PERFORMANCE ANALYSIS OF A CONTROLLER AREA NETWORK SUBJECT TO ASYMMETRIC TRAFFIC LOADS

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CHAPTER I

INTRODUCTION

This research proposes an investigation into the performance of a Controller Area Network (CAN) subject to Asymmetric Traffic Loads (ATL). The CAN model used in the research consists of six stations. Each of the six stations can send messages with different priorities to the CAN bus. Experimental (or network) factors used in this research include the asymmetry of traffic loads, interarrival time variability, and basis arrival rates. Two performance measures, the average message delay and average bus utilization, are used to evaluate the performance. Computer simulation is used as the tool to carry out the experiments.

CAN Protocol

The Controller Area Network is a serial communications protocol which efficiently supports distributed real-time control with a very high level of security. Its domain of application ranges from high speed networks to low cost multiplex wiring. In automotive electronics, engine control units, sensors, anti-skid systems, etc. are connected using a CAN. At the same time, it is cost effective to use a CAN for vehicle body electronics (e.g., electric windows) to replace the wiring harness otherwise required (Bosch GmbH, 1991).

The CAN protocol is a multimaster protocol where messages are transmitted serially. Contention between masters is resolved on a bit-by-bit basis in a non-destructive arbitration which results in the highest priority message gaining access to the bus. The CAN protocol supports 2^{29} different messages and the highest priority message is guaranteed a maximum latency of 150 μsec at the maximum bit rate of 1 Mbit/sec. Integrity of data is guaranteed through complex mechanisms such as bit stuffing, cyclic redundancy checks, and automatic retransmission of erroneous data.

Unlike many serial communication protocols, the CAN message contains no information relating to the destination address. Instead, the message contains an identifier which indicates the type of information contained in the message. This has several important implications. First of all, nodes can be added or removed from the network without any change to the software. Secondly, each node can decide on the basis of the type of message whether the message is of interest to that particular node. Multicasts to many nodes are therefore inherent in this system and the data will be consistent in that either all or none of the nodes will receive the message (Jordan, 1988).

Problem Statement

More recently it has been acknowledged that networks, especially Local Area Networks (LAN), operating in a real user environment are subject to asymmetrically distributed traffic loads (Senior, et al., 1992). Some research on LANs subject to ATL (e.g., Grela-M'Poko, et al., 1991; Senior, et al., 1992) showed that such traffic load distributions alter the network behavior by increasing the average message delay. Although several studies on LANs subject to ATL have been completed, no study has been reported in the area of CANs subject to ATL.

Thus, the problem to be addressed in this research is to better understand the effect of asymmetric traffic loads on the performance of Controller Area Networks.

Research Goal

The goal of this research is to identify the important factors which impact the network performance and to evaluate the performance of a Controller Area Network subject to asymmetric traffic loads under various loads and variations of message arrival.

Research Objectives

Objective 1. The first objective of this study is to define the system, to identify experimental factors, and to choose performance measures for the research. The system definition includes the network model and all assumptions made. The experimental factors seek to identify the critical factors impacting system performance and define their critical levels. Performance measures chosen include the average message delay and average bus utilization.

Objective 2. The second objective of this study is to consider the implementation issues which include the experimental design, number of replications required, steady state simulation, generation of a simulation model, and model verification and validation.

Objective 3. The third objective of this study is to analyze and interpret the simulation outcome and to draw conclusions for this research effort.

Research Scope and Limitations

Due to economic and time constraints, the scope of this research effort is limited to a small network system (i.e., six stations). In particular, large or complex systems are not directly investigated. The study is, instead, directed at a small system or at a sub-system of a larger network system. The basic assumption guiding the investigation is that the findings will be generally transferable to larger systems operating under the same conditions.

CHAPTER II

RESEARCH BACKGROUND

Introduction

This chapter presents a review of relevant research. The applicable literature is related to the performance analysis of networks subject to ATL using analytical approaches (e.g., queueing models) or computer simulation. This is not an exhaustive review, but an effort to review the overall research emphasizing the critical research efforts.

Previous Research on Networks Subject to Asymmetric Traffic Loads

Senior, et al. (1988) identified the major service requirements and traffic types associated with industrial LANs. Two conclusions were drawn from their study. First, it is apparent that high traffic throughput will be a requirement for the LAN together with a capability to guarantee real-time communication for specific devices. The second conclusion relates to the probable asymmetric distribution of traffic loading on the industrial LAN. Although the levels of asymmetry will vary between industrial plants and at different times on the same network, it is clear that asymmetric traffic loads will occur. The mean package delay of the common medium access control (MAC) layer protocols (CSMA/CD, token passing, and TDMA) was found to vary significantly with both the throughput and level of asymmetry in the traffic load distribution. Computer simulation was used as a tool to evaluate the system performance in their study.

Takine, et al. (1988) developed a unified approach to general asymmetric polling systems with a single buffer at each station. They considered two variations of single buffer polling systems: the conventional system and the buffer relaxation system. In the conventional system, a new message is not allowed to queue until the previous message has been completely transmitted. In the buffer relaxation system, a newly arriving message can be stored in its buffer after the previous message's transmission has been started. For each system, they derived the Laplace-Stieltjes transform (LST) of the joint probability distribution function of station times, from which the LST of the probability distribution function of message delay was derived.

Ibe and Cheng (1989) presented an approximate analysis of asymmetric single-service token passing systems. In these systems, stations have infinite buffers and pursue a limited service policy allowing a single message transmission per server visit. The contribution is the development of an accurate expression for the average delay of a message when the traffic at each station follows an asymmetric Poisson distribution.

Grela-M'Poko, et al. (1991) presented an approximate analysis of asymmetric single-service prioritized token passing systems. This study is extended from Ibe and Cheng's study (1989) to an operation with nonpreemptive priority queueing. The number of message priority levels varied from one station to another. The performance, as measured by the mean delay for any message class at any station, was derived. The simulation results showed excellent agreement with the analytical results, even under heavy loading. Both results showed that the mean package delay varied significantly with the throughput, interarrival time distribution, and level of asymmetry in the traffic load distribution.

Senior, et al. (1992) presented a new technique for modeling asymmetric load distribution on LANs. The traffic model is analytical and easy to implement as a discrete computer simulation. The model also has the benefit of providing expressions for the higher mathematical moments of the traffic load distribution. A 100-node token ring LAN was simulated to demonstrate this new technique for modeling asymmetric load distribution. The results showed that the mean package delay varied significantly with both the throughput and level of asymmetry in the traffic load distribution.

Summary

As can been seen from the literature, several studies related to asymmetric traffic loads on LANs have been completed. No effort has been directed to investigate the performance of CANs subject to asymmetric traffic loads. Thus, this research effort is directed at investigating the performance of a Controller Area Network subject to asymmetric traffic loads. Computer simulation is used as the tool to carry out the experiments.

CHAPTER III

RESEARCH METHODOLOGY

Introduction

A schematic diagram for the basic elements of a network study using computer simulation is shown in Figure 3.1. In this diagram, the inputs include the network model, assumptions made, performance measures, and experimental factors. The outputs are research findings based on the outcome of the simulation.

This chapter discusses the research methodology employed in conducting the study. The basic elements required for the study are defined based on Figure 3.1. These elements include the CAN model, assumptions made, experimental factors identified, and performance measures chosen. Then, the implementation issues, which include experimental design, generation of the simulation model, and model verification and validation, are discussed.

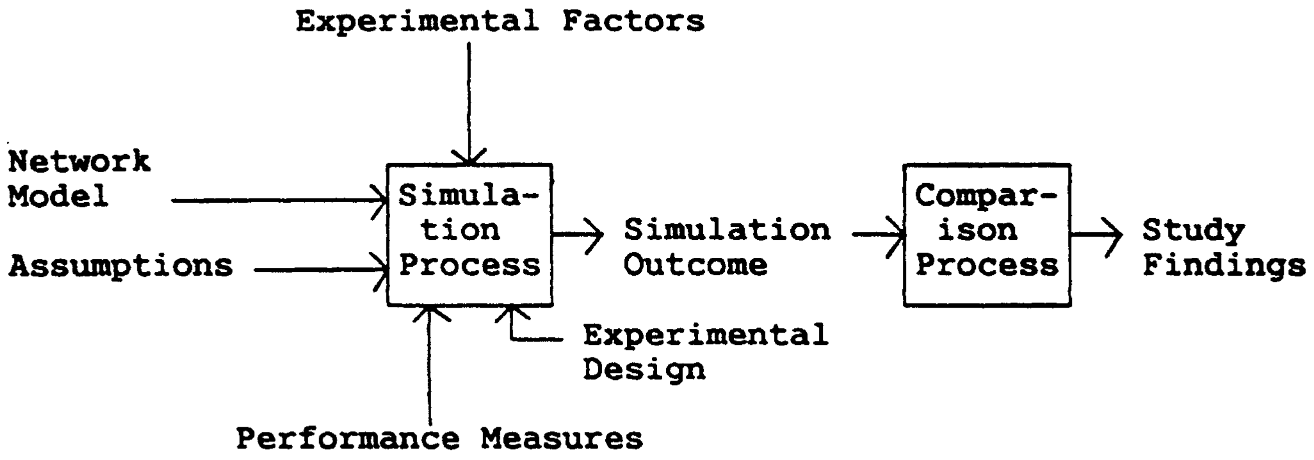


Figure 3.1 Schematic Diagram for Simulations

The CAN Model

This research involves a Controller Area Network consisting of six stations as shown in Figure 3.2. Each of the six stations can send messages with two different priorities to the CAN bus. Totally, there are twelve message priorities. The sending station numbers and the assigned message priorities are listed below.

Sending Station #	Message Priority
1	1 (highest), 2
2	3, 4
3	5, 6
4	7, 8
5	9, 10
6	11, 12

The transmission time of a message is equal to its length multiplied by the unit transmission time. The message length is generated from a uniform distribution in the interval between 64 and 136 bits (i.e., between 8 and 17 bytes) (see Stepper, 1993). The unit transmission time is set to 4.0E-3 msec/bit (i.e., the baud rate is equal to 250 Kbits/second) (see Stepper, 1993). If errors occur during transmission, the messages should be retransmitted. The probability of message transmission errors is assumed to be 1% of the messages transmitted.

Different arrival rates (or basis arrival rates) are investigated in this study. Given a basis arrival rate, the message arrival rates for the six stations may be

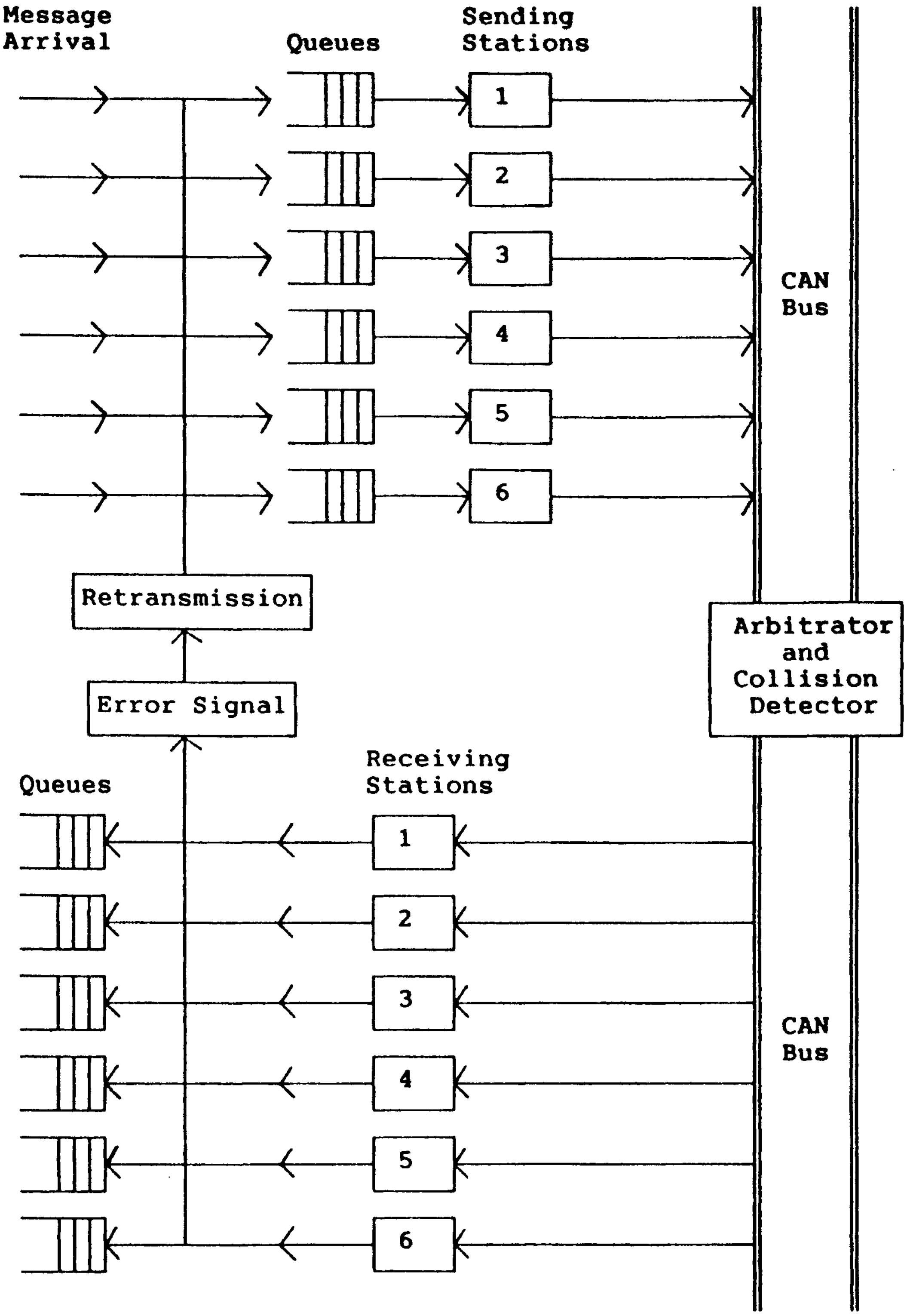


Figure 3.2 Schematic Diagram for the Network Model

different, depending on whether they are heavy stations or not. The message arrival rate for a heavy station is twice that for a normal station. Also, in order to study the impact of the variability of message arrival on the network performance, different degrees of the interarrival time variability (by using the coefficient of variation) are used in this research.

Once the message arrival rate for a station is known, its mean interarrival time can be calculated. The interarrival times of messages for a station are sampled from a normal distribution with the mean equal to the mean interarrival time. Note that a normal distribution can be totally defined by a mean and a standard deviation or a coefficient of variation. The coefficient of variation (abbreviated CV) is the ratio of the standard deviation to the mean.

Assumptions in the Model

The following is a summary of the basic assumptions on which this model is based:

(1) The failures of stations and the bus are not considered.

(2) There are no limits on the queue sizes and, therefore, no blocking occurs.

(3) When two or more messages are transmitted at the same

time, arbitration occurs and the message with the highest priority will gain bus access.

Experimental Factors

Based on the literature review in Chapter II and the features of the CAN, there are three factors which have a major impact on system performance, including the asymmetry of traffic loads, interarrival time variability, and basis arrival rates. These factors are discussed below.

(1) Asymmetry of Traffic Loads

Since the primary goal of this research is to evaluate the performance of a Controller Area Network subject to asymmetric traffic loads, this factor should be investigated with different levels of asymmetry. Three levels of asymmetry of traffic loads, which include one symmetric case and two asymmetric cases, are used in this study. Note that the message arrival rate for a heavy station is twice that for a normal station. The three levels of asymmetry of traffic loads are listed below:

1) All stations have identical traffic loads (i.e., symmetric traffic loads).

   $a_1 = a_2 = a_3 = a_4 = a_5 = a_6 = a_0$

2) The first two stations are heavily loaded (i.e., asymmetric traffic loads).

$a_1 = a_2 = 2a_o, \quad a_3 = a_4 = a_5 = a_6 = a_o$

3) The last two stations are heavily loaded (i.e., asymmetric traffic loads).

$a_1 = a_2 = a_3 = a_4 = a_o, \quad a_5 = a_6 = 2a_o$

Where:

a_i = arrival rate at station i
a_o = basis arrival rate

(2) Interarrival Time Variability

Some studies of LANs subject to ATL (e.g., Takine, et al., 1988; Grela-M'Poko, et al., 1991) show that the interarrival time variability (by using different distributions) has a major impact on the system performance. Most previous studies only included two levels of the interarrival time variability such as constant (CV=0) and exponential distribution (CV=1). In order to study the effect of the interarrival time variability on the network performance (significant or insignificant, linear or nonlinear), a normal distribution with three levels of the coefficients of variation is used in this research.

The objective in choosing these levels is to pick two values that are far enough apart that a discernable difference in performance can be observed, and then to pick a middle point. The three levels of interarrival time variability, which are selected in simulation pilot runs, are the coefficients of variation of 0.1, 0.4, and 0.7. The coefficients of variation of 0.1 and 0.7 are selected to represent the slight and worse cases from a broad range of the interarrival time variability, respectively. A middle point (i.e., CV=0.4) is used to investigate the nonlinear effect of the interarrival time variability.

(3) Basis Arrival Rates

Some studies of LANs subject to ATL (e.g., Grela-M'Poko, et al., 1991; Senior, et al., 1992) used the message arrival rate as an experimental factor and the results indicate that this factor has a major impact on the system performance. Therefore, this factor is investigated in this study. Instead of using arrival rates, basis arrival rates are used here because some of the six stations may be heavy stations. Given a basis arrival rate, the message arrival rate for a normal station is equal to the basis arrival rate, while the message arrival rate for a heavy station is twice the basis arrival rate.

Again, the objective in choosing these levels is to pick two values that are far enough apart that a discernable difference in performance can be observed, and then to pick a middle point. The three levels of basis arrival rates, which are selected in simulation pilot runs, are 180, 230, and 280 (messages/second). The basis arrival rates of 180 and 280 (messages/second) are selected to represent the light and heavy traffic conditions from a broad range of basis arrival rates, respectively. A middle point (i.e., 230 messages/second) is used to investigate the nonlinear effect of basis arrival rates. Choosing the basis arrival rate of 180 messages/second results in an average bus utilization of 43% when the traffic loads are symmetric. While, choosing the basis arrival rate of 280 messages/second results in an average bus utilization of 67% when the traffic loads are symmetric.

Performance Measures

Based on the studies of LANs subject to ATL (e.g., Grela-M'Poko, et al., 1991; Senior, et al., 1992) and the features of the CAN, two performance measures, the average message delay (or average turnaround time) and average bus utilization, are considered in this research. Both of the two measures are calculated by averaging over all messages transmitted by the network. Message delay, which is frequently used in previous studies, can be defined as a measure of the time required for a message to travel from the source station to the destination station. In this study, bus utilization is defined as the percentage of time the bus is actually in use, i.e., total time that bus in use divided by 3000 msec (simulation period).

Experimental Design

Three experimental factors are studied in this research: the asymmetry of traffic loads, interarrival time variability, and basis arrival rates. As can be seen from Table 3.1, three levels for each of the three experimental factors are investigated. To include all possible combinations of the three factors, it requires 27 experiments (or network configurations) (see Table 3.2).

Number of Replications

Due to the stochastic nature of the simulation model the observed performance of the system is only an estimate of the true performance. Therefore, when comparing various experiments (or network configurations), it is critical to determine how much of the performance difference is due to the experimental factors (e.g., asymmetry of traffic loads) and how much is simply error introduced by the stochastic nature of the simulation. This requires some measure of variability of the estimates to construct confidence intervals and, thus, multiple replications are required.

The procedure discussed by Law and Kelton (1991) is used to determine the number of replications required in the experiments.

TABLE 3.1

EXPERIMENTAL FACTORS UTILIZED

Factor	Level
Asymmetry of Traffic Loads (ATL)	1) All stations have identical loads. 2) Stations 1 & 2 are heavily loaded. 3) Stations 5 & 6 are heavily loaded.
Interarrival Time Variability (ITV)	1) CV (Coefficient of Variation) = 0.1 2) CV = 0.4 3) CV = 0.7
Basis Arrival Rates (BAR)	1) 180 (messages/second) 2) 230 3) 280

TABLE 3.2

EXPERIMENTS CONDUCTED

ITV	BAR (messages/ second)	ATL		
		Level 1	Level 2	Level 3
C.V.=0.1	180			
	230			
	280			
C.V.=0.4	180			
	230			
	280			
C.V.=0.7	180			
	230			
	280			

Step 1. We need to choose a network configuration and then estimate the mean and variance of a specific performance measure based on a fixed number of replications (n). The following configuration, which is expected to perform worse with respect to the average message delay, is chosen:

Asymmetry of traffic loads: Level 3
Interarrival time variability: Level 3
Basis arrival rates: Level 3

Ten observations (i.e., n=10 replications) of the average message delay are collected with a run length of 4000 msec, and the estimates of population mean and variance are calculated, as shown below:

Observations (X): 1.356 1.368 1.134 1.415 1.360
1.220 1.386 1.182 1.297 1.403

Sample mean ($\bar{X}$) = 1.3121

Sample variance ($S(X)^2$)= 0.009891

Step 2. If we assume that $S(X)^2$ will not change as the number of replications increases, an approximate expression for the number of replications $n^*(\beta)$, required to obtain an absolute error of β is given by

$$n^*(\beta) = \min \{ i \geq n : t_{i-1,\alpha/2} \cdot [S(X)^2/i]^{1/2} \leq \beta \}.$$

We can determine $n^*(\beta)$ by iteratively increasing i by 1 until a value of i is obtained for which $t_{i-1,\alpha/2} \cdot [S(X)^2/i]^{1/2} \leq \beta$. The absolute error β can be defined as

$|\overline{X} - \mu|$, where, μ is the population mean. If we use a significance level (α) of 0.10 and assume that β is equal to 4% of the sample mean (i.e., 0.05248), the number of replications $n^*(\beta)$ required is 18. Therefore, 18 replications for each of 27 experiments are used in this study based on an α value of 0.10 and a β value of 0.05248 (i.e., 4% of the sample mean).

Steady State Simulation

A steady state simulation is a simulation whose objective is to study long-run (or steady state) behavior of a nonterminating system (Banks and Carson, 1984). The major issue when simulating a steady state system is to determine when the system is in a steady state so as to identify an appropriate warm-up period and run length. The run length of 4000 msec and warm-up period of 1000 msec, which were determined in the simulation pilot runs, are used in this research. That is, only the last 3000 msec of statistics are collected for each of 18 replications. During this period of 3000 msec, on the average, 3218 messages are expected to be transmitted when the traffic loads are symmetric and the basis arrival rate is set to 180 messages/second.

Simulation Model

The SLAM II (Simulation Language for Alternative Modeling) language (Pritsker, 1986; Pritsker, et al., 1989) is used to develop the simulation model utilized in this research effort. SLAM II is a high-level, FORTRAN-based simulation language which provides process, discrete event, and continuous model capabilities. In the process modeling, SLAM employs a "network" structure which consists of specialized symbols called nodes and branches. The entities in the system flow through the network model. In process modeling, if necessary, user-written FORTRAN subprograms can be developed by the modeler to perform the more detailed or complex tasks such as scheduling heuristics. The process modeling approach is used to develop a simulation model in this research. The simulation programs and the network model (graphic model) are shown in Appendices A and B, respectively.

Model Verification and Validation

Verification is the process of comparing the conceptual model with the simulation program that implements the model. Validation, on the other hand, is the process of checking the simulation model against reality for the intended application. Verification and validation should begin at the onset of the model constructing process and continue throughout the study. Actually, simulation model construction, verification, and validation often are in a dynamic, feedback loop. Although the concepts of verification and validation are different, in practice they may overlap to a considerable extent (Carson, 1989; Bratley, et al., 1987).

The following techniques (and their combinations) are used to verify and/or validate the simulation model in this study: documentation, structured programming and modular testing, debugging (i.e., to include additional checks and outputs in the program that will point out the bugs), sensitivity analysis, traces, input-output transformation, testing deterministic models, and testing simplified cases. A brief description of part of the test runs by using traces, input-output transformation, deterministic models, and simplified cases is presented below.

Test 1. This test uses a run length of 4000 msec with the first 1000 msec of data discarded. This test uses 10 replications. Additional collect nodes, denoted COLCT, are added to the network to collect the statistics for each message. The purpose of this test is to check the total number of messages transmitted, the number of messages transmitted from each station, and the number of messages with different priority classes transmitted, etc. All 27 experiments are tested and, in general, the simulation results are within one percent of the expected values. For example, the results show that the average numbers of messages transmitted are 3218, 4111, and 5007 messages (the expected values are 3240, 4140, and 5040 messages) when the traffic loads are symmetric and the basis arrival rates are set to 180, 230, and 280 messages/second, respectively.

Test 2. This test releases a single message from each station into the system. The SLAM control statement "MONTR,TRACE" is used to trace the path and timing when messages flow through the network model. The statistical data (i.e., message delay and bus utilization) are collected. The trace reports are carefully checked to ensure that the developed network model meets the intended applications and the statistical data are correctly collected.

Test 3. This test releases messages with different priority classes from the first station into the system. Again, the SLAM control statement "MONTR,TRACE" is used to trace the sequences that messages are transmitted. The trace reports are carefully checked to ensure that the priority mechanism implemented in the network model is correct.

Test 4. This test releases an error message (ATRIB(5) is set to 0) from the first station into the system. The SLAM control statement "MONTR,TRACE" is used to trace the transmission path and time of this error message. The trace reports are carefully checked to ensure that the transmission mechanism for error messages implemented in the network model is correct.

CHAPTER IV

ANALYSIS OF RESULTS AND CONCLUSIONS

Introduction

This chapter presents the analysis, interpretation, and conclusions of the simulation experiments. First, the average message delays for all priority classes are graphically displayed under each level of asymmetry of traffic loads (ATL) and basis arrival rates (BAR). Second, the average message delays for each sending station are graphically presented under each of the nine combinations of asymmetry of traffic loads (ATL) and basis arrival rates (BAR). Third, the bus utilizations are graphically shown under each level of asymmetry of traffic loads (ATL) and basis arrival rates (BAR). Following each of the graphical presentations of performance measures (i.e., message delay and bus utilization), a discussion of the results is presented. Finally, the conclusions drawn from the study and suggestions for future research are presented.

Average Message Delay for all Priority Classes

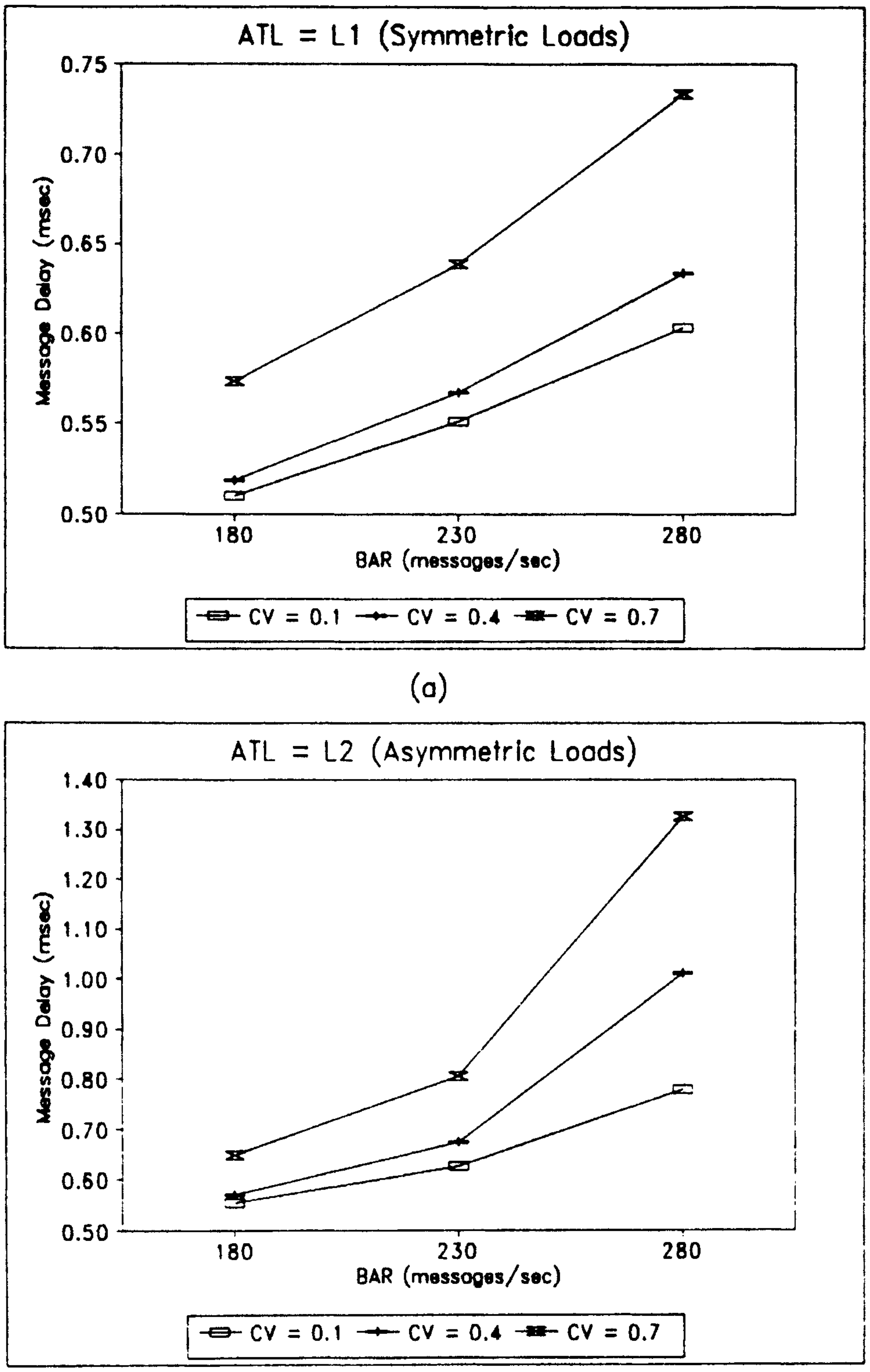
First, a listing of the abbreviations for the terms used in this chapter is shown in Table 4.1.

TABLE 4.1

ABBREVIATIONS

Term	Abbreviation
Asymmetry of Traffic Loads	ATL
Interarrival Time Variability	ITV
Basis Arrival Rates	BAR
Coefficient of Variation	CV
Sending Station # 1	S1
Sending Station # 2	S2
Sending Station # 3	S3
Sending Station # 4	S4
Sending Station # 5	S5
Sending Station # 6	S6
Level 1	L1
Level 2	L2
Level 3	L3

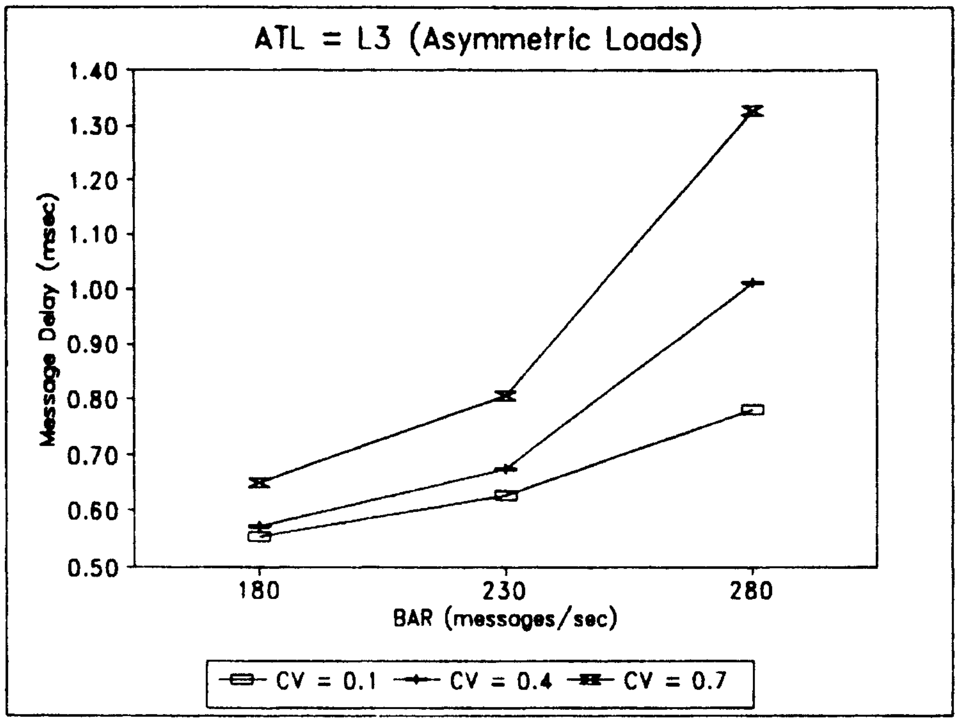
The average message delays for all priority classes under each level of asymmetry of traffic loads (ATL) and basis arrival rates (BAR) are graphically presented in Figure 4.1. The graphs in Figure 4.1 (a), (b), (c) show the average message delay as a function of the basis arrival rate (BAR) under each level of asymmetry of traffic



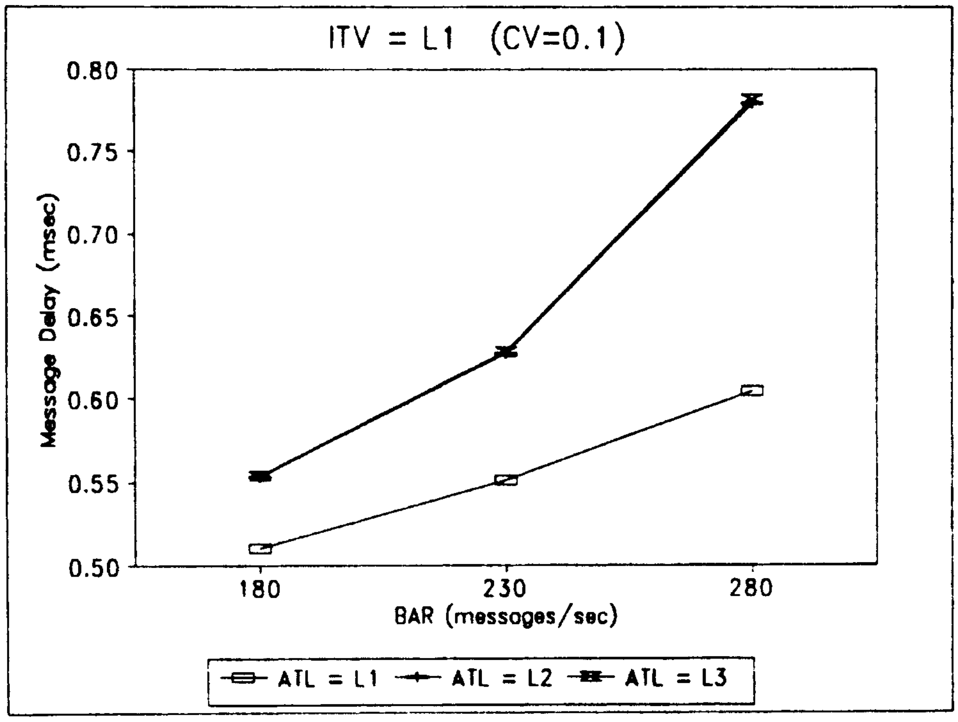
(a)

(b)

Figure 4.1 Average Message Delay for All Priority Classes

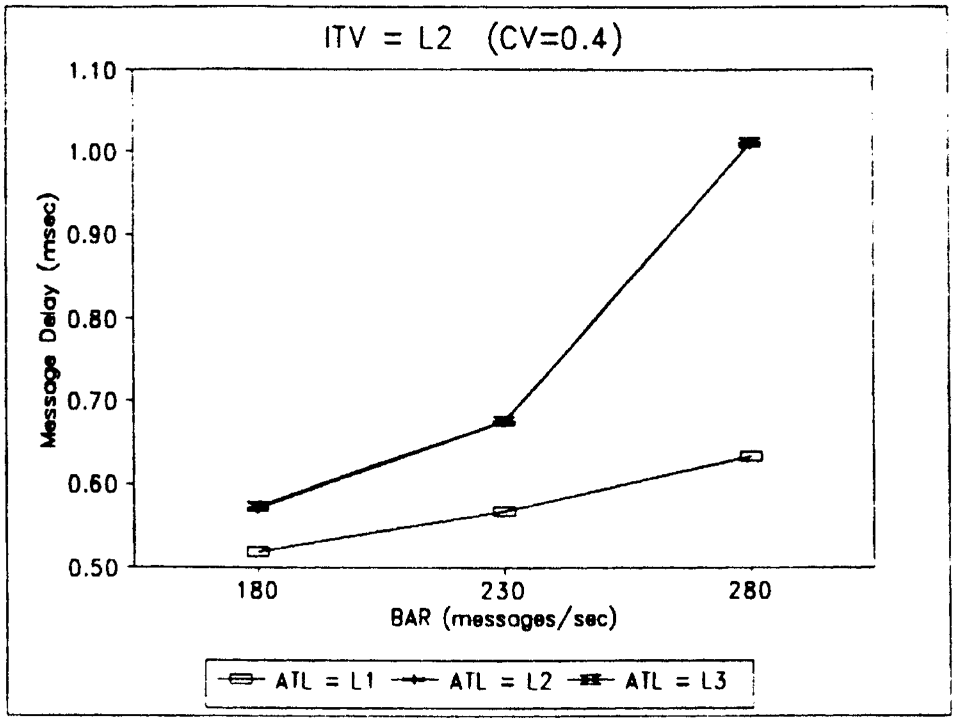


(c)

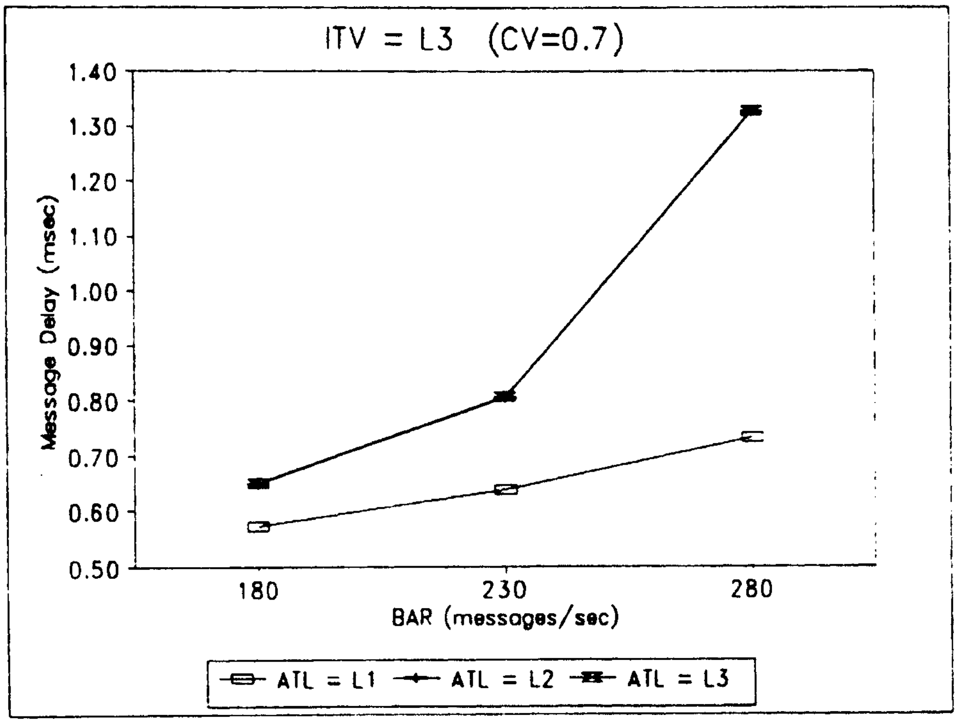


(d)

Figure 4.1 (Continued)



(e)



(f)

Figure 4.1 (Continued)

loads (ATL). The graphs in Figure 4.1 (d), (e), (f) show average message delay as a function of the basis arrival rate (BAR) under each level of interarrival time variability (ITV).

Graphs in Figure 4.1 show that, given a level of asymmetry of traffic loads (ATL) and a level of interarrival time variability (ITV), the average message delay increases as the level of basis arrival rates (BAR) increases. As can be seen from the graphs in Figure 4.1 (a), (b), (c), given a level of asymmetry of traffic loads (ATL) and a level of basis arrival rates (BAR), the average message delay increases as the level of interarrival time variability (ITV or CV) increases.

As can be seen from the graphs in Figure 4.1 (d), (e), (f), given a level of interarrival time variability (ITV or CV) and a level of basis arrival rates (BAR), the average message delay for asymmetric traffic loads is larger than that for symmetric traffic loads. Moreover, the average message delays for the two levels of asymmetric traffic loads are not significantly different.

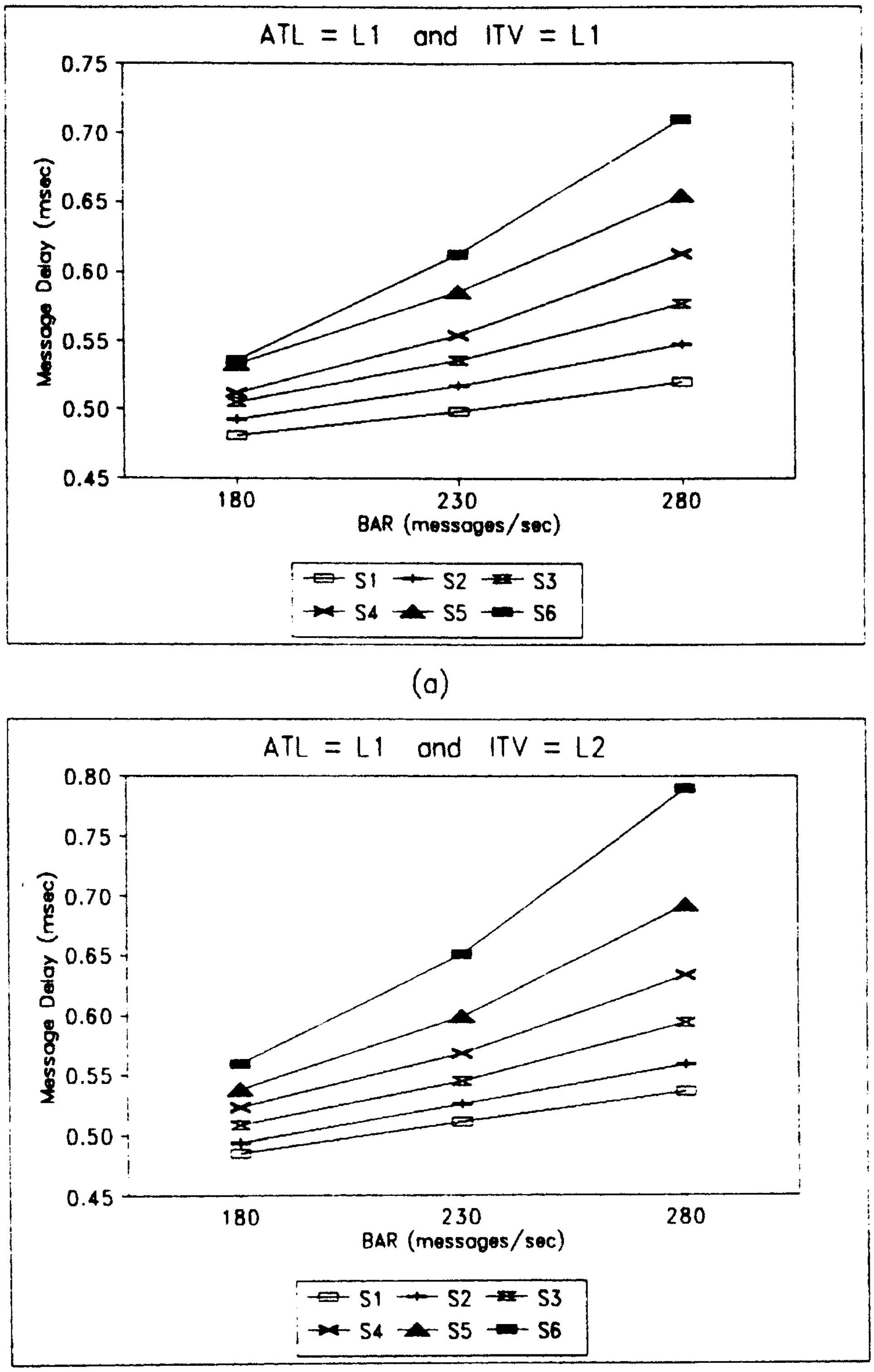
With higher levels of asymmetry of traffic loads (ATL), interarrival time variability (ITV), and basis arrival rates (BAR), the patterns of average message delays become sharper. This can be explained as follows: with higher levels of asymmetry of traffic loads (ATL), interarrival time variability (ITV), and basis arrival rates (BAR), the nonlinear effects of these three factors on the average message delays are more significant.

Average Message Delay for each Sending Station

The average message delays for each sending station under each of the nine combinations of asymmetry of traffic loads and basis arrival rates (ATL and BAR) are graphically presented in Figure 4.2. Each of the six stations can send messages with two different priorities to the CAN bus. For example, station 1 (S1) can send messages with priorities 1 (highest) and 2, and station 6 (S6) can send messages with priorities 11 and 12 (lowest).

Graphs in Figure 4.2 show that, given a combination of asymmetry of traffic loads and interarrival time variability (ATL and ITV), and a sending station, the average message delay increases as the level of basis arrival rates (BAR) increases. It also can be seen from Figure 4.2 that, given a combination of asymmetry of traffic loads and interarrival time variability (ATL and ITV), and a basis arrival rate (BAR), the average message delay increases as the number of the sending station increases. Recall that higher numbered stations send messages with lower priorities.

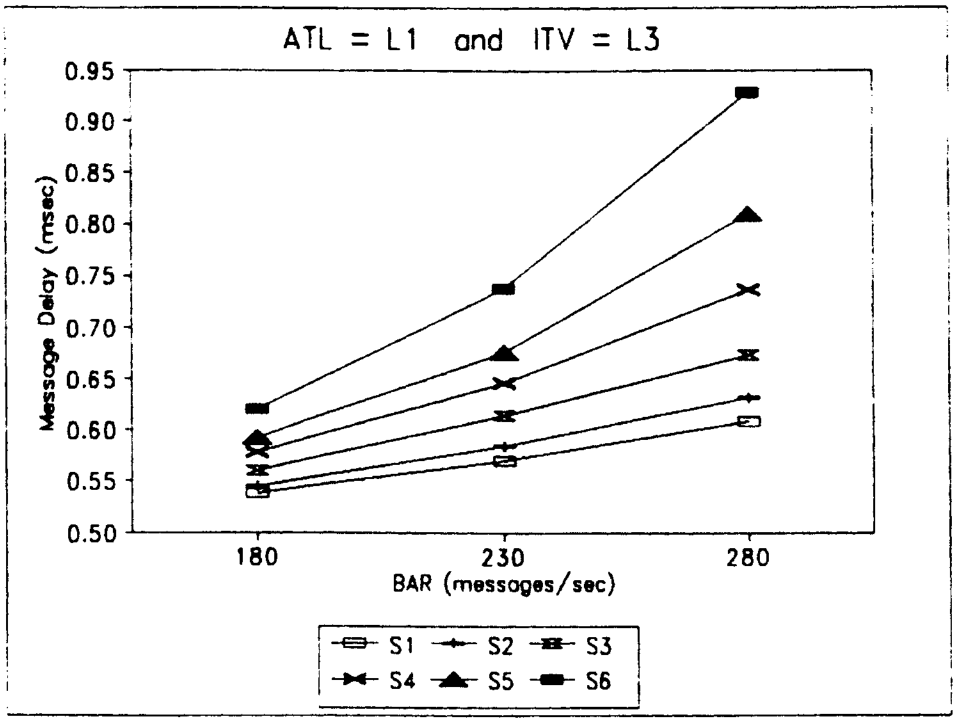
Overall, the effect of the sending station number (i.e., the message priority) on the average message delay is significant. In addition, with higher levels of the



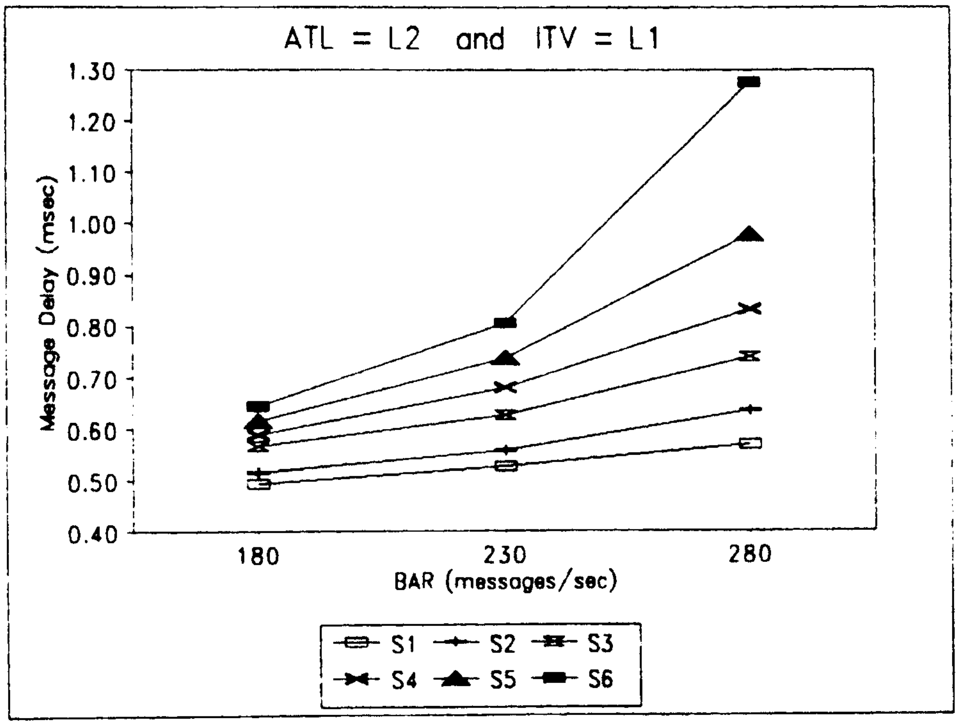
(a)

(b)

Figure 4.2 Average Message Delay for Each Sending Station

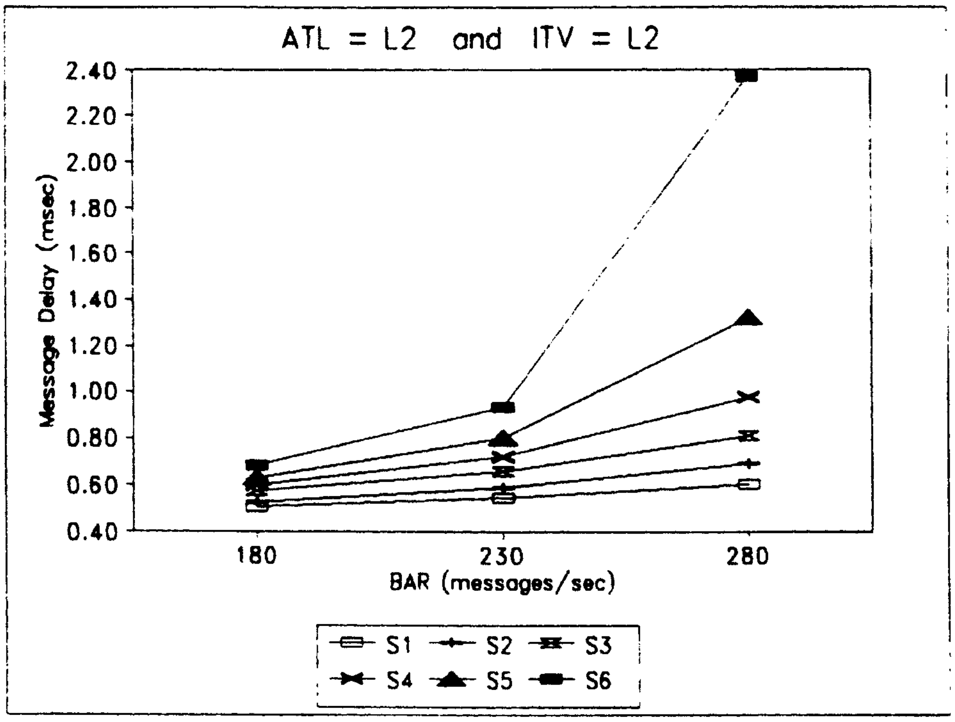


(c)

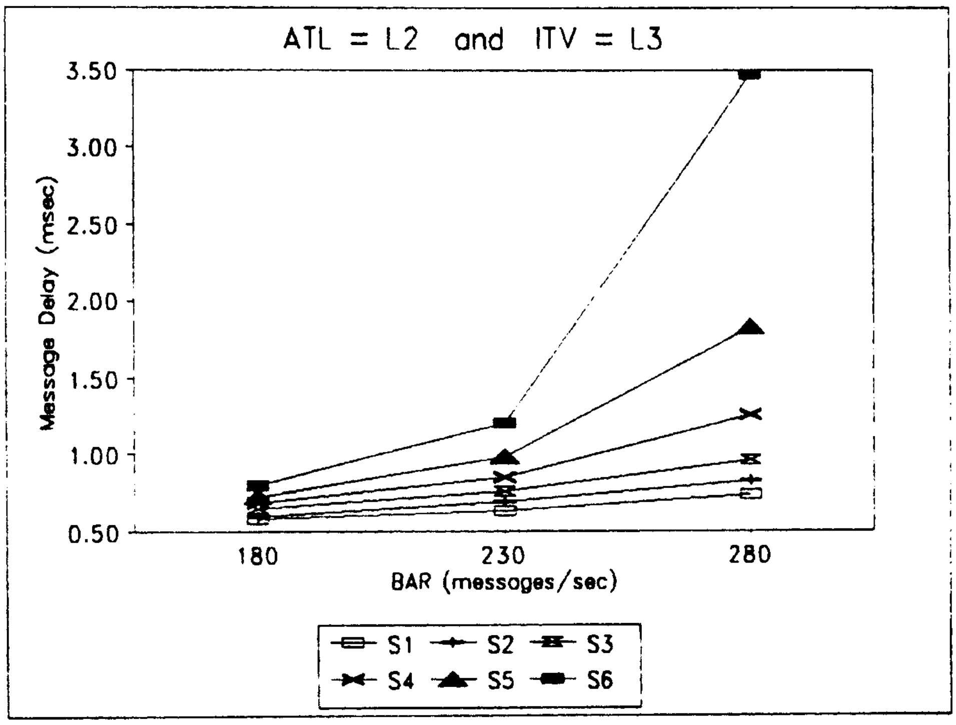


(d)

Figure 4.2 (Continued)

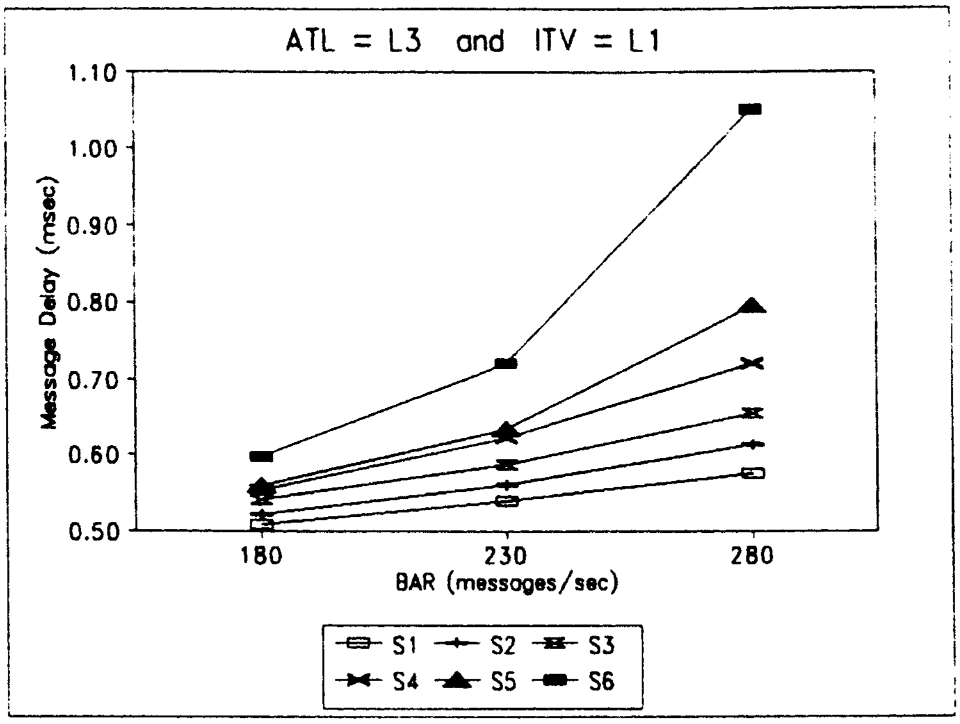


(e)

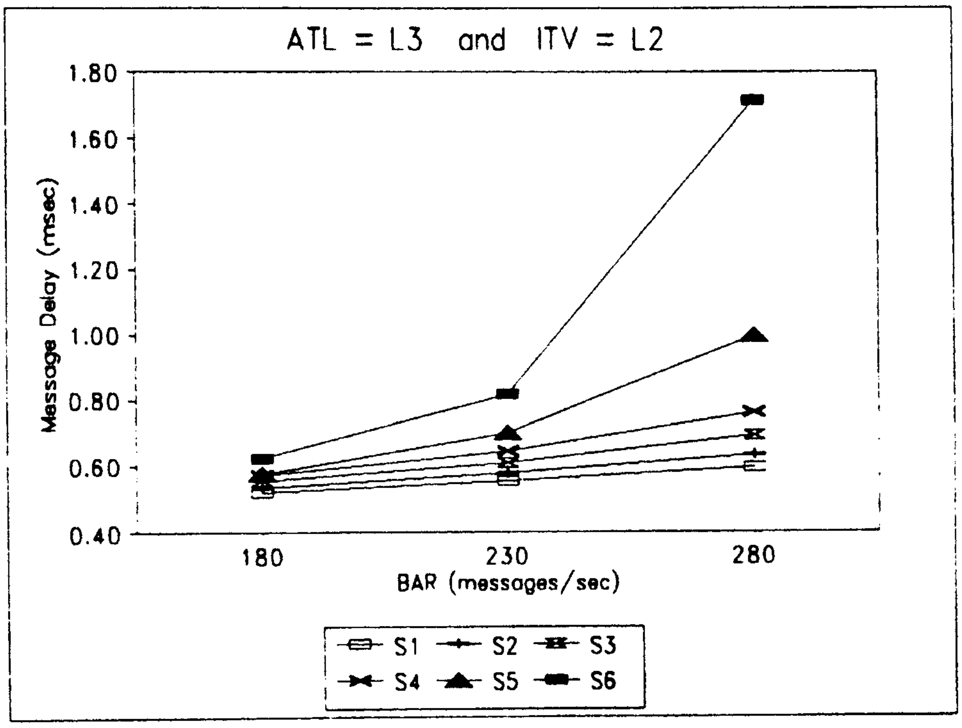


(f)

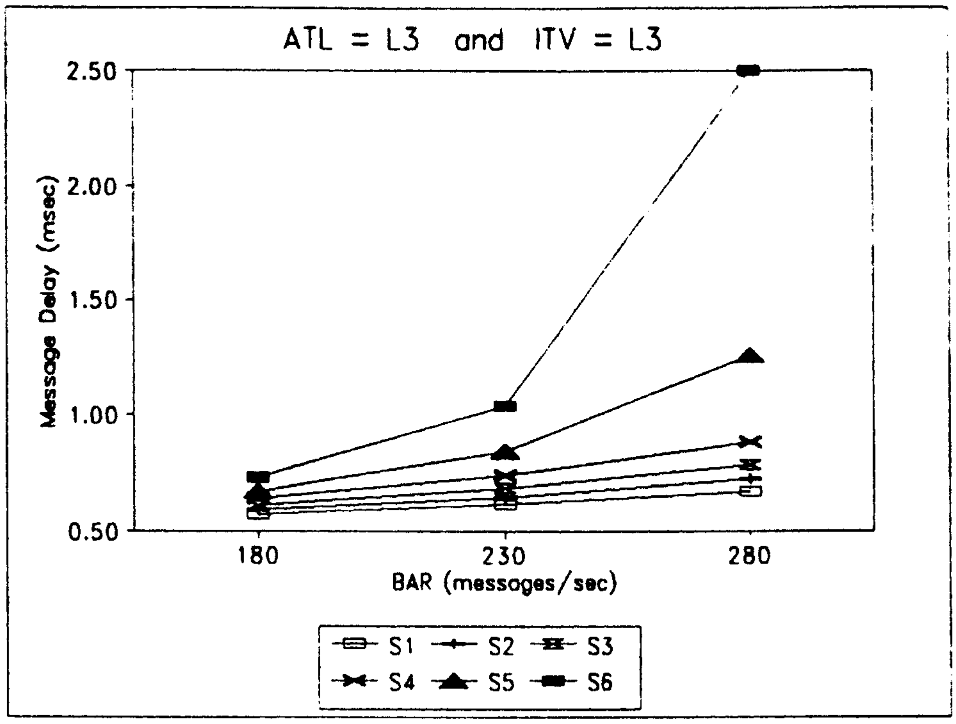
Figure 4.2 (Continued)



(g)



(h)
Figure 4.2 (Continued)



(i)
Figure 4.2 (Continued)

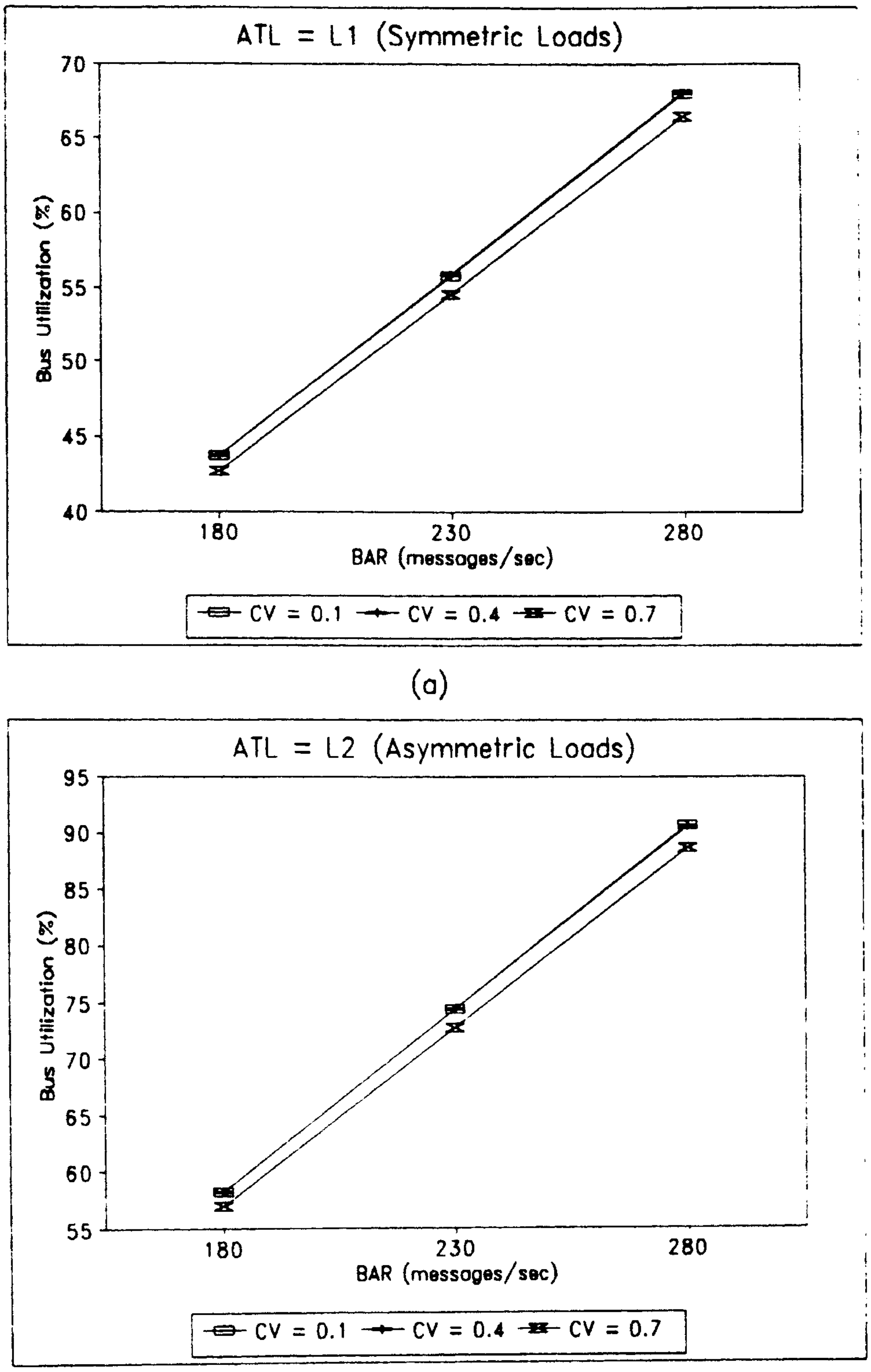
three experimental factors, the patterns of average message delays become sharper (especially for station 6). This can be explained as follows: with higher levels of the three factors, the effect of the sending station number (i.e., the message priority) on the average message delay is more significant.

Average Bus Utilization

The average bus utilization under each level of asymmetry of traffic loads (ATL) and basis arrival rates (BAR) are graphically presented in Figure 4.3. The graphs in Figure 4.3 (a), (b), (c) show the average bus utilization as a function of the basis arrival rates (BAR) under each level of asymmetry of traffic loads (ATL). The graphs in Figure 4.3 (d), (e), (f) show the average bus utilization as a function of the basis arrival rates (BAR) under each level of interarrival time variability (ITV).

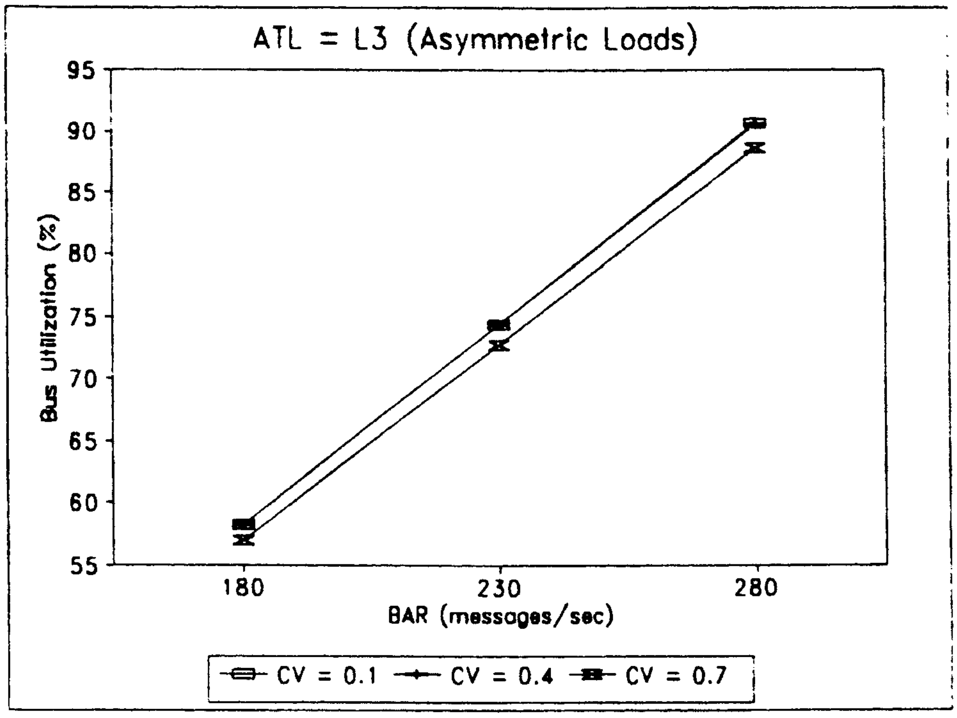
Graphs in Figure 4.3 show that, given a level of asymmetry of traffic loads (ATL) and a level of interarrival time variability (ITV), the average bus utilizations increases as the basis arrival rate (BAR) increases.

As can be seen from the graphs in Figure 4.3 (a), (b), (c), given a level of asymmetry of traffic loads (ATL) and a basis arrival rate (BAR), the average bus utilization for CV=0.1 or 0.4 is larger than that for CV=0.7. Moreover,

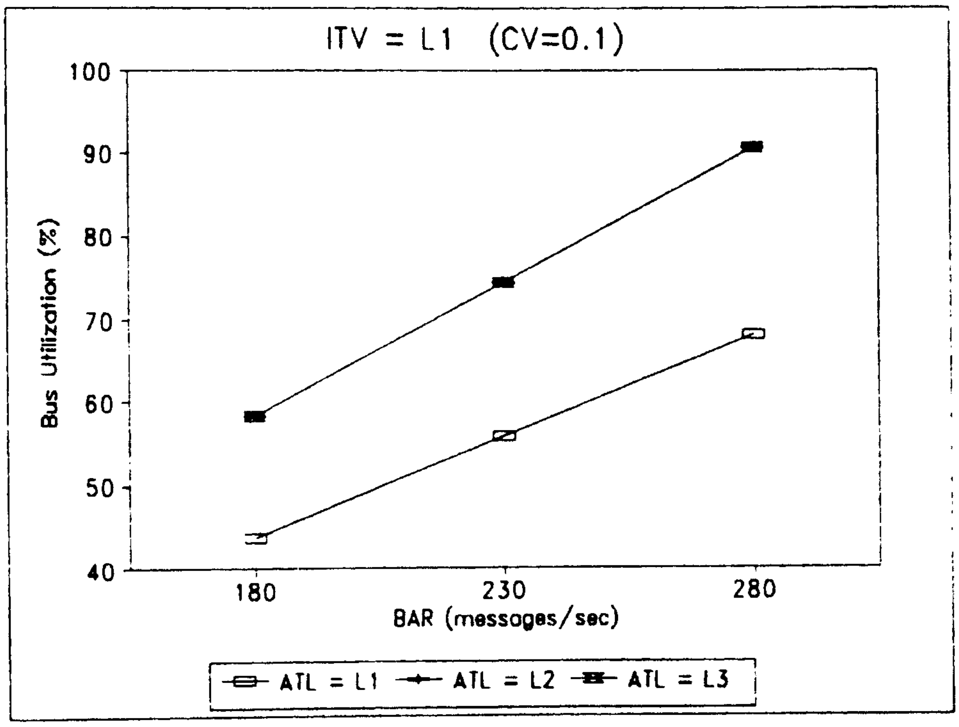


(b)

Figure 4.3 Average Bus Utilization

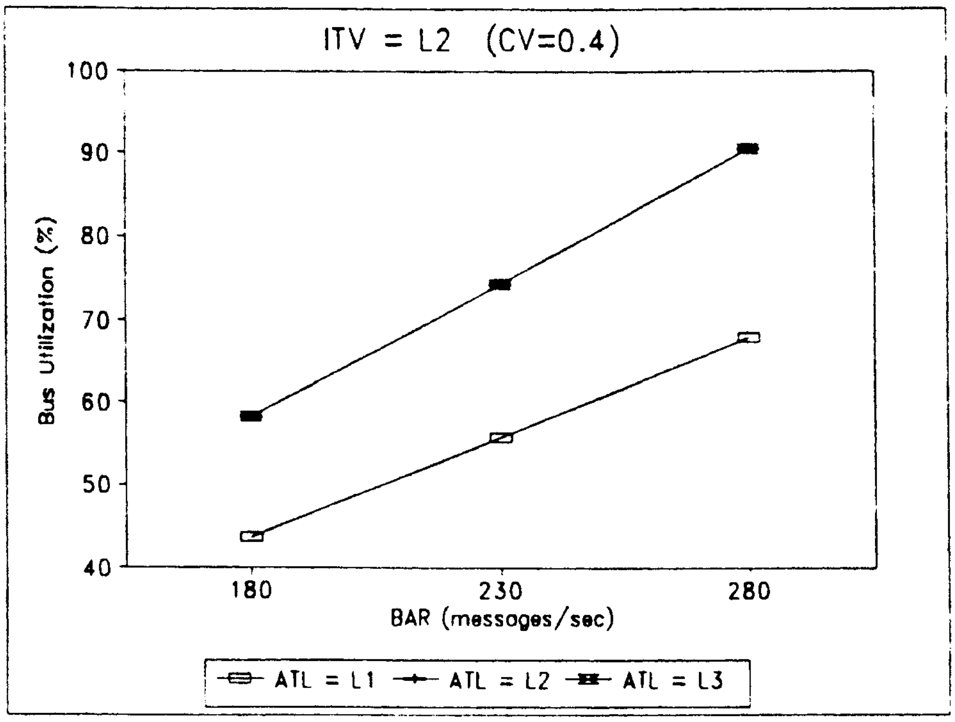


(c)

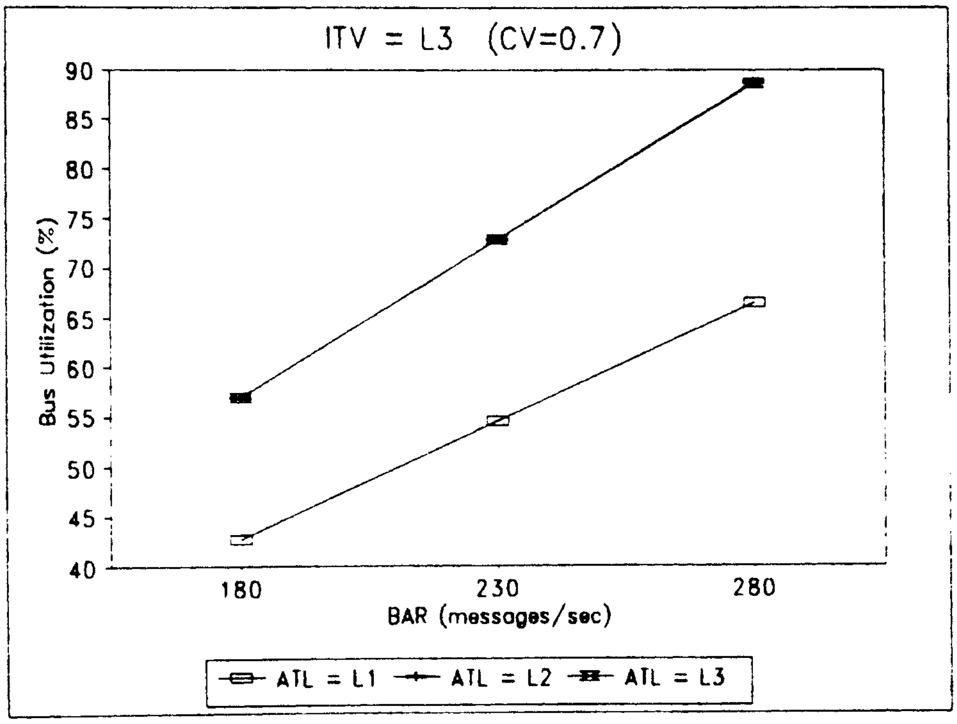


(d)

Figure 4.3 (Continued)



(e)



(f)

Figure 4.3 (Continued)

the average bus utilization for CV=0.1 and CV=0.4 are not significantly different.

As can be seen from the graphs in Figure 4.3 (d), (e), (f), given an interarrival time variability (ITV or CV) and a basis arrival rate (BAR), the average bus utilization for asymmetric traffic loads is larger than that for symmetric traffic loads. Moreover, the average bus utilizations for the two levels of asymmetric traffic loads are not significantly different.

Overall, the patterns of change in the average bus utilizations are nearly linear. This can be explained as follows: the nonlinear effects of the three factors on the average bus utilizations are not significant. The bus utilizations are between 43% and 68% for symmetric systems and between 58% and 91% for asymmetric systems.

Conclusions

The general conclusion drawn from Figures 4.1 and 4.2 is that the asymmetry of traffic loads (ATL), interarrival time variability (ITV), basis arrival rates (BAR), and message priority classes all impact the performance of the network with respect to the average message delay. With higher levels of asymmetry of traffic loads (ATL), interarrival time variability (ITV), basis arrival rates (BAR), and lower message priorities, the patterns of average message delays become sharper. The average message delays are not significantly different for the two levels of asymmetric traffic loads.

The general conclusion drawn from Figure 4.3 is that the asymmetry of traffic loads (ATL), interarrival time variability (ITV), and basis arrival rates (BAR) all impact the performance of the network with respect to the average bus utilization. With higher levels of asymmetry of traffic loads (ATL), interarrival time variability (ITV), and basis arrival rates (BAR), the average bus utilizations become larger. The average bus utilizations are not significantly different for the two levels of asymmetric traffic loads, and for CV=0.1 and CV=0.4.

In general, the nonlinear effects of the three experimental factors (i.e., ATL, ITV, and BAR) on the average message delays are significant. In addition, with higher levels of these factors, the patterns of the average message delays become sharper. Since the patterns of the average bus utilization are very similar and close to linear, it can be said that the nonlinear effects of the three factors on the average bus utilizations are not significant.

By comparing the performance of the symmetric system with the other two asymmetric systems with respect to the average message delay and average bus utilization under different levels in the interarrival time variability (ITV) and basis arrival rates (BAR), it can be finally concluded that the asymmetry of traffic loads (ATL) alters the behavior of a CAN by increasing the average message delay. This conclusion is consistent with the results of previous studies on LANs with ATL (e.g., Grela-M'Poko, et al., 1991; Senior, et al., 1992).

Future Research

By necessity, the scope of this research has been limited to a CAN with six stations and twelve message priorities, three experimental factors, and two performance measures. However, this research has provided the foundation for further research. Some examples of such research directions are described below.

Since the results of this research are obtained through the simulation of a hypothetical network model, the question arises as to the applicability of the results to a real CAN system. We can see this research as a preliminary experimental study in the area of Controller Area Networks subject to asymmetric traffic loads. Further research needs to be performed to evaluate network performance in broader scenarios of Controller Area Networks. These scenarios can have different network configurations, numbers of stations, and message priority classes.

In this research, the only three factors that appear to have a major impact on the performance of the network are selected and only three levels of each factor are chosen. Further research needs to be performed to investigate the effects of different factors and/or to include more levels of each factor in the investigation. For example, one conclusion drawn from the results of this research is that the asymmetry of traffic loads impacted the performance of the network. Therefore, it is logical to extend this research to include other degrees of asymmetry of traffic loads.

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APPENDICES

APPENDIX A

LISTING OF SIMULATION PROGRAMS

```
;*****************************************************
;*                                                   *
;*          SLAM II SIMULATION MODEL FOR             *
;*          CONTROLLER AREA NETWORKS (CAN)           *
;*            WRITTEN BY TSAO-JEAN LEU               *
;*                    IN NOVEMBER 1993               *
;*                                                   *
;*****************************************************
;
GEN,JEAN LEU,_THESIS,11/1/1993,18,N,N,,N,N,72;
LIMITS,7,5,32000;
;
;***** SET FILE OR QUEUE PRIORITY ==>
PRIORITY/1,LVF(3)/2,LVF(3)/3,LVF(3)/4,LVF(3)/
         5,LVF(3)/6,LVF(3)/7,LVF(3);
;
;***** EXPERIMENTAL FACTORS ==>
;****************************************************
;***  XX(1)=ATL (1-3), XX(5)=COMB OF ATV & BAR (1-9)
INTLC,XX(1)=1,XX(5)=1;
;****************************************************
;
;***** 3 LEVELS OF ATV (COEFF. OF VARIATION) ==>
INTLC,XX(28)=0.1,XX(29)=0.4,XX(30)=0.7;
;
;***** 3 LEVELS OF BAR (MESS/SEC), ATL MULTIPIER ==>
INTLC,XX(31)=180,XX(32)=230,XX(33)=280,XX(36)=2;
;
;***** BIT TRANSM TIME (MICROSEC/BIT, OR BAUD RATE =
;      250 KBIT/SEC) ==>
INTLC,XX(12)=4.E-3;
;
;***** MESSAGE LENGTH (BIT, OR 8 - 17 BYTES) ==>
INTLC,XX(14)=64.,XX(15)=136.;
;
;***** PROB OF ERRORS, ERROR MESSAGE LENGTH (BIT) ==>
INTLC,XX(13)=0.01,XX(16)=14;
;
;***** DEFINE ATTRIBUTES ==>
;ATRIB(1): MESSAGE CREATION TIME
;ATRIB(2): ORIGINAL STATION #
;ATRIB(3): MESSAGE PRIORITY (1 - 12)
;ATRIB(4): MESSAGE LENGTH (BIT)
;ATRIB(5): CORRECT (1) OR ERROR (0) MESSAGE
;
;***** DEFINE GLOBAL VARIABLES ==>
;XX(1): LEVEL OF ASYMMETRIC TRAFFIC LOAD [ATL]
;XX(2): LEVEL OF ARRIVAL TIME VARIABILITY [ATV]
;XX(3): LEVEL OF BASIS ARRIVAL RATE [BAR]
;XX(5): COMBINATION OF ATV & BAR
;XX(12): UNIT TRANSMISSION TIME (MSEC/BIT)
;XX(13): PROBABILITY OF MESSAGE ERROR
;XX(14),XX(15): MESSAGE LENGTH (BIT)
```

```
;XX(16): ERROR MESSAGE LENGTH (BIT)
;XX(18): RUN# TO BEG PRINTING REP (CURRENT RUN)
;XX(19): RUN# TO BEG PRINTING REP (OVERALL AVG)
;XX(21) - XX(26): MEAN INTERARRIVAL TIME (MSEC)
;                 AT STATIONS 1 - 6
;XX(28) - XX(30): COEFFICIENT OF VARIATION (C.V.)
;XX(31) - XX(33): BASIS ARRIVAL RATES
;XX(36): ATL MULTIPLIER FOR HEAVY STATIONS
;
;***** OBSERVATION BASED VARIABLES ==>
STAT,14,BUS UTILIZATION;
STAT,15,NUM MESS TRANSM;
STAT,21,DELAY P1_OA;
STAT,22,DELAY P2_OA;
STAT,23,DELAY P3_OA;
STAT,24,DELAY P4_OA;
STAT,25,DELAY P5_OA;
STAT,26,DELAY P6_OA;
STAT,27,DELAY P7_OA;
STAT,28,DELAY P8_OA;
STAT,29,DELAY P9_OA;
STAT,30,DELAY P10_OA;
STAT,31,DELAY P11_OA;
STAT,32,DELAY P12_OA;
STAT,33,DELAY ALL_OA;
STAT,34,BUS UTILIZAT_OA;
STAT,35,N MESS TRANS_OA;
;
;************** NETWORK BEGIN. *****************
;
NETWORK;
;
;*** DEFINE RESOURCES
;
      RESOURCE/STA1,1/STA2,2/STA3,3/STA4,4/STA5,5;
      RESOURCE/STA6,6/BUS,7;
;
;*** MESSAGE CREATION AT STATIONS 1 - 6
;
      CREATE,USERF(1),,1;
      ASSIGN,ATRIB(2)=1,II=UNFRM(1,3,2);
        ACT,,,AS1;
      CREATE,USERF(2),,1;
      ASSIGN,ATRIB(2)=2,II=UNFRM(3,5,2);
        ACT,,,AS1;
      CREATE,USERF(3),,1;
      ASSIGN,ATRIB(2)=3,II=UNFRM(5,7,2);
        ACT,,,AS1;
      CREATE,USERF(4),,1;
      ASSIGN,ATRIB(2)=4,II=UNFRM(7,9,2);
        ACT,,,AS1;
      CREATE,USERF(5),,1;
      ASSIGN,ATRIB(2)=5,II=UNFRM(9,11,2);
```

```
          ACT,,,AS1;
       CREATE,USERF(6),,1;
       ASSIGN,ATRIB(2)=6,II=UNFRM(11,13,2);
;
;*** ASSIGN ATTRIBUTES AND VARIABLES
;
AS1    ASSIGN,ATRIB(3)=II,ATRIB(5)=1;
       ASSIGN,ATRIB(4)=UNFRM(XX(14),XX(15),3);
;
;*** WAIT FOR RESOURCE: STATION
;
GO1    GOON,1;
          ACT,,ATRIB(2).EQ.1,T1;
          ACT,,ATRIB(2).EQ.2,T2;
          ACT,,ATRIB(2).EQ.3,T3;
          ACT,,ATRIB(2).EQ.4,T4;
          ACT,,ATRIB(2).EQ.5,T5;
          ACT,,ATRIB(2).EQ.6,T6;
T1     AWAIT(1),STA1;
          ACT,,,BUS;
T2     AWAIT(2),STA2;
          ACT,,,BUS;
T3     AWAIT(3),STA3;
          ACT,,,BUS;
T4     AWAIT(4),STA4;
          ACT,,,BUS;
T5     AWAIT(5),STA5;
          ACT,,,BUS;
T6     AWAIT(6),STA6;
;
;*** WAIT FOR RESOURCE: CAN BUS
;
BUS    AWAIT(7),BUS;
;
;*** MESSAGE TRANSMISSION
;
          ACT/1,ATRIB(4)*XX(12);
       GOON,1;
          ACT,,ATRIB(5).EQ.0,NER;
          ACT,,ATRIB(5).EQ.1,GO2;
NER    FREE,BUS;
       COLCT,BET,# OF ERRORS;
       TERM;
GO2    GOON,1;
          ACT,,XX(13),ERR;
          ACT,,1-XX(13),OK;
;
;*** TRANSMISSION ERROR BRANCH
;
ERR    GOON,2;
          ACT,,,AS2;
          ACT,,,FR1;
AS2    ASSIGN,ATRIB(4)=XX(16),ATRIB(5)=0;
```

```
          ACT,,,BUS;
FR1     FREE,ATRIB(2);
        FREE,BUS;
          ACT,,,GO1;
;
;*** TRANSMISSION OK BRANCH
;
OK      FREE,ATRIB(2);
        FREE,BUS;
;
;*** COLLECT STATISTICS: MEAN MESSAGE DELAY
;
        COLCT(13),INT(1),MES DELAY_ALL,,1;
          ACT,,ATRIB(3).EQ.1,P1;
          ACT,,ATRIB(3).EQ.2,P2;
          ACT,,ATRIB(3).EQ.3,P3;
          ACT,,ATRIB(3).EQ.4,P4;
          ACT,,ATRIB(3).EQ.5,P5;
          ACT,,ATRIB(3).EQ.6,P6;
          ACT,,ATRIB(3).EQ.7,P7;
          ACT,,ATRIB(3).EQ.8,P8;
          ACT,,ATRIB(3).EQ.9,P9;
          ACT,,ATRIB(3).EQ.10,P10;
          ACT,,ATRIB(3).EQ.11,P11;
          ACT,,ATRIB(3).EQ.12,P12;
P1      COLCT(1),INT(1),DELAY1;
          ACT,,,TME;
P2      COLCT(2),INT(1),DELAY2;
          ACT,,,TME;
P3      COLCT(3),INT(1),DELAY3;
          ACT,,,TME;
P4      COLCT(4),INT(1),DELAY4;
          ACT,,,TME;
P5      COLCT(5),INT(1),DELAY5;
          ACT,,,TME;
P6      COLCT(6),INT(1),DELAY6;
          ACT,,,TME;
P7      COLCT(7),INT(1),DELAY7;
          ACT,,,TME;
P8      COLCT(8),INT(1),DELAY8;
          ACT,,,TME;
P9      COLCT(9),INT(1),DELAY9;
          ACT,,,TME;
P10     COLCT(10),INT(1),DELAY10;
          ACT,,,TME;
P11     COLCT(11),INT(1),DELAY11;
          ACT,,,TME;
P12     COLCT(12),INT(1),DELAY12;
TME     TERM;
        END;
;
;*************** NETWORK END. ******************
;
```

```
;***** INIT:  TTBEG=0 (BEGINNING TIME OF A RUN)
;             TTFIN=4000 MSEC (ENDING TIME OF A RUN)
;             JJCLR=Y/21 --> CLEAR STAT ARRAYS BET RUNS?
;                CLEAR VAR TYPES 1-20
;                CUMULATE VAR TYPES FROM 21
;***** MONTR: TFRST=1000 MSEC (WARM-UP PERIOD)
INIT,0,4000,Y/21;
MONTR,CLEAR,1000;
FIN;
```

```
C******************************************************
C*                                                    *
C*              FORTRAN SUBPROGRAMS FOR               *
C*           CONTROLLER AREA NETWORKS (CAN)           *
C*              WRITTEN BY TSAO-JEAN LEU              *
C*                      IN NOVEMBER 1993              *
C*                                                    *
C******************************************************
C
      PROGRAM MAIN
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     1  MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     2  SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(1000000)
      DIMENSION NSET(1000000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=1000000
      NCRDR=5
      NPRNT=6
      NTAPE=7
C*** OUTPUT ALL MEASURES FOR STATISTICAL ANALYSIS
      OPEN (70, FILE= 'JEAN.SAS', STATUS= 'NEW')
      OPEN (80, FILE= 'JEAN.VIP', STATUS= 'NEW')
      CALL SLAM
      STOP
      END
C
C*********************************************************
C*          SUBROUTINE INTLC                             *
C*          -- SET INITIAL CONDITIONS AT THE BEGINNING   *
C*             OF EACH RUN                               *
C*********************************************************
C
      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     1  MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     2  SSL(100),TNEXT,TNOW,XX(100)
C
      DATA XX(18),XX(19) /1,18/
C
C***** DEFINE XX(5): COMB. OF ATV & BAR (XX(2) & XX(3))
C             1-9                         1-3     1-3
C
      IF(XX(5).EQ.1.OR.XX(5).EQ.2.OR.XX(5).EQ.3) XX(2)=1
      IF(XX(5).EQ.4.OR.XX(5).EQ.5.OR.XX(5).EQ.6) XX(2)=2
      IF(XX(5).EQ.7.OR.XX(5).EQ.8.OR.XX(5).EQ.9) XX(2)=3
      IF(XX(5).EQ.1.OR.XX(5).EQ.4.OR.XX(5).EQ.7) XX(3)=1
      IF(XX(5).EQ.2.OR.XX(5).EQ.5.OR.XX(5).EQ.8) XX(3)=2
      IF(XX(5).EQ.3.OR.XX(5).EQ.6.OR.XX(5).EQ.9) XX(3)=3
C
C***** ASSIGN INTERARRIVAL TIMES FOR 6 STATIONS
C
      IF(XX(3).EQ.1) BASIS=XX(31)
```

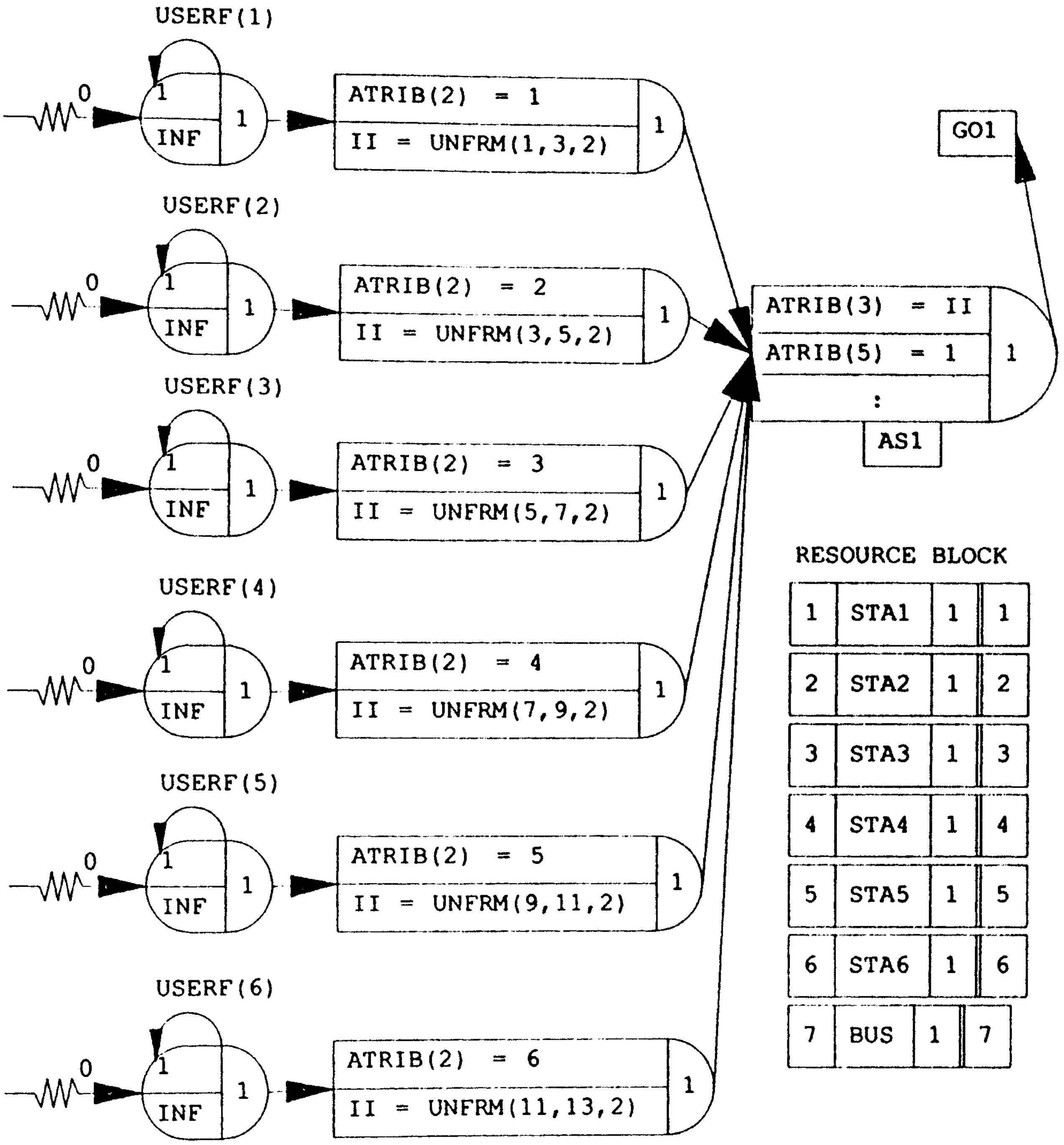
```
      IF(XX(3).EQ.2) BASIS=XX(32)
      IF(XX(3).EQ.3) BASIS=XX(33)
C
      DO 50 I=21,26
        XX(I)=1000./BASIS
  50  CONTINUE
C
      IF(XX(1).EQ.2) THEN
        XX(21)=1000./(BASIS*XX(36))
        XX(22)=1000./(BASIS*XX(36))
      ELSEIF(XX(1).EQ.3) THEN
        XX(25)=1000./(BASIS*XX(36))
        XX(26)=1000./(BASIS*XX(36))
      ENDIF
      RETURN
      END
C
C*********************************************************
C*          SUBROUTINE OTPUT                             *
C*          -- END-OF-RUN PROCESSING AT THE END OF       *
C*             EACH RUN                                  *
C*********************************************************
C
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     1  MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     2  SSL(100),TNEXT,TNOW,XX(100)
C
C***** COLLECT STATISTICS
C
C*** BUS UTILIZATION
      UTIL=AAAVG(1)*100.
      CALL COLCT(UTIL,14)
C*** # OF MESSAGES TRANSMITTED
      TOTMES=CCNUM(13)
      CALL COLCT(TOTMES,15)
C
C*** COLLECT WIHIN A RUN
      GRAND1=CCAVG(1)
      GRAND2=CCAVG(2)
      GRAND3=CCAVG(3)
      GRAND4=CCAVG(4)
      GRAND5=CCAVG(5)
      GRAND6=CCAVG(6)
      GRAND7=CCAVG(7)
      GRAND8=CCAVG(8)
      GRAND9=CCAVG(9)
      GRAND10=CCAVG(10)
      GRAND11=CCAVG(11)
      GRAND12=CCAVG(12)
      GRAND13=CCAVG(13)
      GRAND14=CCAVG(14)
      GRAND15=CCAVG(15)
```

```
C*** COLLECT AMONG RUNS (OVERALL)
      CALL COLCT(GRAND1,21)
      CALL COLCT(GRAND2,22)
      CALL COLCT(GRAND3,23)
      CALL COLCT(GRAND4,24)
      CALL COLCT(GRAND5,25)
      CALL COLCT(GRAND6,26)
      CALL COLCT(GRAND7,27)
      CALL COLCT(GRAND8,28)
      CALL COLCT(GRAND9,29)
      CALL COLCT(GRAND10,30)
      CALL COLCT(GRAND11,31)
      CALL COLCT(GRAND12,32)
      CALL COLCT(GRAND13,33)
      CALL COLCT(GRAND14,34)
      CALL COLCT(GRAND15,35)
C
C***** OUTPUT TO "JEAN.SAS"
C        (13) DELAY_ALL, (14) BUS_UTILIZATION
C
C***** CURRENT RUN =====>
      IF(NNRUN.GE.XX(18)) THEN
        IF(NNRUN.EQ.1) THEN
          WRITE(70,50) XX(1),XX(5)
  50      FORMAT(1X,'***** ATL/COM = ',F2.0,'/',F2.0,' ===>')
        ENDIF
C
      WRITE(70,55) CCAVG(13),CCAVG(14)
  55  FORMAT(2F10.2)
      ENDIF
C
C***** OVERALL AVERAGE (ACROSS ALL RUNS) =====>
      IF(NNRUN.GE.XX(19)) THEN
        WRITE(80,*)
     1   '--------------------------------------------'
        WRITE(80,60) XX(1),XX(5),NNRUN
  60    FORMAT(1X,'ATL/COM = ',F2.0,'/',F2.0,', NNRUN = ',I2)
        WRITE(80,61) CCAVG(21)
  61    FORMAT(1X,'MES DELAY P1_OA',F15.3)
        WRITE(80,62) CCAVG(22)
  62    FORMAT(1X,'MES DELAY P2_OA',F15.3)
        WRITE(80,63) CCAVG(23)
  63    FORMAT(1X,'MES DELAY P3_OA',F15.3)
        WRITE(80,64) CCAVG(24)
  64    FORMAT(1X,'MES DELAY P4_OA',F15.3)
        WRITE(80,65) CCAVG(25)
  65    FORMAT(1X,'MES DELAY P5_OA',F15.3)
        WRITE(80,66) CCAVG(26)
  66    FORMAT(1X,'MES DELAY P6_OA',F15.3)
        WRITE(80,67) CCAVG(27)
  67    FORMAT(1X,'MES DELAY P7_OA',F15.3)
        WRITE(80,68) CCAVG(28)
  68    FORMAT(1X,'MES DELAY P8_OA',F15.3)
```

```
      WRITE(80,69) CCAVG(29)
69    FORMAT(1X,'MES DELAY P9_OA',F15.3)
      WRITE(80,70) CCAVG(30)
70    FORMAT(1X,'MES DELAY P10_OA',F15.3)
      WRITE(80,71) CCAVG(31)
71    FORMAT(1X,'MES DELAY P11_OA',F15.3)
      WRITE(80,72) CCAVG(32)
72    FORMAT(1X,'MES DELAY P12_OA',F15.3)
      WRITE(80,73) CCAVG(33)
73    FORMAT(1X,'MES DELAY ALL P_OA',F15.3)
      WRITE(80,74) CCAVG(34)
74    FORMAT(1X,'BUS UTILIZATION_OA',F15.2)
     ENDIF
     RETURN
     END
C
C**********************************************************
C*           FUNCTION USERF                              *
C*           -- DETERMINE TIME BETWEEN CREATIONS (TBC)   *
C*              FOR CREATE NODES                         *
C**********************************************************
C
      FUNCTION USERF(N)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     1  MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     2  SSL(100),TNEXT,TNOW,XX(100)
C
      IF(XX(2).EQ.1) CV=XX(28)
      IF(XX(2).EQ.2) CV=XX(29)
      IF(XX(2).EQ.3) CV=XX(30)
C
      IF(N.EQ.1) USERF=RNORM(XX(21),XX(21)*CV,1)
      IF(N.EQ.2) USERF=RNORM(XX(22),XX(22)*CV,1)
      IF(N.EQ.3) USERF=RNORM(XX(23),XX(23)*CV,1)
      IF(N.EQ.4) USERF=RNORM(XX(24),XX(24)*CV,1)
      IF(N.EQ.5) USERF=RNORM(XX(25),XX(25)*CV,1)
      IF(N.EQ.6) USERF=RNORM(XX(26),XX(26)*CV,1)
      RETURN
      END
```

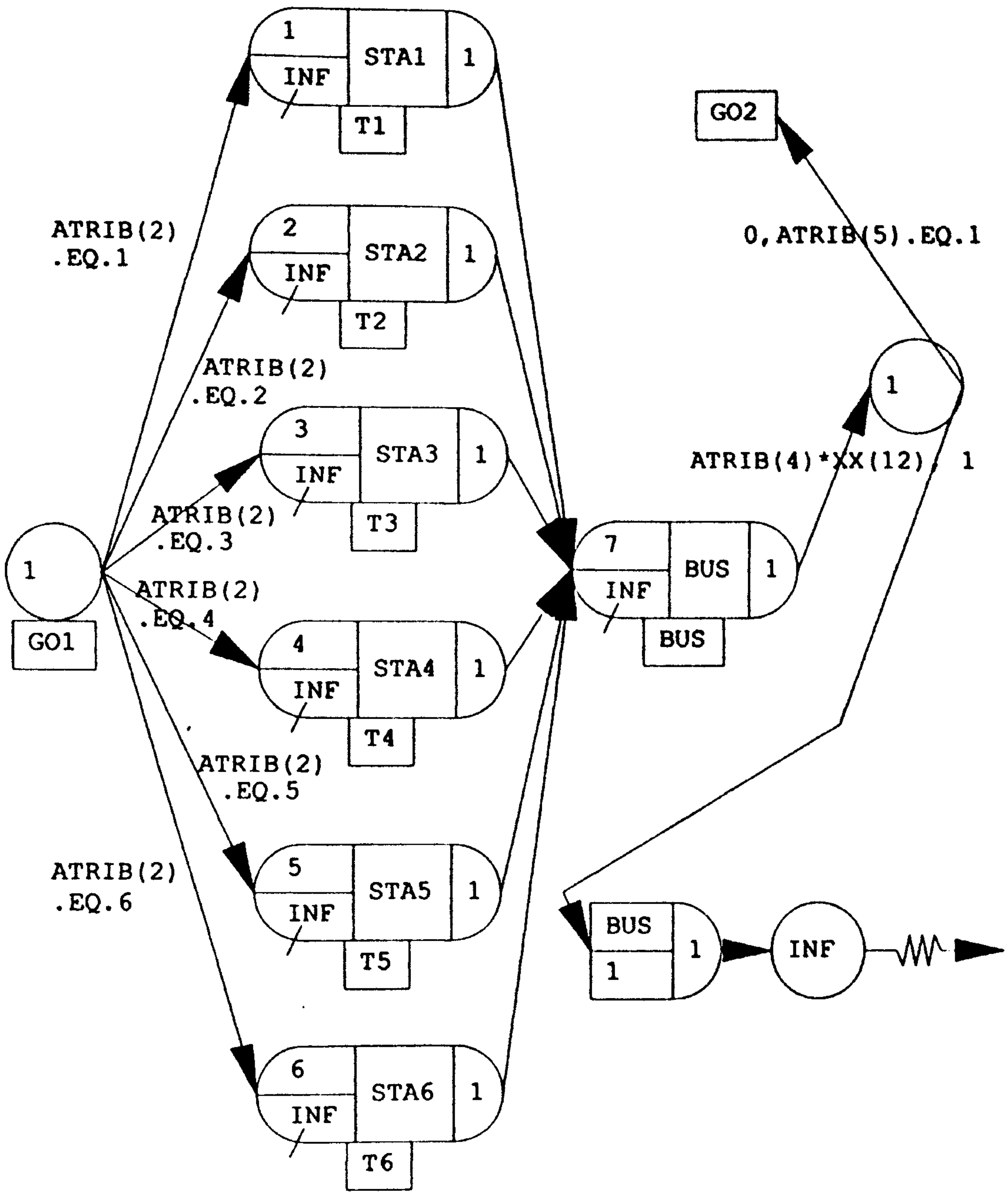
APPENDIX B

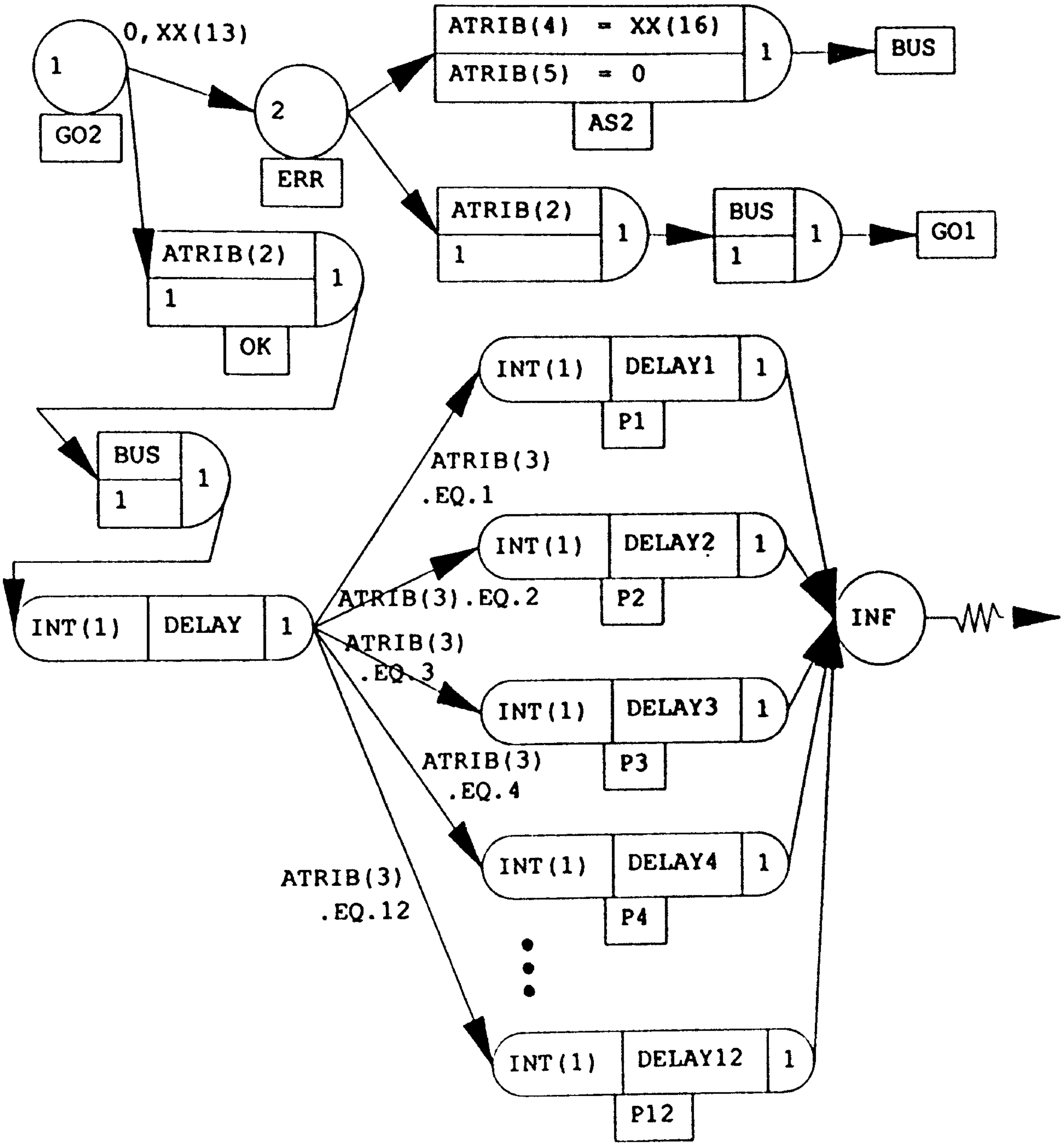
SLAM II NETWORK MODEL



RESOURCE BLOCK

1	STA1	1	1
2	STA2	1	2
3	STA3	1	3
4	STA4	1	4
5	STA5	1	5
6	STA6	1	6
7	BUS	1	7


1
INF
STA1
1
T1
GO2
ATRIB(2)
.EQ.1
2
INF
STA2
1
T2
0,ATRIB(5).EQ.1
ATRIB(2)
.EQ.2
3
INF
STA3
1
T3
1
ATRIB(4)*XX(12), 1
ATRIB(2)
.EQ.3
1
GO1
ATRIB(2)
.EQ.4
7
INF
BUS
1
BUS
4
INF
STA4
1
T4
ATRIB(2)
.EQ.5
ATRIB(2)
.EQ.6
5
INF
STA5
1
T5
BUS
1
1
INF
6
INF
STA6
1
T6


1
0,XX(13)
GO2
2
ERR
ATRIB(4) = XX(16)
ATRIB(5) = 0
1
AS2
BUS
ATRIB(2)
1
1
BUS
1
1
GO1
ATRIB(2)
1
1
OK
BUS
1
1
INT(1)
DELAY
1
INT(1)
DELAY1
1
P1
ATRIB(3)
.EQ.1
INT(1)
DELAY2
1
P2
ATRIB(3).EQ.2
ATRIB(3)
.EQ.3
INT(1)
DELAY3
1
P3
ATRIB(3)
.EQ.4
INT(1)
DELAY4
1
P4
ATRIB(3)
.EQ.12
INT(1)
DELAY12
1
P12
INF

VITA

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