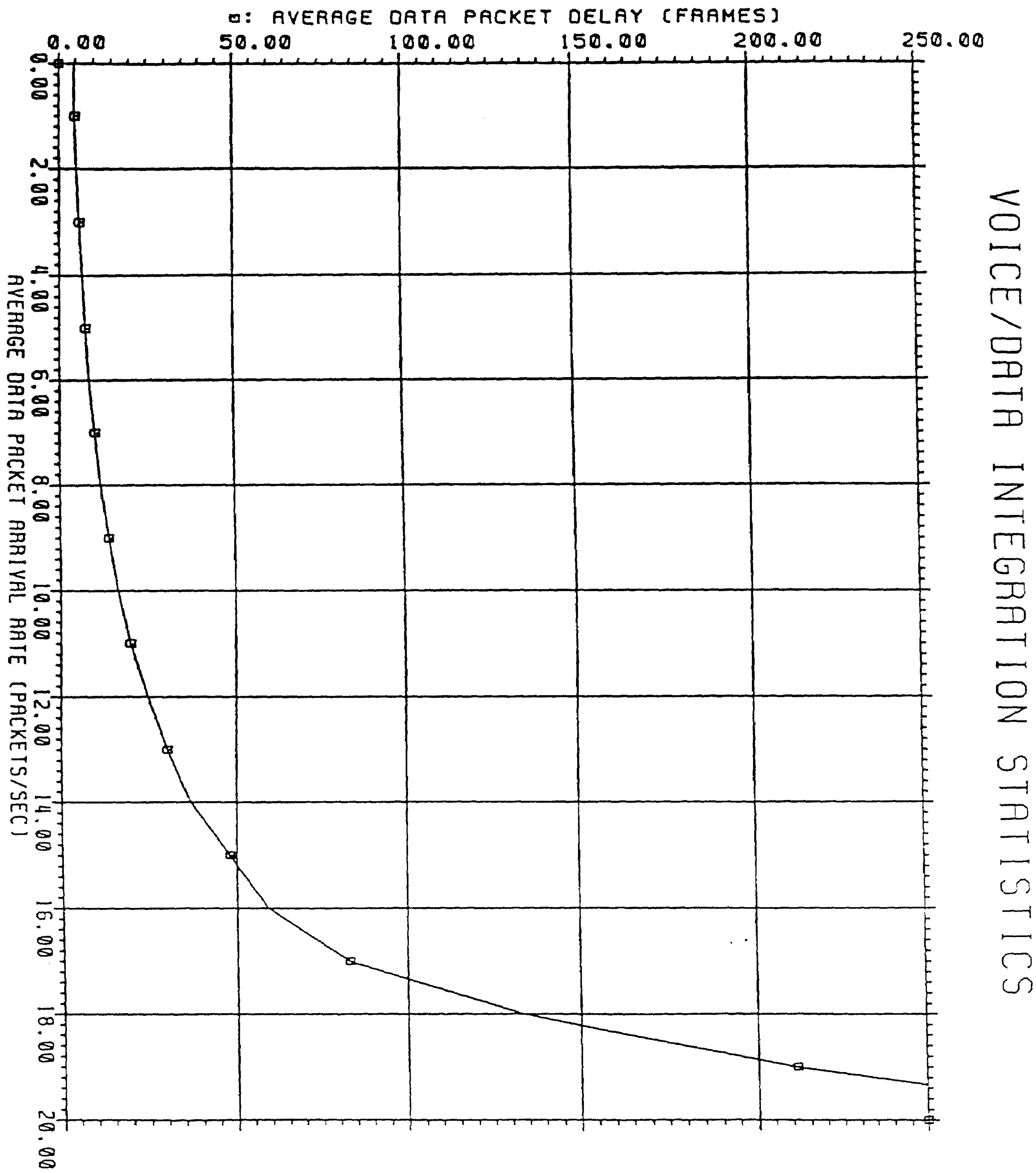

Figure 4.7 Voice/Data Integration Statistics

TABLE: 4.2

VOICE/DATA INTEGRATION STATISTICS

OPTIMUM ARRIVAL RATE = 6.000000
MAX. RATIO OF AR. RATE TO DELAY = 0.7114190

ARRIVAL RATE (PACKETS/SEC)	RATIO OF AR.RATE TO DELAY
1	0.2147363
2	0.3880031
3	0.5186939
4	0.6160392
5	0.6760408
6	0.7114190
7	0.7025142
8	0.6964237
9	0.6519014
10	0.6080706
11	0.5543447
12	0.4868061
13	0.4347122
14	0.3802761
15	0.3128622
16	0.2711470
17	0.2047789
18	0.1349617
19	0.0900401
20	0.0607464

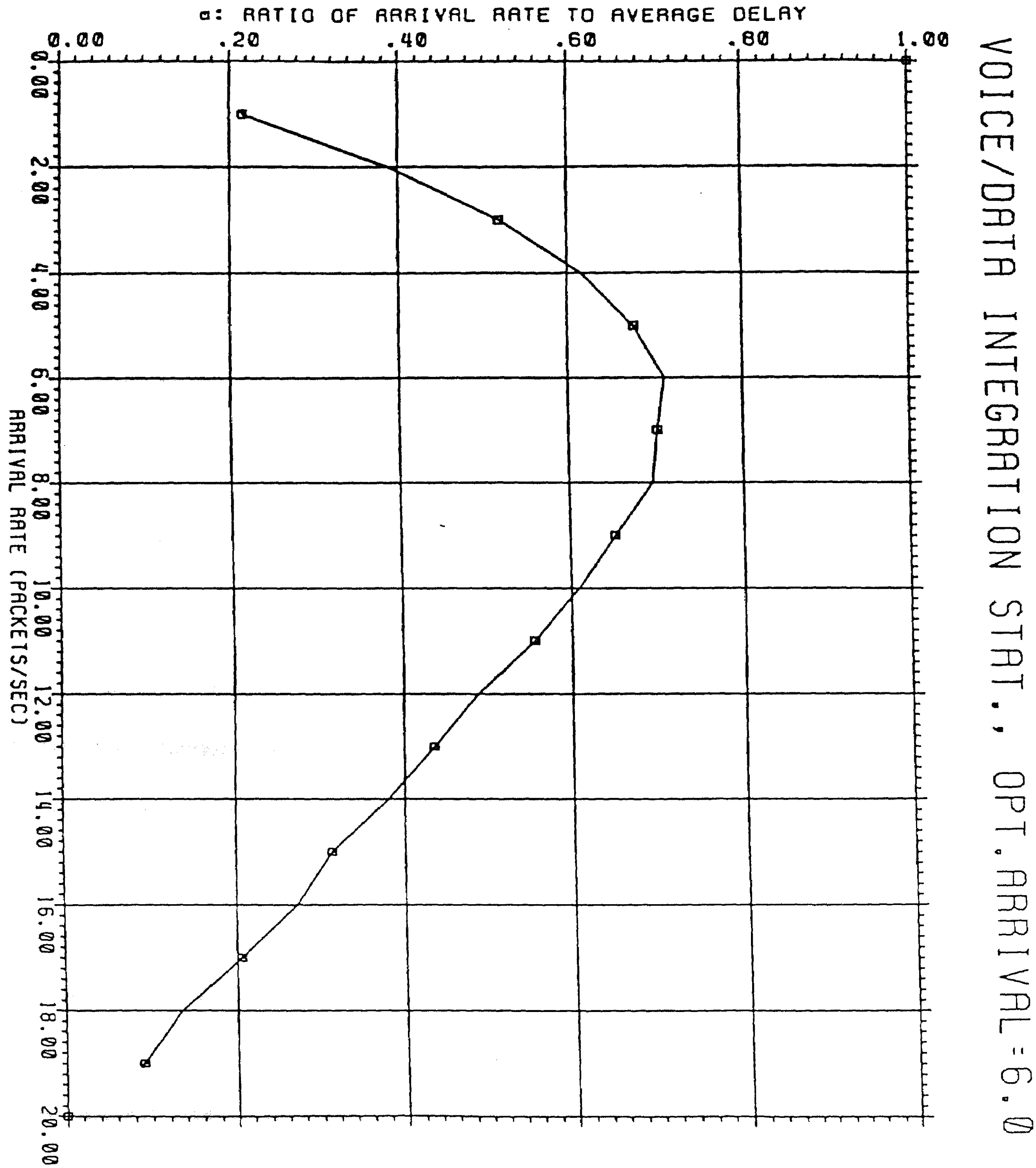

Figure 4.8 Optimum Arrival rate

between 5 and 8 packets/second. The curve shows performance degradation with an arrival rate higher than 8 packets/second and less than 5 packets/second. Maximum system performance can be achieved with an arrival rate of 6 packets/second.

4.7 PROBABILITY OF WAIT TIME VS. ARRIVAL RATE

Results of probability delay statistics with four different arrival rates are presented in figures 4.9 to 4.12. Comparing these figures, it is obvious that the slope of the probability distribution flattens out as data packet arrival rate increases. That means the probability of any given delay increases with arrival rate. The probability of having a data packet delay of 50 frames has probability of 0.000035, 0.0013, 0.0035, and 0.0053 for arrival rates 4, 8, 12 and 16 packets/second respectively. Thus, average data packet delay also increases with arrival rate.

Average delay is equal to 6.44 frames at a rate of 4 packets/second. As arrival rate increases to 16 packets/second, then average delay jumps to 59 frames. Now, we can see that as arrival rate increases the probability of higher data packet delay also increases.

4.8 PROBABILITY OF ZERO WAIT TIME VS. ARRIVAL RATE

Table 4.3 shows voice and data integration statistics for zero waiting time. Zero waiting time means that an incoming packet is serviced immediately without waiting in the queue. This table and figure 4.13 shows the probability of zero waiting time decreases with increasing arrival rate. This means that the data packet will have to wait in queue for service. Chances of immediate service are reduced as arrival rate increases.

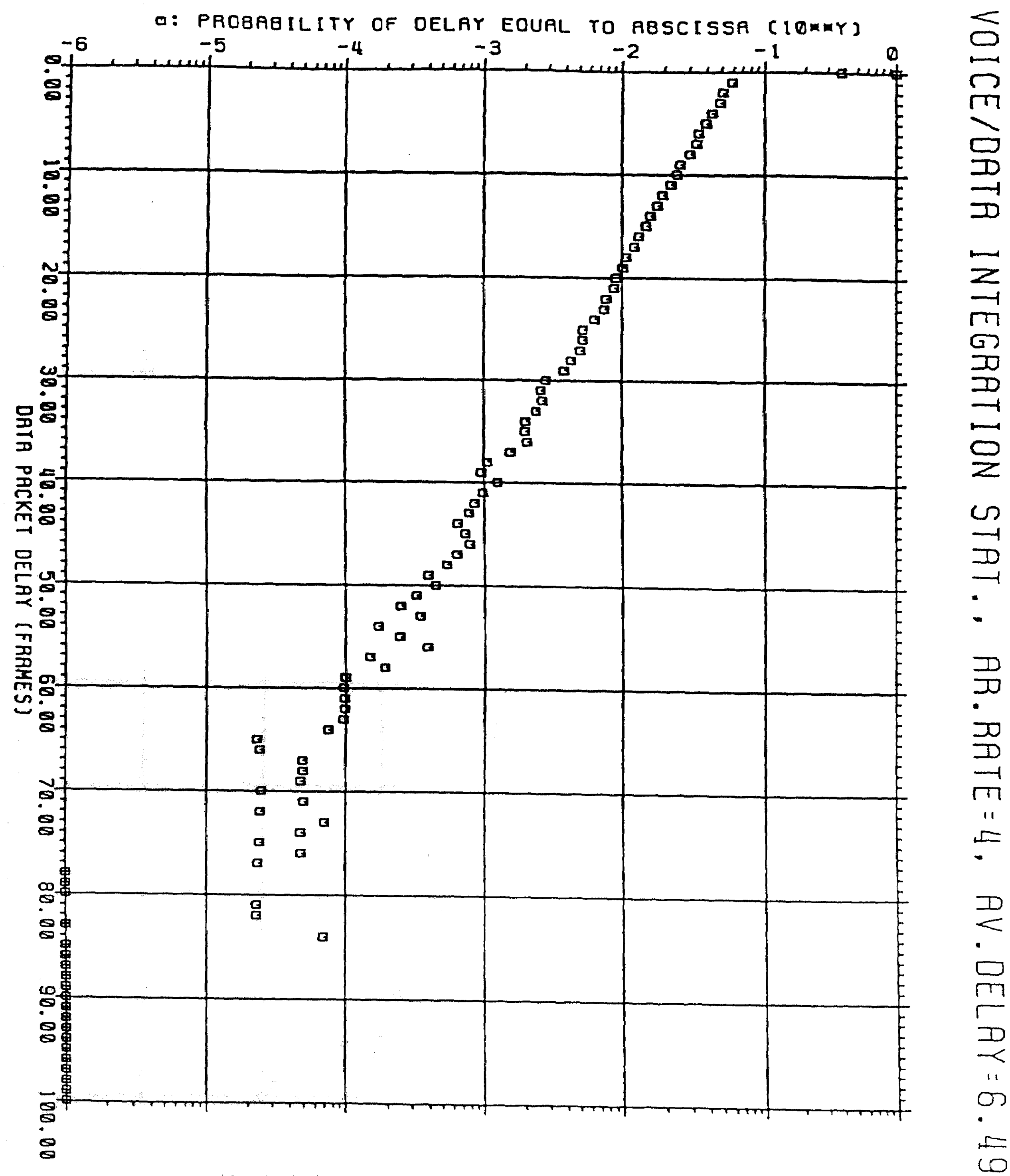

Figure 4.9 Probability of wait time at rate 4 packets/sec.

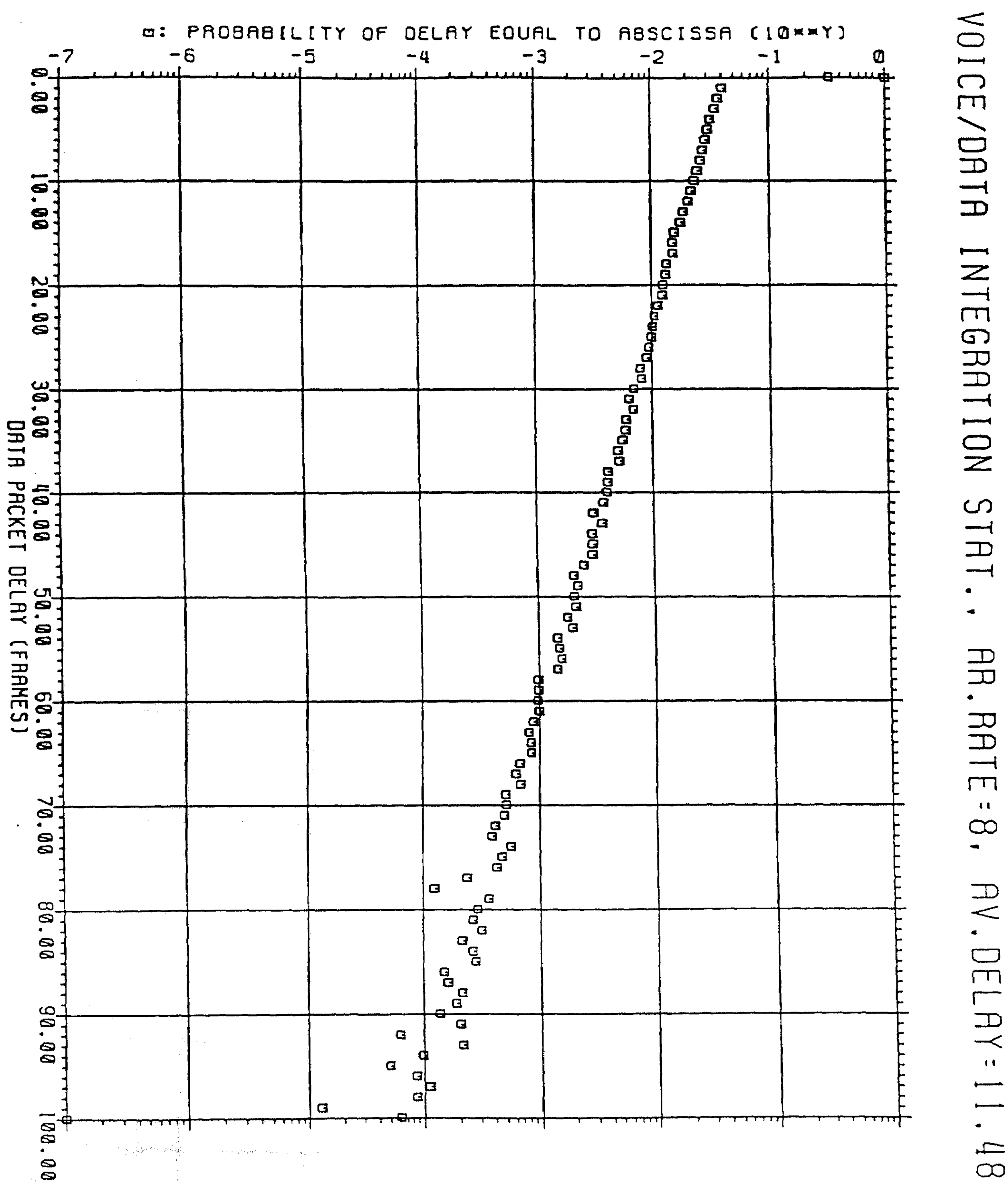

Figure 4.10 Probability of wait time at rate 8 packets/sec.

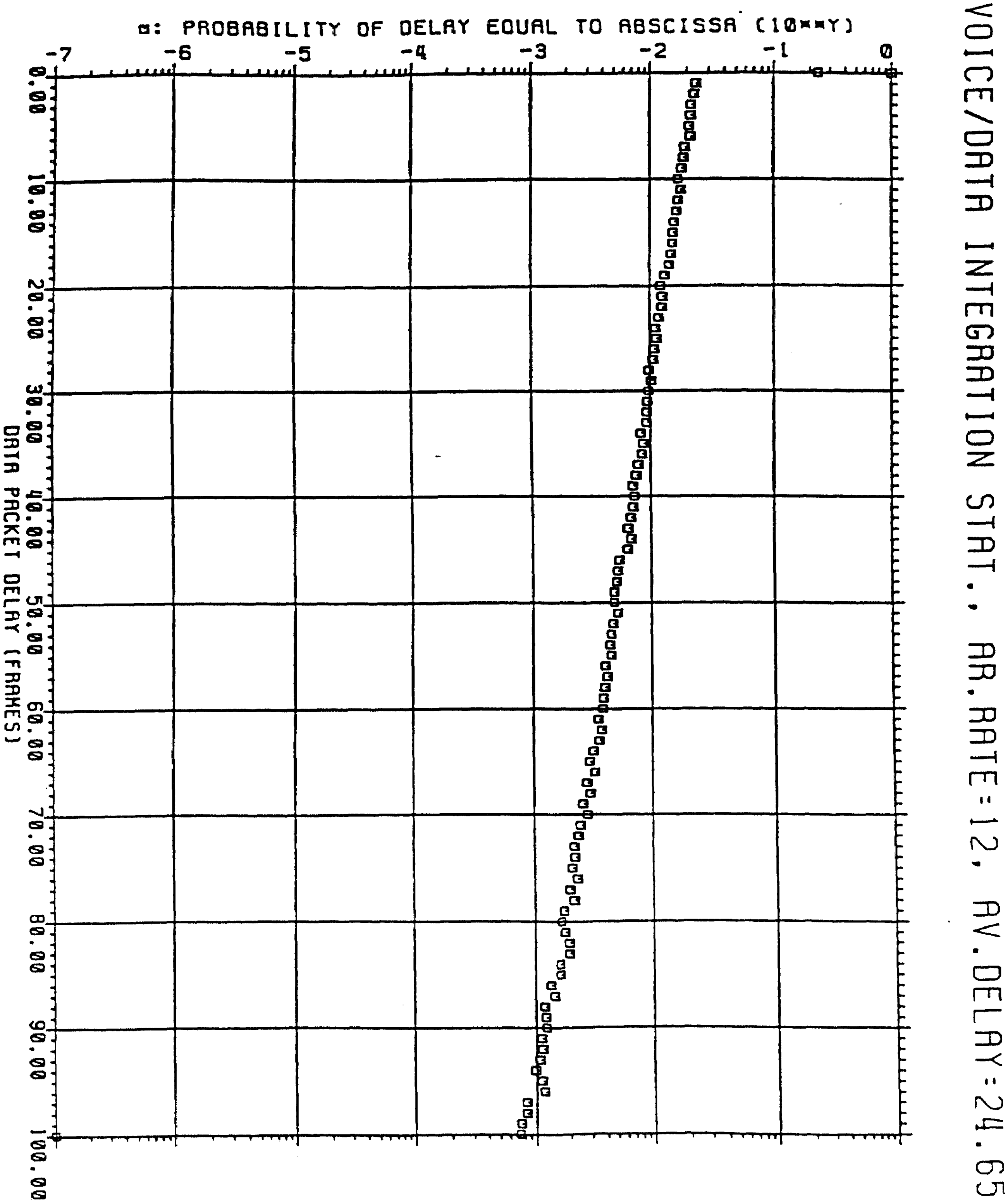

Figure 4.11 Probability of wait time at rate 12 packets/sec.

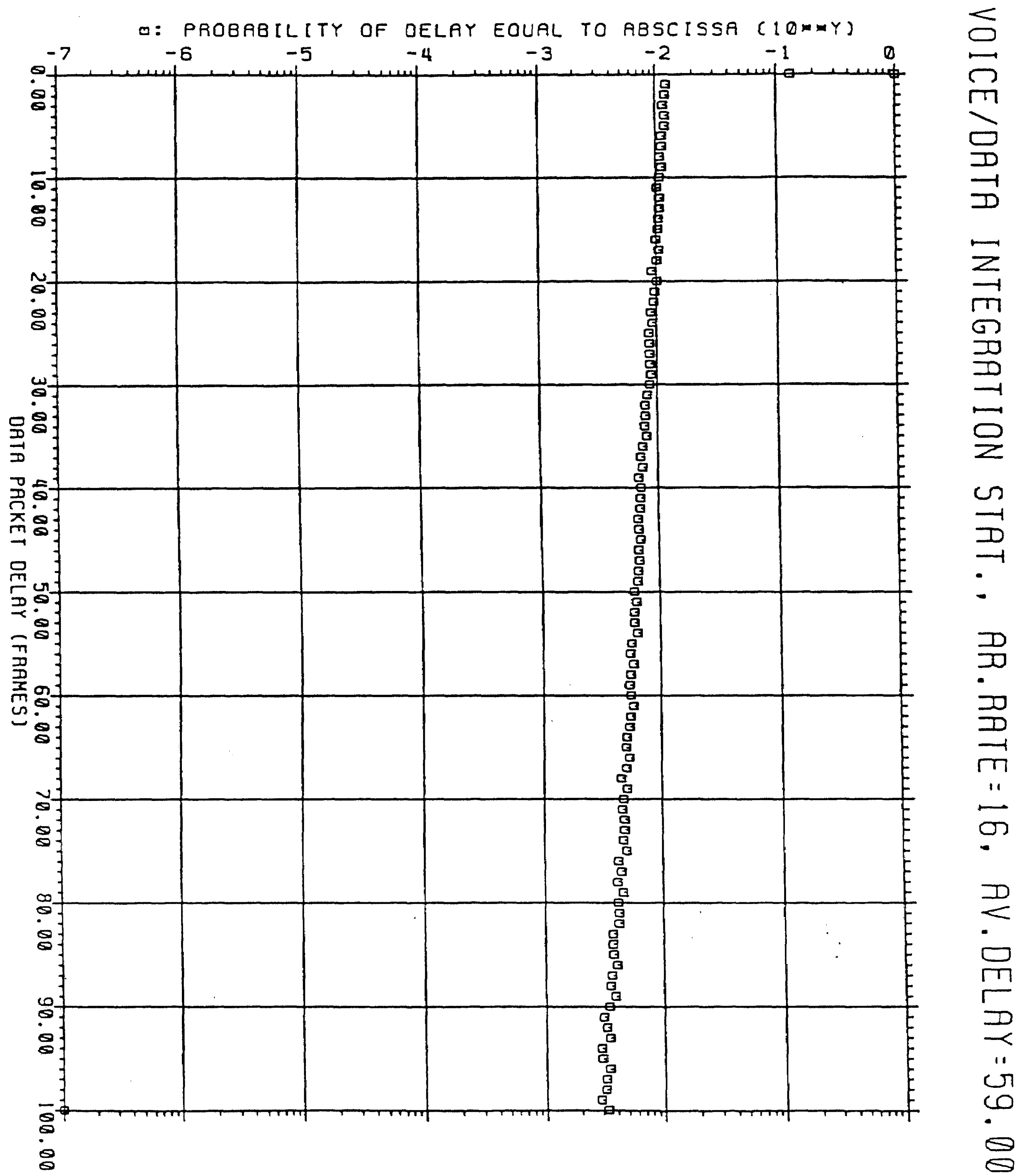

Figure 4.12 Probability of wait time at rate 16 packets/sec.

TABLE : 4.3

VOICE/DATA INTEGRATION STATISTICS

SEED VALUE = 16807 TOTAL SIM. TIME (SEC) = 10000.00
AVERAGE TALK SPURT RATE (PER SEC)= 3.29

AVERAGE DATA PACKET ARRIVAL RATE (PACKETS/SEC)	PROBABILITY OF ZERO WAIT TIME
1.000000	0.4221061
2.000000	0.4176050
3.000000	0.4005996
4.000000	0.3824100
5.000000	0.3722043
6.000000	0.3580433
7.000000	0.3351898
8.000000	0.3207938
9.000000	0.2995426
10.00000	0.2797738
11.00000	0.2585041
12.00000	0.2348689
13.00000	0.2128907
14.00000	0.1861750
15.00000	0.1568836
16.00000	0.1295601
17.00000	0.1000240
18.00000	6.9931388E-02
19.00000	4.4454310E-02
20.00000	2.6428798E-02

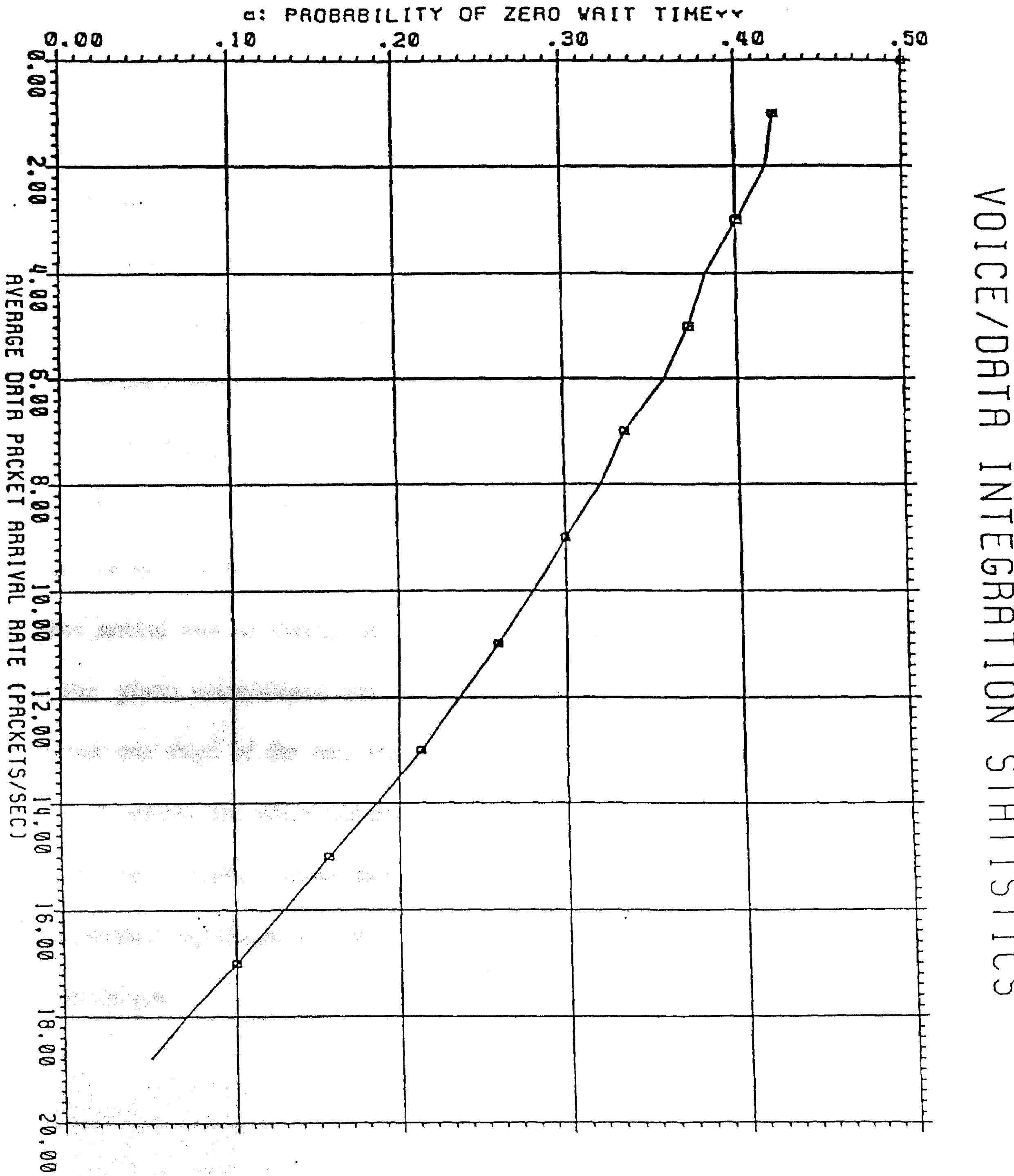

Figure 4.13 Probability of zero wait time vs. Arrival rate

CHAPTER 5

CONCLUSION

A simulation study of several aspects of Voice/Data integration performance is presented. Voice (talkspurt) process is generated using geometric distribution. A silence duration process algorithm was developed by use of weighted geometric distribution. The data arrival process was also modelled using geometric distribution. The simulated outcome of all these models match closely with the theory.

The results of voice/data integration simulation shows that: (1.) Data packet delay increases (2.) Probability of zero wait time decreases and (3.) Probability of longer delay increases with increases in data packet arrival rate. The ratio of data packet arrival rate to average delay provides a performance measure of the system. For the given voice/silence statistics, the optimal arrival rate is 6 packets/sec. which is about one third of the data transmission capacity of the system.

A scheme for voice and data integration is provided which can be incorporated into a larger model. Simulation shows that the integrated voice/data system can accommodate significant growth in data traffic and still perform with acceptable data packet delays.

APPENDIX A

SOURCE CODES

APPENDIX A.1


```
**********************************************************
C
C       THIS PROGRAM GENERATE RANDOM  NUMBER
C
C       WITH "GEOMETRIC " PDF.
C
C       "TALKSPURT" LENGTH IN "N" NUMBERS OF
C
C       FRAMES.  "N" IS GEOMETRICALLY DISTRIBUTED.
C
C               - URMI PATEL, FEB. 1991
C
C**********************************************************
C
C       THE PROGRAM PROMPTS FOR A SEED VALUE AND A
C       NUMBER FOR TOTAL NUMBERS OF THE RANDOM NUMBERS TO BE
C       GENERATED. IT ALSO ASKS FOR THE OUTPUT FILE NAME.
C
C       IT GENERATES THE GEOMETRICALLY DISTRIBUTED RANDOM
C       NUMBERS AND COMPUTES  THEORETICAL AS WELL AS
C       SIMULATED PROBABILITY DISTRIBUTION FUNCTIONS.
C
C**********************************************************
C
        IMPLICIT NONE
        INTEGER*4 IS,NT,N,IX(100),SUM
        REAL    RSUM,XT(100),X(100),RHO,R,RN,RG,XX
        INTEGER K,NRG
        CHARACTER*12 FILENAME
        PRINT *,' ENTER SEED VALUE  AND TOTAL RANDOM NUMBERS'
        READ *,IS,NT
        PRINT *,' ENTER OUTPUT FILE NAME'
        READ (*,'(A)')FILENAME
C       PRINT *,' ENTER RHO'
C       READ *,RHO
C
        RHO=.8674
        R=LOG(RHO)
C
C       INITIALIZING THE VARIABLES
C
        SUM=0
        DO K=1,100
        IX(K)=0
        END DO
C
        CALL SEED(IS)
C
        DO N=1,NT
50      CALL RANDOM(RN)            ! UNIFORM RANDOM NUMBER (RN) GENERATION
        IF(RN .LE. 0.0)GO TO 50
        RG=(LOG(RN)/R)+.5          ! MAPPING "RN" TO GEOMETRIC DISTRIBUTED
        NRG =NINT(RG)              ! "NRG".
        SUM=SUM+NRG
C
C       COMPUTING PROBABILITY DISTRIBUTION FUNCTION
C
          DO K=1,100
          IF (NRG .EQ. K)IX(K)=IX(K)+1
          END DO
C
        END DO
        RSUM=SUM
        PRINT *,' AVERAGE TALK SPURT LENGTH = ',RSUM/NT
C
        OPEN(UNIT=3,FILE=FILENAME,STATUS='UNKNOWN')
```

```
      WRITE(3,*)'        VOICE ACTIVITY (TALK SPURT) STATISTICS'
      WRITE(3,*)' '
      WRITE(3,*)' '
      WRITE(3,*)' SEED VALUE = ',IS,'  TOTAL NUMBERS = ',NT
      WRITE(3,*)' AVERAGE TALK SPURT LENGTH (FRAMES) = ',RSUM/NT
      WRITE(3,*)' '
      DO K=1,100
      XT(K)=(1-RHO)*RHO**(K-1)     ! THEORETICAL DISTRIBUTION
      XX=IX(K)
      X(K)=XX/NT
      PRINT *,K,XT(K),X(K)
      WRITE(3,200)K,XT(K),X(K)
200   FORMAT(2X,I5,2X,2F12.7)
      END DO
      CLOSE(UNIT=3)
      STOP
      END
```

APPENDIX A.2

```
C***********************************************************
C
C       THIS PROGRAM GENERATE RANDOM  NUMBER
C
C       WITH "Weighted GEOMETRIC " PDF.
C
C       "SILENCE DURATION" IS "N" FRAME LONG.
C
C       THE DISTRIBUTION  OF THE "N" IS WEIGHTED
C
C       GEOMETRIC.
C
C                    - URMI PATEL, FEB. 1991
C
C************************************************************
C
C       THIS PROGRAM PROMPTS FOR A SEED VALUE AND
C       A NUMBER FOR TOTAL RANDOM NUMBERS TO BE
C       GENERATED.  IT ALSO ASKS FOR A OUTPUT FILE.
C
C       IT GENERATES WEIGHTED GEOMETRICALLY DISTRIBUTED
C       NUMBERS AND COMPUTES THEORETICAL AS WELL AS
C       SIMULATED PROBABILITY DISTRIBUTION.
C
C************************************************************
C
        IMPLICIT NONE
        INTEGER*4 IS,NT,N,IX(108),SUM
        INTEGER   K,J,TS
        REAL      C1,C2,R1,R2,RN,GJ1,GJ
        REAL      RSUM,XT(108),X(108),XX
        CHARACTER*12 FILENAME
        PRINT *,' ENTER SEED VALUE  AND TOTAL RANDOM NUMBERS'
        READ *,IS,NT
        PRINT *,' ENTER OUTPUT FILE NAME'
        READ (*,'(A)')FILENAME
C
C       C1=.8746
        C1=.8531
        R1=.5372
        C2=.1469
        R2=.9695
C
C       INITIALIZING THE VARIABLES
C
        SUM=0
        DO K=1,108
        IX(K)=0
        END DO
C
        CALL SEED(IS)
C
        DO N=1,NT
90      CALL RANDOM(RN)             ! UNIFORM RANDOM NUMBER (RN) GENERATED
        IF(RN .LE. 0.0) GO TO 90
C
C       MAPPIN OF "RN" IN TO WEIGHTED GEOMETRICALLY DISTRIBUTED
C       RANDOM NUMBER. (NEXT 8 LINES)
        J=1
110     IF(J .GE. 109)GO TO 90
        GJ1=C1+C2-(C1*R1**(J-1)+C2*R2**(J-1))
        GJ=C1+C2-(C1*R1**J+C2*R2**J)
        IF((RN .GE. GJ1) .AND. (RN .LT. GJ))GO TO 121
        J=J+1
        GO TO 110
121     TS=J
```

```
C
        SUM=SUM+TS
C       COMPUTING SIMULATED DISTRIBUTION FUNCTION
          DO K=1,108
          IF (TS .EQ. K)IX(K)=IX(K)+1
          END DO
C
        END DO
        RSUM=SUM
        PRINT *,' AVERAGE SILENCE DURATION = ',RSUM/NT
C
        OPEN(UNIT=3,FILE=FILENAME,STATUS='UNKNOWN')
        WRITE(3,*)'               SILENCE DURATION STATISTICS'
        WRITE(3,*)' '
        WRITE(3,*)' '
        WRITE(3,*)' SEED VALUE = ',IS,'  TOTAL NUMBERS = ',NT
        WRITE(3,*)' AVERAGE SILENCE DURATION (FRAMES) =',RSUM/NT
        WRITE(3,*)' '
        DO K=1,108
        XT(K)=C1*(1-R1)*R1**(K-1)+C2*(1-R2)*R2**(K-1)   ! THEORETICAL
        XX=IX(K)
        X(K)=XX/NT
C       PRINT *,K,XT(K),X(K)
        WRITE(3,200)K,XT(K),X(K)
200     FORMAT(2X,I5,2X,2F12.7)
        END DO
        CLOSE(UNIT=3)
        STOP
        END
```

APPENDIX A.3

```
*********************************************************
C
C       THIS PROGRAM GENERATE RANDOM  NUMBER
C
C       WITH "GEOMETRIC " PDF FOR DATA PACKET
C
C       INTER-ARRIVAL TIME. ("N" FRAME LONG)
C
C       "N" IS GEOMETRICALLY DISTRIBUTED.
C
C               - URMI PATEL, FEB. 1991
C
C**********************************************************
C
C       THE PROGRAM PROMPTS FOR A SEED VALUE AND A
C       NUMBER FOR TOTAL NUMBERS OF THE RANDOM NUMBERS TO BE
C       GENERATED. IT ALSO ASKS FOR AN AVERAGE DATA PACKET
C       ARRIVAL RATE (LAMBDA) AND A OUTPUT FILE NAME.
C
C       EACH PACKET IS ONE FRAME (22.5 MILLI-SECOND) LONG.
C       AN INTER-ARRIVAL TIME IS INTEGRAL MULTIPLE OF FRAME
C       TIME.
C
C       IT GENERATES THE GEOMETRICALLY DISTRIBUTED RANDOM
C       NUMBERS AND COMPUTES  THEORETICAL AS WELL AS
C       SIMULATED PROBABILITY DISTRIBUTION FUNCTIONS.
C
C**********************************************************
C
        IMPLICIT NONE
        INTEGER*4 IS,NT,N,IX(100),SUM
        REAL  RSUM,XT(100),X(100),LAMBDA,RN,RG,RHO,R,XX
        INTEGER K,NRG
        CHARACTER*12 FILENAME
        PRINT *,' ENTER SEED VALUE, TOTAL RANDOM NUMBERS AND'
        PRINT *,' AVERAGE DATA PACKET ARRIVAL RATE (LAMBDA).'
        READ *,IS,NT,LAMBDA
        PRINT *,' ENTER OUTPUT FILE NAME'
        READ (*,'(A)')FILENAME
C
C
        RHO=1.-.0225*LAMBDA
        R=LOG(RHO)
C
C       INITIALIZING  VARIABLES
C
        SUM=0
        DO K=1,100
        IX(K)=0
        END DO
C
        CALL SEED(IS)
C
        DO N=1,NT
50      CALL RANDOM(RN)             ! UNIFORM RANDOM NUMBER (RN) GENERATION
        IF(RN .LE. 0.0)GO TO 50
        RG=(LOG(RN)/R)+.5           ! MAPPING "RN" TO GEOMETRIC DISTRIBUTED
        NRG =NINT(RG)               ! "NRG".
        SUM=SUM+NRG
C
C       COMPUTING PROBABILITY DISTRIBUTION FUNCTION
C
          DO K=1,100
          IF (NRG .EQ. K)IX(K)=IX(K)+1
          END DO
C
```

```
      END DO
      RSUM=SUM
      PRINT *,' AVERAGE INTER-ARRIVAL TIME(FRAMES) = ',RSUM/NT
C
      OPEN(UNIT=3,FILE=FILENAME,STATUS='UNKNOWN')
      WRITE(3,*)'          DATA PACKET ARRIVAL STATISTICS'
      WRITE(3,*)' '
      WRITE(3,*)' '
      WRITE(3,*)' SEED VALUE = ',IS,'  TOTAL NUMBERS = ',NT
      WRITE(3,*)' AVERAGE DATA PACKET ARRIVAL RATE =',LAMBDA
      WRITE(3,*)' AVERAGE INTER-ARRIVAL TIME(FRAMES) = ',RSUM/NT
      WRITE(3,*)' '
      DO K=1,100
      XT(K)=(1-RHO)*RHO**(K-1)     ! THEORETICAL DISTRIBUTION
      XX=IX(K)
      X(K)=XX/NT
      PRINT *,K,XT(K),X(K)
      WRITE(3,200)K,XT(K),X(K)
200   FORMAT(2X,I5,2X,2F12.7)
      END DO
      CLOSE(UNIT=3)
      STOP
      END
```

APPENDIX A.4

```
C*****************************************************************
C*****************************************************************
C
C       THIS PROGRAM SIMULATES VOICE/DATA INTEGRATION
C       IN DATA COMMUNICATION SYSTEM.
C
C       THE DATA PACKETS ARE TRANSMITED DURING INACTIVITY
C       OF VOICE CHANNEL (i.e. DURING SILENCE).
C
C                           URMI PATEL
C                           FEB. 1991.
C               NEW JERSEY INSTITUTE OF TECHNOLOGY
C
C*****************************************************************
C       A DATA PACKETS ARE ASSUMED TO BE ONE FRAME LENTH LONG.
C       AN INTER ARRIVAL TIME OF DATA PACKET IS ASSUMED TO BE
C       GEOMETRICALLY DISTRIBUTED.
C
C       A VOICE IS PACKETIZED. ITS LENTH IS EXPRESSED IN AN
C       INTEGRAL NUMBER OF FRAMES. A FRAME IS 22.5 MILLI-SEC
C       LONG. A VOICE TALK-SPURT LENTH (IN TERMS OF FRAMES)
C       IS GEOMETRICALLY DISTRIBUTED.
C
C       A SILENCE DURATION CAN ALSO BE EXPRESSED IN TERMS OF
C       FRAMES. THE DURATION (IN TERMS OF FRAMES) FOLLOWS
C       WEIGHTED GEOMETRICAL DISTRIBUTION.
C
C*****************************************************************
C
C       THIS PROGRAM PROMPTS FOR SEED VALUE, MAXIMUM SIMULATION
C       TIME AND PACKET ARRIVAL RATE (LAMBDA).
C       IT ALSO ASKS AN OUTPUT FILE NAME WHERE PACKET DELAY
C       DISTRIBUTION AND OTHER STATISTICS BE STORED.
C
C*****************************************************************
C*****************************************************************
C
        IMPLICIT NONE
        INTEGER*4 TA(0:15000),TD(0:15000)
        INTEGER*4 IS,NMAX,TT,TTV,TQS,N,SUMD,NAR,NSERV
        INTEGER*4 WNAR,WNSERV
        INTEGER   E,TV,TS,SAV,L,I,J,K,M,NREP
        INTEGER   Q,V,IX(0:200),DLY(0:15000)
        REAL      LAMBDA,TMAX,RSUMD,TN,VV,X(0:200)
        REAL      APAR,APIAT,ATSR,ADPD,XX
        REAL      WAPAR,WAPIAT,WATSR,WADPD,WX(0:200)
        COMMON    LAMBDA,E,TV,TS,IS
        CHARACTER*15 FILENAME
C
C       PROMPTS FOR INPUTS
C
        PRINT *,' ENTER SEED VALUE, MAX. SIMULATION TIME AND'
        PRINT *,' PACKET ARRIVAL RATE(LAMBDA)'
        READ *, IS,TMAX,LAMBDA
        PRINT *,' ENTER OUTPUT FILE NAME'
        READ(*,'(A)')FILENAME
C
        CALL SEED(IS)            ! Used in micro-soft FORTRAN
C
        NMAX=10000
        NREP=NINT((TMAX/225.)+.5)     ! .0225*NMAX = 225
C
C       INITIALIZES LONG LOOP
C
        WNAR=0
        WNSERV=0
```

```
        WAPAR=0.
        WAPIAT=0.
        WADPD=0.
        DO K=0,200
        X(K)=0.
        END DO
C
        DO M=1,NREP          ! LONG LOOP STARTS....
C
C       INITIALIZES  VARIABLES FOR MAIN PROGRAM
C
        N=0
        Q=0
        V=0
        TT=0
        TTV=0
        TQS=0
        TA(N)=0
        TD(N)=0
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
C
C       MAIN PROGRAM STARTS........
C
20      IF (TA(N) .GE. NMAX) GO TO 800
        CALL VOICE(TV)
        CALL SILENCE(TS)
        TTV=TT+TV
        TT=TT+TV+TS
        V=V+1
C
50      IF(TA(N) .GE. TTV) GO TO 100
        Q=Q+1
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
        GO TO 50
C
100     IF (TS.GT.Q) GO TO 500
        SAV=TS
        TQS=TTV
C
150     IF(SAV.LE.0) GO TO  200
        TD(N-Q)=TQS
        Q=Q-1
        TQS=TQS+1
        SAV=SAV-1
        GO TO 150
C
200     IF(TA(N).GE.TT) GO TO 20
        Q=Q+1
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
        GO TO 200
C
500     SAV=TS
        TQS=TTV
550     IF(Q.LE.0)GO TO 600
        TD(N-Q)=TQS
        Q=Q-1
        TQS=TQS+1
        SAV=SAV-1
        GO TO 550
C
```

```
600     IF(TA(N) .LT. TQS)GO TO 700
650     IF (TA(N) .GE. TT) GO TO 20
        TD(N)=TA(N)
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
        GO TO 650
C
700     TD(N)=TQS
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
        TQS=TQS+1
        SAV=SAV-1
C
        IF (SAV .GT. 0) GO TO 600
C
750     IF(TA(N) .GE. TT)GO TO 20
        Q=Q+1
        CALL ARRIVAL(LAMBDA,E)
        N=N+1
        TA(N)=TA(N-1)+E
        GO TO 750
C
800     CONTINUE
C
C       MAIN PROGRAM ENDS.
C
C       DELAY STATISTICS CALCULATION STARTS....
C
        DO L=0,200
        IX(L)=0
        END DO
C
        SUMD=0
        NSERV=N-1-Q
C
        DO I=1,NSERV
        DLY(I)=TD(I)-TA(I)
C       PRINT *,TD(I),TA(I),DLY(I)
        SUMD=SUMD+DLY(I)
C
C          DELAY DISTRIBUTION  CALCULATION
           J=0
1100       IF(J .GT. 200)GO TO 1201
           IF(DLY(I) .EQ. J)GO TO 1200
           J=J+1
           GO TO 1100
1200       IX(J)=IX(J)+1
1201       CONTINUE
C
        END DO
C
C       DELAY STATISTICS CALCULATION ENDS.
C
        RSUMD=SUMD
        NAR=N-1
        TN=NAR
        VV=V
        APAR=TN/(0.0225*NMAX)
        APIAT=1./APAR
        ATSR=VV/(0.0225*NMAX)
        ADPD=RSUMD/NSERV
C
        DO K=0,200
        XX=IX(K)
```

```
      X(K)=XX/NSERV
      END DO
C
C     ACCUMULATES  RESULT OF REPEATED CALCULATIONS
C
      WNAR=WNAR+NAR
      WNSERV=WNSERV+NSERV
      WAPAR=WAPAR+APAR
      WAPIAT=WAPIAT+APIAT
      WATSR=WATSR+ATSR
      WADPD=WADPD+ADPD
      DO K=0,200
      WX(K)=WX(K)+X(K)
      END DO
C
      END DO
C
C     LONG LOOP ENDS.
C
C     NORMALIZES THE RESULTS
C
      WAPAR=WAPAR/NREP
      WAPIAT=WAPIAT/NREP
      WATSR=WATSR/NREP
      WADPD=WADPD/NREP
      DO K=0,200
      WX(K)=WX(K)/NREP
      END DO
C
C     DATA PROCESSING COMPLETE.
C
      PRINT *,' TOTAL NUMBER OF DATA PACKETS GENERATED =',WNAR
      PRINT *,' TOTAL NUMBER OF DATA PACKETS SERVICED =',WNSERV
      PRINT *,' AVERAGE PACKET ARRIVAL RATE (PER SEC)= ',WAPAR
      PRINT *,' AVERAGE PACKET INTER-ARRIVAL TIME (SEC) = ',WAPIAT
      PRINT *,' AVERAGE TALK SPURT RATE (PER SEC) = ',WATSR
      PRINT *,' PROBABILITY OF ZERO WAITING TIME =',WX(0)
      PRINT *,' AVERAGE DATA PACKET DELAY (FRAMES) =',WADPD
C
      OPEN(UNIT=3,FILE=FILENAME,STATUS='UNKNOWN')
      WRITE(3,*)'            VOICE/DATA INTEGRATION STATISTICS'
      WRITE(3,*)' '
      WRITE(3,*)' '
      WRITE(3,*)' SEED VALUE =',IS,'    TOTAL SIM. TIME (SEC) =',TMAX
      WRITE(3,*)' AVERAGE DATA PACKET ARRIVAL RATE =',LAMBDA
      WRITE(3,*)' '
      WRITE(3,*)' TOTAL NUMBER OF DATA PACKETS GENERATED =',WNAR
      WRITE(3,*)' TOTAL NUMBER OF DATA PACKETS SERVICED =',WNSERV
      WRITE(3,*)' AVERAGE PACKET ARRIVAL RATE (PER SEC)=',WAPAR
      WRITE(3,*)' AVERAGE PACKET INTER-ARRIVAL TIME (SEC) =',WAPIAT
      WRITE(3,*)' AVERAGE TALK SPURT RATE (PER SEC)=',WATSR
      WRITE(3,*)' PROBABILITY OF ZERO WAITING TIME =',WX(0)
      WRITE(3,*)' AVERAGE DATA PACKET DELAY (FRAMES) =',WADPD
      WRITE(3,*)' '
      DO K=0,200
C     PRINT *,K,WX(K)
      WRITE(3,2000)K,WX(K)
2000  FORMAT(2X,I5,2X,F12.7)
      END DO
      CLOSE(UNIT=3)
      STOP
      END
```

```
C*************************************************
C
C       THIS SUBROUTINE PROGRAM GENERATE RANDOM
C
C       NUMBER WITH "GEOMETRIC " PDF.
C
C       "ARRIVAL"
C
C*************************************************
C
        SUBROUTINE ARRIVAL(LAMBDA,E)
        INTEGER E
        REAL    LAMBDA
C
C       FRAME TIME IS 0.0225 SEC
C
        RHO=1.-.0225*LAMBDA
C
950     CALL RANDOM(RN)                 ! Used in Microsoft FORTRAN
C950    RN=RAN(IS)                      ! Used in VAX FORTRAN
        IF (RN .LE. 0.0) GO TO 950
        RG=(LOG(RN)/LOG(RHO))+.5
        E=NINT(RG)
        RETURN
        END
```

```
C*************************************************
C
C       THIS SUBROUTINE PROGRAM GENERATE RANDOM
C
C       NUMBER WITH "GEOMETRIC " PDF.
C
C       TALK SPURT LENGTH (IN NUMBERS OF FRAMES)
C
C*************************************************
        SUBROUTINE VOICE(TV)
        INTEGER TV
C
        RHO=.8674
C
960     CALL RANDOM(RN)                 ! Used in Microsoft FORTRAN
C960    RN=RAN(IS)                      ! Used in VAX FORTRAN
        IF (RN .LE. 0.0)GO TO 960
        RG=(LOG(RN)/LOG(RHO))+.5
        TV=NINT(RG)
        RETURN
        END
```

```
C*********************************************
C
C       THIS SUBROUTINE PROGRAM GENERATE RANDOM
C
C       NUMBER WITH "WEIGHTED GEOMETRIC " PDF.
C
C       SILENCE DURATION (IN NUMBERS OF FRAMES)
C
C*********************************************
        SUBROUTINE SILENCE(TS)
        INTEGER TS
C
C       C1=.8746
        C1=.8531
        C2=.1469
        RHO1=.5372
        RHO2=.9695
C
70      CALL RANDOM(RN)                    ! Used in Microsoft FORTRAN
C70     RN=RAN(IS)                         ! Used in VAX FORTRAN
        IF(RN .LE. 0.0)GO TO 70
        J=1
100     IF(J .GT. 108)GO TO 70
        GJ1=C1+C2-(C1*RHO1**(J-1)+C2*RHO2**(J-1))
        GJ=C1+C2-(C1*RHO1**J+C2*RHO2**J)
        IF((RN .GE. GJ1) .AND. (RN .LT. GJ))GO TO 101
        J=J+1
        GO TO 100
101     TS=J
        RETURN
        END
```

VOICE/DATA INTEGRATION STATISTICS

SEED VALUE = 16807 TOTAL SIM. TIME (SEC) = 10000.00
AVERAGE DATA PACKET ARRIVAL RATE = 8.000000

TOTAL NUMBER OF DATA PACKETS GENERATED = 81070
TOTAL NUMBER OF DATA PACKETS SERVICED = 81010
AVERAGE PACKET ARRIVAL RATE (PER SEC)= 8.006913
AVERAGE PACKET INTER-ARRIVAL TIME (SEC) = 0.1249437
AVERAGE TALK SPURT RATE (PER SEC)= 3.289185
PROBABILITY OF ZERO WAITING TIME = 0.3207938
AVERAGE DATA PACKET DELAY (FRAMES) = 11.48726

0	0.3207938	52	0.0017867
1	0.0404727	53	0.0019525
2	0.0372732	54	0.0014397
3	0.0350123	55	0.0014836
4	0.0319934	56	0.0015548
5	0.0306121	57	0.0014376
6	0.0290981	58	0.0009768
7	0.0278116	59	0.0009827
8	0.0264579	60	0.0009632
9	0.0249116	61	0.0009883
10	0.0233643	62	0.0008766
11	0.0220555	63	0.0008023
12	0.0208089	64	0.0008363
13	0.0188981	65	0.0008413
14	0.0179621	66	0.0006688
15	0.0159293	67	0.0006196
16	0.0153949	68	0.0006701
17	0.0153903	69	0.0005057
18	0.0136165	70	0.0005074
19	0.0132796	71	0.0004937
20	0.0126734	72	0.0004099
21	0.0124952	73	0.0003858
22	0.0113466	74	0.0005527
23	0.0105034	75	0.0004682
24	0.0101976	76	0.0004190
25	0.0099131	77	0.0002331
26	0.0094074	78	0.0001234
27	0.0089500	79	0.0003575
28	0.0079056	80	0.0002828
29	0.0080814	81	0.0002580
30	0.0068322	82	0.0003085
31	0.0062634	83	0.0002090
32	0.0067986	84	0.0002574
33	0.0058808	85	0.0002707
34	0.0058038	86	0.0001476
35	0.0054839	87	0.0001583
36	0.0049887	88	0.0002091
37	0.0051216	89	0.0001850
38	0.0040891	90	0.0001350
39	0.0040730	91	0.0002002
40	0.0039747	92	0.0000612
41	0.0037085	93	0.0002086
42	0.0030570	94	0.0000978
43	0.0035961	95	0.0000497
44	0.0029876	96	0.0000860
45	0.0029928	97	0.0001115
46	0.0029687	98	0.0000863
47	0.0024977	99	0.0000127
48	0.0020434	100	0.0000612
49	0.0022024	101	0.0000241
50	0.0020322	102	0.0000366
51	0.0021017	103	0.0000737
		104	0.0001098
		105	0.0000504
		106	0.0000500
		107	0.0000737
		108	0.0000489
		109	0.0000613
		110	0.0000490
		111	0.0000246
		112	0.0000625
		113	0.0000380
		114	0.0000000
		115	0.0000000
		116	0.0000251
		117	0.0000257

118	0.0000244
119	0.0000124
120	0.0000124
121	0.0000000
122	0.0000122
123	0.0000246
124	0.0000122
125	0.0000122
126	0.0000000
127	0.0000000
128	0.0000122
129	0.0000124
130	0.0000124
131	0.0000368
132	0.0000124
133	0.0000000
134	0.0000000
135	0.0000122
136	0.0000368
137	0.0000247
138	0.0000124
139	0.0000369
140	0.0000244
141	0.0000244
142	0.0000000
143	0.0000000
144	0.0000000
145	0.0000000
146	0.0000000
147	0.0000000
148	0.0000000
149	0.0000000
150	0.0000244
151	0.0000122
152	0.0000000
153	0.0000000
154	0.0000000
155	0.0000000
156	0.0000000
157	0.0000000
158	0.0000000
159	0.0000000
160	0.0000000
161	0.0000000
162	0.0000000
163	0.0000000
164	0.0000000
165	0.0000000
166	0.0000000
167	0.0000000
168	0.0000000
169	0.0000000
170	0.0000000
171	0.0000000
172	0.0000000
173	0.0000000
174	0.0000000
175	0.0000000
176	0.0000000
177	0.0000000
178	0.0000000
179	0.0000000
180	0.0000000
181	0.0000000
182	0.0000000
183	0.0000000
184	0.0000000
185	0.0000000
186	0.0000000
187	0.0000000
188	0.0000000
189	0.0000000
190	0.0000000
191	0.0000000
192	0.0000000
193	0.0000000
194	0.0000000
195	0.0000000
196	0.0000000
197	0.0000000
198	0.0000000
199	0.0000000
200	0.0000000

APPENDIX B

DERIVATION OF EXPECTED VALUE

Expected Value of Silence Duration:

The probability of silence duration is given by weighted geometric function as below:

$$f_I(k) = C_1\ (1-r_1)\ r_1^{k-1} + C_2\ (1-r_2)\ r_2^{k-1}$$

$$E(X) = \sum_{k=1}^{\infty} \{k[\ C_1\ (1-r_1)\ r_1^{k-1} + C_2\ (1-r_2)\ r_2^{k-1}\ ]\}$$

$$= C_1 \sum_{k=1}^{\infty} k\ (1-r_1)\ r_1^{k-1} + C_2 \sum_{k=1}^{\infty} k\ (1-r_2)\ r_2^{k-1}$$

$$= C_1\ (1-r_1) \sum_{k=1}^{\infty} kr_1^{k-1} + C_2\ (1-r_2) \sum_{k=1}^{\infty} k\ r_2^{k-1}$$

Let $$S = \sum_{k=1}^{\infty} k\ r_1^{k-1} = 1 + 2r^1 + 3r^2 + 4r^3 + \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\therefore\ r_1 S = \sum_{k=1}^{\infty} k\ r_1^{k} = r + 2r^2 + 3r^3 + 4r^4 + \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Subtracting equation (3) from equation (2) we get:

$$S - r_1 S = 1 + r^1 + r_1^2 + r_1^3 + r_1^4 \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$S\ (1 - r_1) = 1\ /\ (1 - r_1)$$

$$\therefore\ S = 1\ /\ (1 - r_1)^2$$

$$E(X) = C_1 \frac{(1-r_1)}{(1 - r_1)^2} + C_2 \frac{(1-r_2)}{(1 - r_2)^2}$$

$$= \frac{C_1}{(1 - r_1)} + \frac{C_2}{(1 - r_2)} \qquad \ldots\ldots\ldots\ldots(5)$$

E(X) is a theoretical expected value of silence duration. For C_1 = .8531, C_2 = .1469, r_1 = .5372 and r_2 = .9695,

E(X) = 6.659 frames.

Expected Value of Talkspurt:

If $C_1 = 1$, $C_2 = 0$ and $r_1 = r$ than, equation (5) becomes:

$$E(X) = 1/(1 - r)$$

for r = .8675,

$$E(X) = 7.541 \text{ frames.}$$

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