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Delay performance of CEBUS and modified CEBUS schemes

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ABSTRACT

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by

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In this thesis the performance of the CEBUS (Consumer Electronics Bus), a local area network proposed by the Electronics Industries Association for the 'Smart House,' is analyzed under varying network load and traffic patterns that would occur in a typical home environment. Reduced complexity versions of the CEBUS scheme are compared with the standard CEBUS scheme.

It was found from simulation analysis that the delay in the CEBUS network, at a given network bandwidth, is dependent upon the message priority and the traffic pattern in the network. It was also observed that the performance of a modified CEBUS scheme was comparable to that of the regular CEBUS scheme.

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Dedicated to Parents

Passing year's steal something everyday;
at last they steal us from ourselves away.

-unknown-

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Chapter 1

Introduction

The Consumer Electronics Industry, which spans the range from entertainment products to appliances and alarm systems, is ever expanding. The amount of intelligence built into consumer appliances is also considerable. However most of these devices are stand alone devices having isolated control. A bus linking virtually all the electronic equipment in the home can provide the consumer with a comprehensive system of home information and control. In this environment, home appliances are given a new ability to communicate with each other, resulting in a single unified control for all the home devices.

Even though a power line home control system known as X-10 has been in existence for quite some time, it is a one way open loop system with limited potential for intelligent home control. The Electronic Industries Association, after six years of painstaking effort, has come out with a standard known as the Consumer Electronic Bus, or in short CEBUS, in Dec. 1989[1]. This standard provides the guideline by means of which all the electronic equipment in the home can be made to communicate over various media, to exchange control signals and other useful information. The Japanese and the Europeans have their own home automation standards, and an effort is being made to work out a combination of the three for a true world wide home automation standard.

CEBUS is a network specification based on the ISO/OSI seven layer network model. With CEBUS equipped products, home automation and control is very much simplified. For example, the home owner can check electronically his or her home security system, lock the doors, turn off the lights, adjust the thermostat, and switch off the TV, all from a single control panel.

The CEBUS can be used in any home as it defines the existing power line as a possible communication medium. Also the fact that CEBUS is a local area network gives it distributed intelligence, enabling new appliances to be added and removed as required. Hence the CEBUS will be required to operate under varying network loads and traffic patterns.

After the announcement of the CEBUS standard, research work is going on in this area. A study was made to analyze the performance of the CEBUS for a particular traffic pattern[2]. A scheme was suggested to reduce the delay of particular type of messages by modifying the CEBUS scheme[3]. Though the CEBUS was supposed to revolutionize the home automation area, it has not yet gained much popularity. This could because of the complexity of the scheme and the need to make existing home appliances compatible with the CEBUS.

The main objective of this thesis is to study the behavior and performance of the CEBUS under varying network loads and traffic patterns, especially under traffic patterns that would occur in a typical home environment in the near future. A modified CEBUS scheme of reduced complexity is proposed. Its performance is compared with that of the standard CEBUS scheme.

Chapter 2 describes the CEBUS architecture and organization. Chapter 3 discusses the simulation model of the CEBUS used in our study, and Chapter 4 presents the results obtained from the simulation study. Chapter 5 presents conclusions and suggestions for further work.

Chapter 2

CEBUS Description

In recent years many advancements have taken place in home automation. Many home control system components are available in the market. A bus linking virtually all the electronic equipment in the home can provide the consumer with a comprehensive system of home information, telecommunication, entertainment and control. To achieve this we need a standard to unify all the appliances, consumer electronics, security and other devices in the house so that they can interact economically.

The Electronics Industries Association (EIA) has promulgated a new standard for home communication through which standardized electronic equipment in the home can communicate[1]. This new standard is called the Home Automation standard or the Consumer Electronics Bus (CEBUS) standard. CEBUS is a local area network which provides a standardized communication facility for the exchange of control information and services among the various devices in the home. It is intended primarily to support non-data intensive functions such as remote control, status indication, remote instrumentation, energy management, security systems, entertainment module coordination and clock synchronization.

The CEBUS is based on the ISO/OSI seven layer model. However the CEBUS does not use all the layers defined by the OSI model. Figure 2.1 provides a graphical presentation of the CEBUS layering scheme. As can be seen from this figure the Presentation, Session and Transport layers are not present in the CEBUS. Their intended functions either do not apply to the spirit of the CEBUS, or are incorporated in other layers.

The services provided by each of the CEBUS network layers are outlined below.

2.1 CEBUS Physical Layer

This layer is at the lowest level and is responsible for the actual generation and reception of signals in the physical medium. CEBUS has been specified such that it can be used in six different physical media : Power line, Coaxial cable, Twisted pair, Infra-red, Radio frequency and Fiber optics.

2.1.1 Power Line Medium

Since all houses and buildings are wired for AC power, it is the most readily available low cost medium for CEBUS installations. However its biggest drawback is that it is a harsh and noisy environment. Though slow compared to the telephone line, for example, it is still able to attain a maximum data rate of about 700 bits/sec. Symbols are pulse-width encoded for transmission in an alternating sequence of SUPERIOR and INFERIOR states. The SUPERIOR state is denoted by the transmission of a burst of 120 KHz signal, and an INFERIOR state by the absence of the 120 KHz signal. Thus a symbol is represented by the duration of a state on the medium. The value of the symbol is conveyed by the pulse width.

There are four physical layer symbols defined. They are :

ONE = 1 Unit Symbol Time (UST)

ZERO = 2 Unit Symbol Times

EOF (End of Field) = 3 Unit Symbol Times

EOP (End of Packet) = 4 Unit Symbol Times

The symbol time for the shortest symbol (ONE) is defined as the Unit Symbol Time or UST. For the power line 1 UST = 1 msec, and the maximum signalling rate will be 1000 ONE bits/sec. The signal encoding of the power line is shown in Figure 2.2. As can be seen from this figure any symbol can be represented by either the SUPERIOR or INFERIOR states.

2.2 CEBUS Data Link Layer

The Data Link Layer provides to the Network Layer the facility to transmit and receive the data along a single segment of the physical medium. The Data Link Layer is subdivided into the Logical Link Control (LLC) sublayer and the Medium Access Control (MAC) sublayer as indicated in Figure 2.1.

2.2.1 Logical Link Control Sublayer

The data from the Network Layer, called Network Layer Protocol Data Unit (NPDU), are passed into this sublayer. The LLC sublayer administers the transmission and reception of the NPDU's through two types of service: i) Unacknowledged Connectionless Service and ii) Acknowledged Connectionless Service. Connectionless refers to the fact that each packet is individually and independently routed to its destination.

Unacknowledged connectionless service provides an exchange of data between peer Network layers without using an acknowledgement mechanism to verify the success of transmission. This service may operate on a local medium or may use a router to reach other media.

Acknowledged connectionless service transfers an NPDU between peer network layers using the Immediate Acknowledgement (IACK) mechanism to determine the success of the message delivery. When the originating message frame has been properly received, the receiver node forms an IACK frame. This IACK frame is sent out onto the local medium within 2 Unit Symbol Times of the EOP symbol from the originating node. During this time, all other nodes are in the minimum wait period of 6 Unit Symbol Times, which follows the end of packet. Hence by immediately taking control of the channel, the receiver node is assured of sending the IACK without having to contend for the channel.

An IACK correctly received within the allotted 4 Unit Symbol Times indicates the successful delivery of the originating frame. If no IACK is received, the originating data link layer sets the Retry status bit of the original frame to '1' and transmits the frame again without relinquishing control of the channel. Retransmission must begin during the fifth Unit Symbol Time after EOP. CEBUS allows only one retransmission by the Data Link Layer.

In the LLC sublayer a header is added to the front of the NPDU to form a Logical link control sublayer protocol data unit (LPDU). A local data frame is used to transmit data to nodes in the local medium and a non-local data frame is directed to routers for forwarding to the other media. Unprivileged frames originate at the Network layer and Privileged frames from the Layer System Management. The Retry bit is used to denote whether the packet is the original or the second copy sent if acknowledge was not received. The LPDU's are passed down from the LLC sublayer to the MAC sublayer.

2.2.2 Medium Access Control Sublayer

The MAC sublayer adds information onto the LPDU to create the MAC frame for transmission through the media. Figure 2.3 shows the final format of the MAC frame. All the fields are separated by the EOF symbol. The Preamble field is a fixed length 8 bit field which contains a random value for collision detection purposes. This a non-information bearing field, transmitted ahead of the information carrying fields to vie for the use of the channel. The Control field directs the handling of the frame and is generated by the LLC sublayer. It contains 8 bits.

The Destination address field specifies which node within a network or home system is to receive the frame. The Destination address field may address one or more network nodes. The Destination house code identifies the destination home system out of a group of systems, which share a common communication medium. Together the Destination address and the Destination house code identify a unique node. Similarly the Source address field and the Source house code identify the node from which the frame originated. Each of these fields is variable in length up to a maximum of 16 bits.

The Information field contains either an NPDU from the Network layer or Privileged data from the Layer System management. The Data link layer performs no operation on this field and is not aware of its contents. This field is variable in length up to a maximum of 32 bytes.

The Frame Check Sequence (FCS) field is the last field in the frame and provides a means for error detection at the receiving end. This field is variable in length up to a maximum of 8 bits and is generated in the MAC sublayer.

In the CEBUS, since multiple nodes are connected to an individual channel, the potential exists for conflicting transmissions. When this occurs the conflicting nodes are said to be in a state of contention. Hence CEBUS uses a modified CSMA/CD scheme called CSMA/CDCR (CSMA With Contention Detection and Contention Resolution). The contention resolution schemes employed by the CEBUS are prioritization of channel access, creation of a queued state and randomization of start time delay interval within each priority level. These schemes are outlined below.

2.2.3 Prioritization

Associated with each message is a priority level which is passed from the Network Layer, and denotes the relative level of importance of the message. Three priority levels are used, High, Standard and Deferred. High priority messages are given the first chance to access the channel. A Standard priority will impose 4 Unit Symbol Times of additional delay and Deferred priority will impose 8 Unit

Symbol Times of additional delay, to the initiation of message transmission. This allows nodes with higher priority frames to seize the channel before nodes with lower priority frames. Figure 2.4 illustrates these priority delays following the End Of Packet (EOP) symbol. Following the EOP symbol of the passing frame, all nodes on the network must wait a minimum of 6 Unit Symbol Times before accessing the channel.

2.2.4 Queueing

The prioritization scheme reduces the probability for conflict over use of the channel. However contention may still arise between nodes at the same priority level. To ensure that each contending node has an equal opportunity for channel access, a round robin queueing method within each priority level is used.

A transmitting node is considered to be in either a 'queued' or an 'unqueued state'. A node which has successfully completed a transmission once will be placed in the queued state. This state introduces an additional delay of 4 Unit Symbol Times into the node's channel access delay. A node which has not yet successfully transmitted a packet is in the unqueued state and no additional delay is added to an unqueued node's transmit process.

Because a queueing delay of 4 Unit Symbol Times is used, a selective overlap results in the delay times between different priority levels as shown in Figure 2.4. Although this overlap may introduce contention between higher priority nodes in the queued state and lower priority nodes in the unqueued state, such contention will affect the higher priority node during only one channel access.

Once a node completes a successful transmission, it places itself in the queued state, and imposes the additional delay on itself the next time it has a frame to transmit. When a queued node notices that no other nodes attempt to send a message during the 4 Unit Symbol times of its unqueued delay, it can be sure that there are no more unqueued nodes at that priority to transmit. If the queued node does not successfully transmit during its allocated time frame, it places itself in the unqueued state in the next channel access interval.

2.2.5 Randomization of Start Interval

As more than one node may be in the same priority level and queueing state, chances of contention still exist. To reduce this probability each node randomizes its transmission start time into four distinct periods within its priority and queue as shown in Figure 2.5. Specifically a delay of either 0, 1, 2 or 3 Unit Symbol Times is added to each transmitting node's channel access delay.

2.2.6 Contention Detection and Resolution

The use of SUPERIOR and INFERIOR media states enables contention detection. A SUPERIOR state will dominate any attempt to transmit an INFERIOR state. Hence transmitting nodes which sense a SUPERIOR state while sending INFERIOR states become aware of the presence of other transmitting nodes and abort their transmissions. However nodes transmitting in the SUPERIOR state cannot detect the presence of other transmitting nodes and retain control of the channel during a SUPERIOR state.

Contention normally occurs at the beginning of transmission. Since the

PREAMBLE field at the beginning of a frame contains a random sequence of bits, the probability is very high that transmitters will begin to hear each other and drop out until only one node is left in control of the channel. Although bits of a frame's PREAMBLE field may have been corrupted, the rest of the frame contents will be transmitted intact. When two or more nodes transmit simultaneously during some part of the frame past the PREAMBLE, interference occurs and data are lost. Such interference results in a bad received frame.

2.3 CEBUS Network Layer

The Network layer is concerned with communication across multiple media where the media are interconnected by devices known as routers. Hence the Network layer takes care of routing and flow control of the packets. The Network layer receives its messages from the Application layer, as depicted in Figure 2.1.

The parameters passed by the Application layer to the Network layer include the Application Layer Protocol Data unit (APDU), and other information such as addressing, allowed media and the level of service required by the Application layer. From this information the Network layer creates a Network Layer Protocol Data unit (NPDU) and this is passed down onto the LLC sublayer.

There are two possible NPDU formats, Normal and Extended. Normal formatted NPDUs are used for unsegmented data, when the message can be transmitted in a single packet. Extended NPDUs are used for segmented data, when the message size is large and must be broken into several packets for transmission. Messages are routed either by employing flood routing or by directory routing. In flood routing the packet is sent to all the available media, whereas in directory routing, the packet is transmitted only on the medium to which the destination node is connected. Flow control is provided by the Network layer by using the acknowledgement scheme when transmitting packets.

2.4 CEBUS Application Layer

CEBUS has no Transport, Sessions and Presentation layers. Hence the layer above the Network layer is the Applications Layer. Services are offered by the Application Layer to the user element and the application process by means of a language called Common Applications Language (CAL). CAL is a complete control language which CEBUS devices use to communicate with each other, and also for allocating resources and control.

CAL is table driven and has numerous commands for resource allocation and control of various device categories. Once a CAL command has been assembled, the message transfer section of the Application Layer adds a header to the front of the data to create an APDU (Application Layer Protocol Data unit), which is passed onto the Network layer.

Some of the CAL command messages are much larger than can be carried in a single packet. In such cases the Application layer breaks the long messages into smaller segments that can be contained in a single CEBUS packet. The segments are then passed down to the Network layer in sequence for delivery to the peer Application layer.

2.5 Layer System Management

Layer System Management is the entity in the network responsible for initializing variables and processes and for keeping and reporting network status information. The Layer System Management interacts with each layer of the network and may be envisioned as sitting adjacent to all the layers in the network hierarchy as shown in Fig 2.1.

2.6 Modified CEBUS Schemes

In a CEBUS scheme, three different message priorities exist. HIGH priority is allotted to messages which cannot tolerate much delay, whereas STANDARD or DEFERRED priority are allotted to messages which can tolerate some delay. There can be no ambiguity about which messages are to be allotted HIGH priority. When it comes to deciding whether a message has to be allotted STANDARD or DEFERRED priority, the decision could be quite difficult. This three priority is quite complex. The standard CEBUS scheme was modified in this work to reduce its complexity, and the performance of the schemes was compared.

2.6.1 Modified CEBUS Two Priority Scheme (2P-CEBUS)

Instead of having a three priority scheme, we define only two priorities, HIGH and STANDARD with wider time slots shown in Figure 2.6. Here HIGH priority is allotted to messages which cannot tolerate much delay, and STANDARD priority to messages which can tolerate some delay, reducing the complexity of the CEBUS scheme. This is referred to as 2P-CEBUS scheme in later chapters. This scheme is compared with the standard CEBUS scheme.

2.6.2 Modified CEBUS Non-Priority Scheme (NP-CEBUS)

If the priority scheme is completely eliminated, there is only one message type with access times as shown in Figure 2.7. Accordingly the slot size is made much wider than the other schemes. It is studied mainly because its performance is one that the other schemes must exceed to justify their complexity. This is referred to as NP-CEBUS scheme in later chapters. This scheme is also compared with the standard CEBUS scheme.

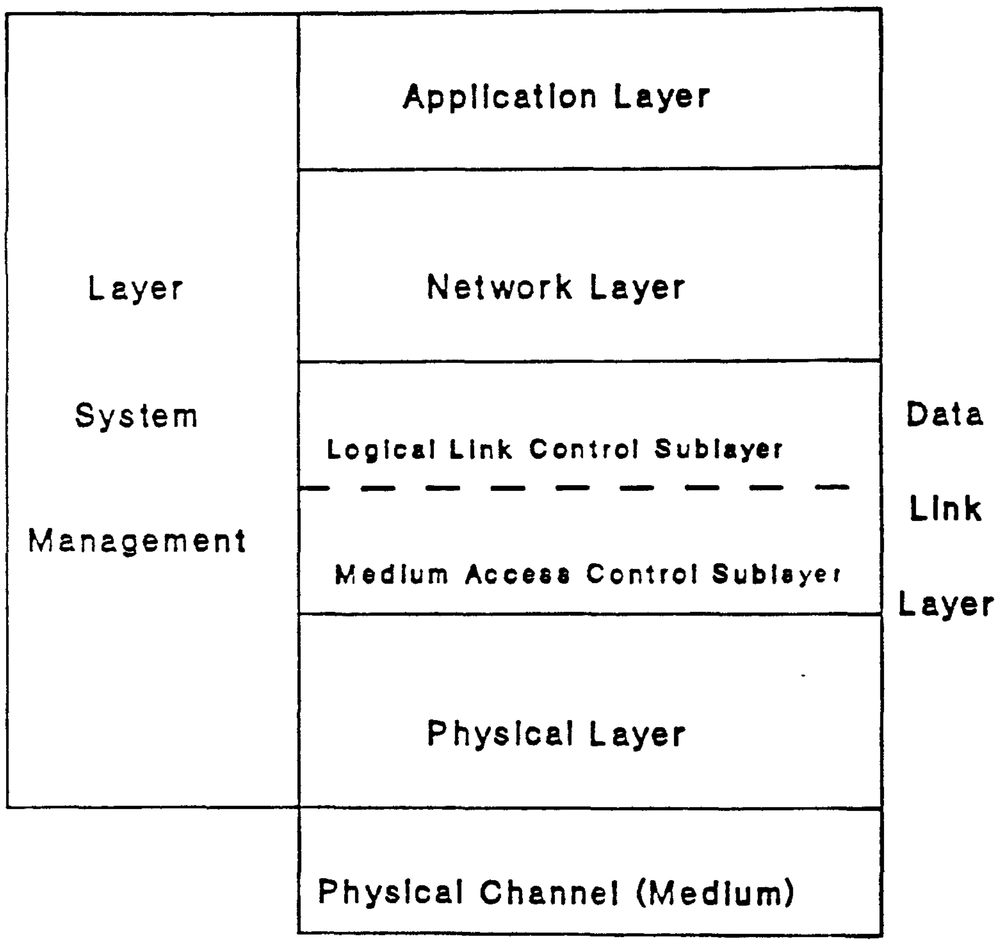

Figure 2.1 Layers of the CEBUS

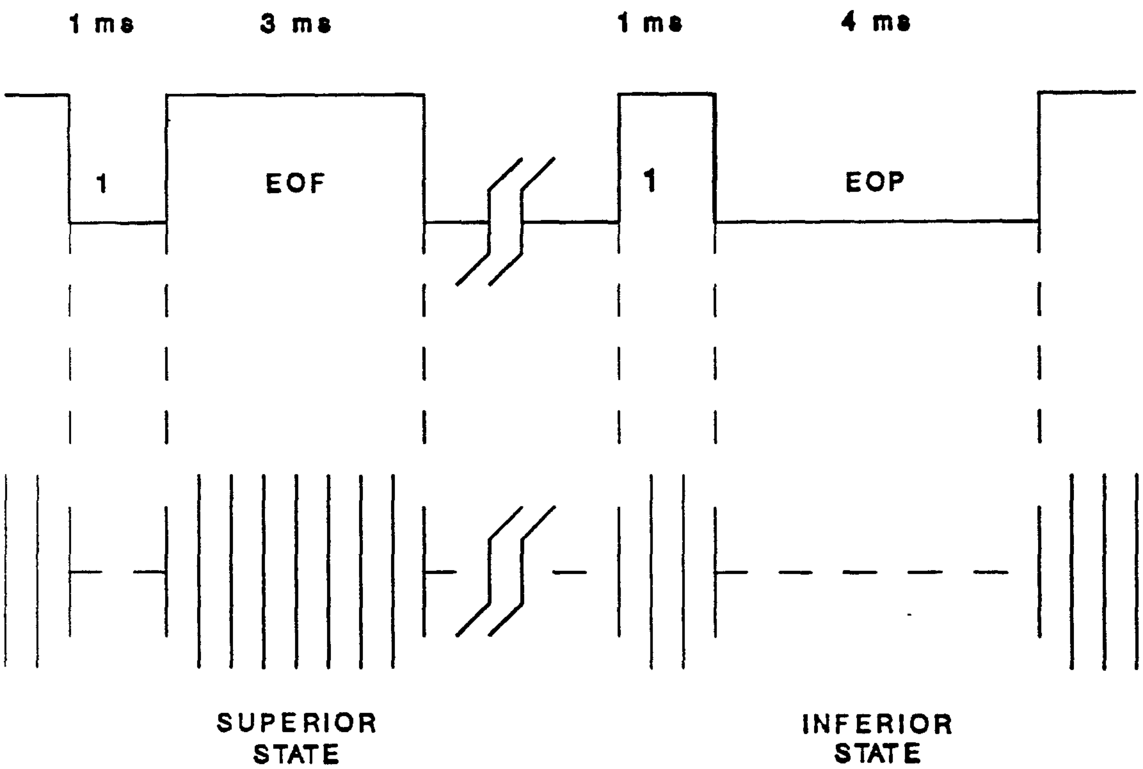

Figure 2.2 Physical Layer Symbol Encoding

PRE	Control	DA	DHC	SA	SHC	Information	FCS

PRE - Preamble

DA - Destination Address

DHC - Destination House Code

SA - Source Address

SHC - Source House Code

FCS - Frame Check Sequence

Figure 2.3 Normal Frame Format

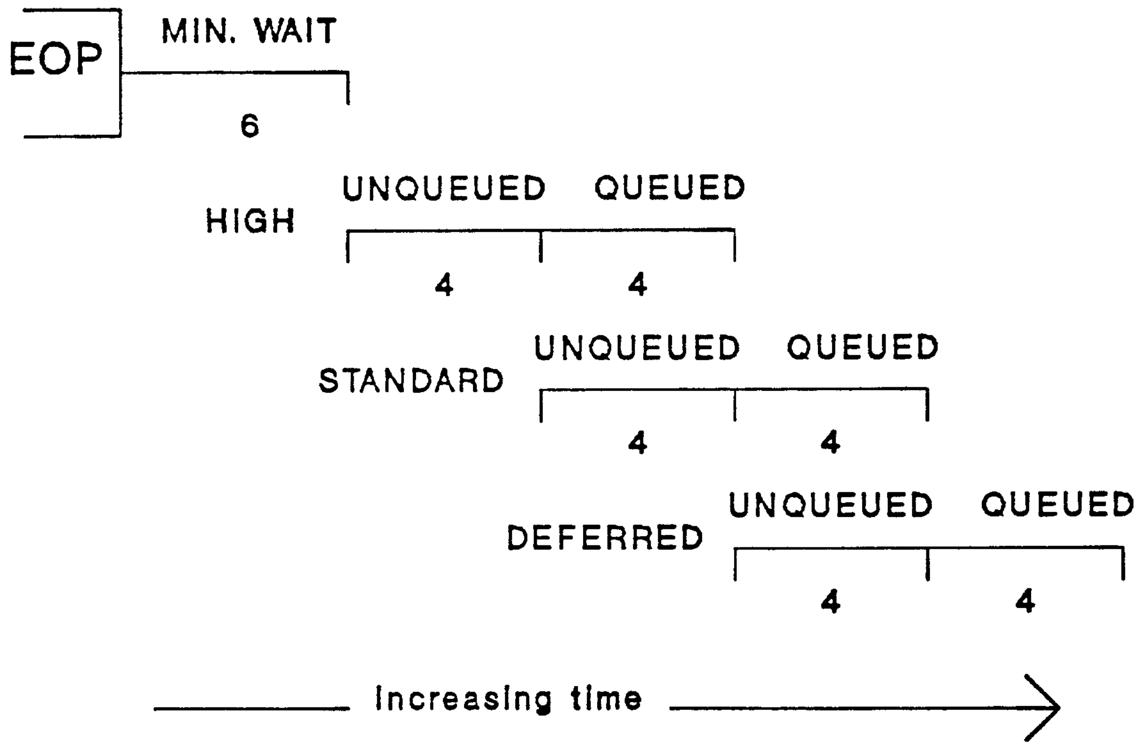

Figure 2.4 Priority and Queueing Channel Access Times

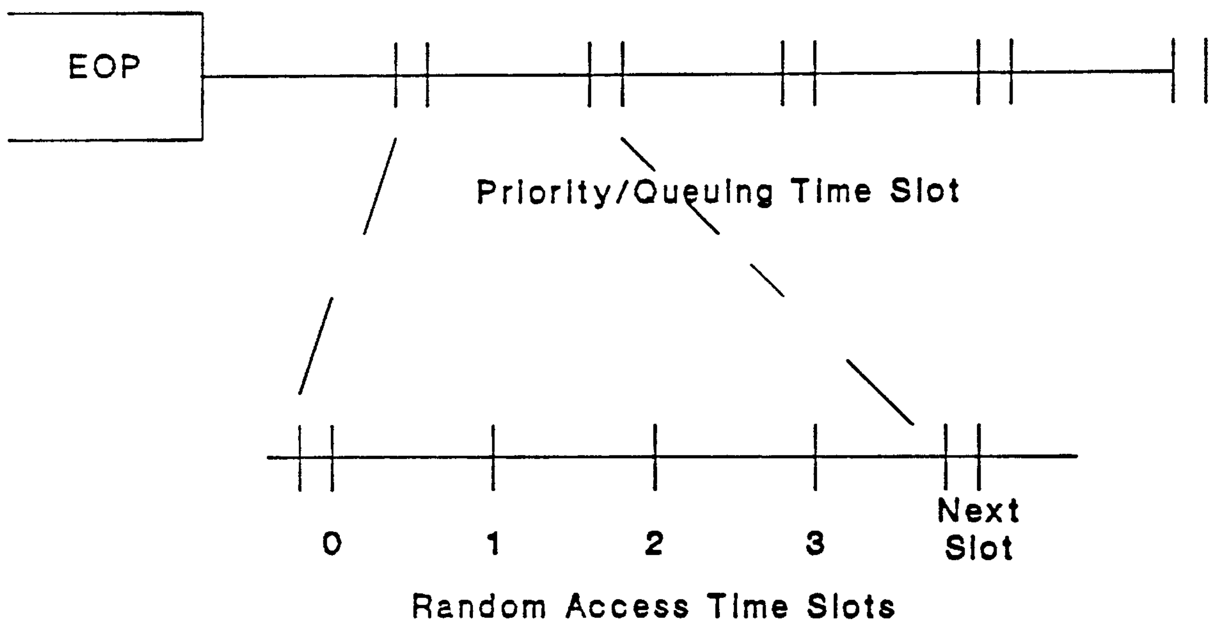

Figure 2.5 Randomization within Priority and Queue

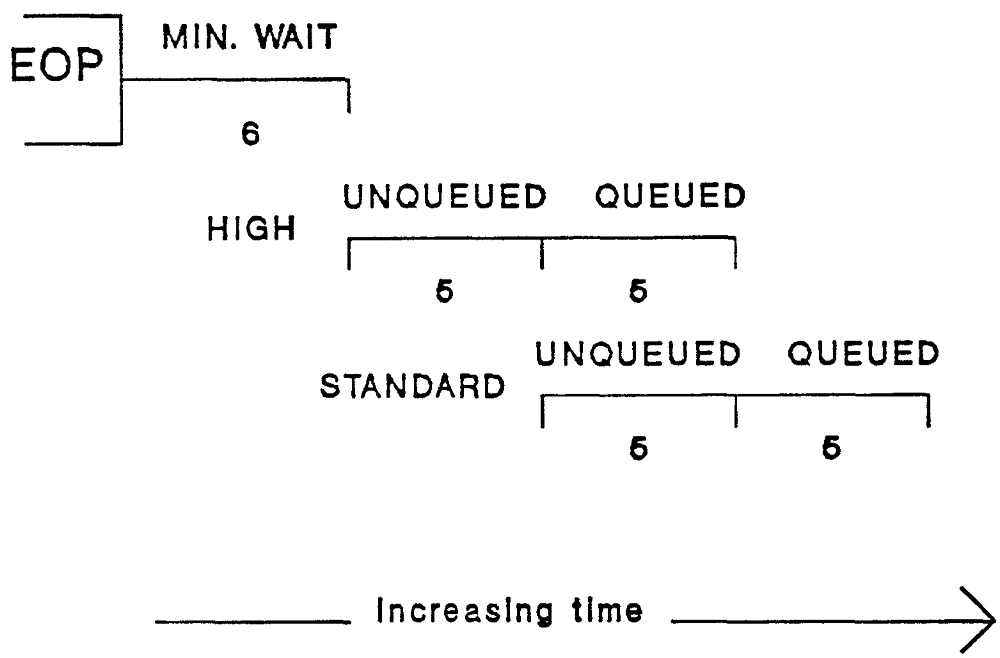

Figure 2.6 Priority and Queueing channel access times

of the modified two priority CEBUS scheme

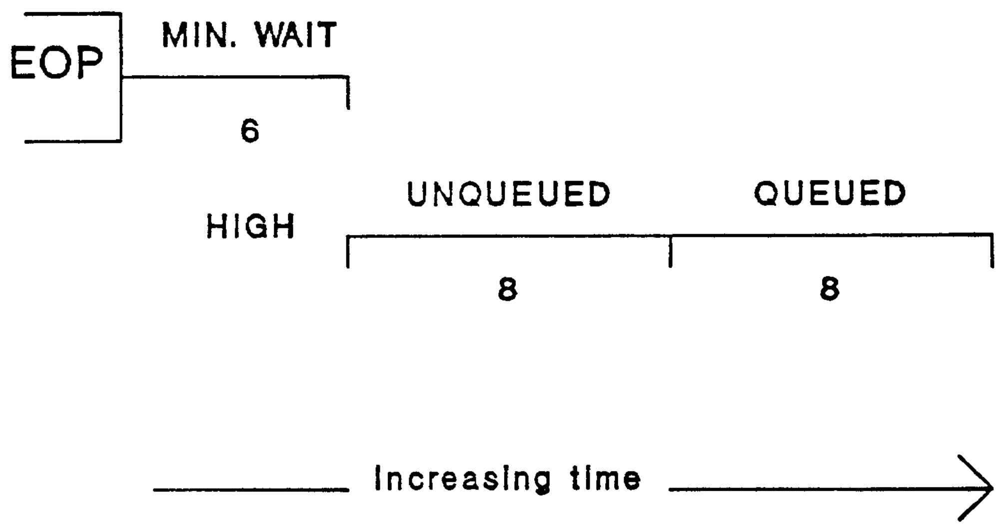

Figure 2.7 Priority and Queueing channel access times of the modified non-priority CEBUS scheme

Chapter 3

Simulation Model

3.1 Model Description

To study the behavior and performance of the CEBUS under various traffic patterns, a simulation model was developed under the LANSF environment [11]. LANSF is a protocol modeling environment which can be used for modeling communication systems. Modeling in LANSF involves defining the protocol behavior in C language using the functions provided by LANSF. The simulator model developed was based on the EIA CEBUS standard [2], and on variants defined here. This model was used to measure the following parameters of the CEBUS network.

Message Delay : the time elapsed since a message is queued at the sending station to the moment the entire message is successfully received at the destination.

Packet Delay : the time elapsed since a packet becomes ready for transmission (queuing time excluded) to the moment the entire packet is successfully received at its destination.

Throughput : is computed as the ratio of the total number of information bits received at their proper destination to the simulation time measured in bit times. Information bits are bits belonging to the information part of a packet, and do not include the header and trailer bits of the packet.

In addition to computing the average values of the packet and message delays, the maximum values of these delays were also recorded.

3.1.1 Overview of the Simulator

The dynamic (executable) part of the CEBUS protocol specification is defined in the protocol.c file. In this file two processes are defined, the transmitter and receiver processes of the CEBUS protocol. Each process is organized as a finite state automaton. Thus a process operates in a perpetual cycle. In this cycle a process is awakened by an event, does some processing and then puts itself back to sleep. Before going to sleep, a process can specify a list of events that may wake it up when they occur in the future.

3.2 Standard CEBUS Simulation Model

Each station in the network has a Receiver process and a Transmitter process. Both these processes are described below.

3.2.1 Receiver Process

The code for the receiver process is given below :

```
case WAIT_FOR_PACKET:
/* Wait until end of a packet addressed to the current */
/* station appears on the port */
wait_event (BUS, END_MY_PACKET, PACKET_RECEIVED);
return;
case PACKET_RECEIVED:
/* Receive the packet and wait for the next packet */
accept_packet (THE_PACKET, THE_PORT);
skip_and_continue_at (NEXT_PACKET);
return;
```

The Receiver process calls the standard function wait_event which declares a class of events that may restart the process later. The first of them identifies the source of events. In this case it is BUS, the communication channel between all the stations. The second parameter END_MY_PACKET stands for an event which corresponds to the complete reception of a packet for which the current station is the rightful receiver. The last parameter PACKET_RECEIVED identifies the next event, the process continues its execution. Next the process executes return which puts it to sleep. The process will then remain suspended until it is awakened by the complete reception of a packet by the current station.

Upon reception of a packet, the process calls the standard function accept_packet, whose exclusive purpose is to update the performance measures of the network. Having accepted the packet, the process awaits the arrival of the next one.

3.2.2 Transmitter Process

The code for the transmitter process is given below:

```
case NEXT_PACKET:
/* Attempt to acquire a packet for transmission */
if (!get_packet(BUFFER,min_packet_length, max_packet_length, frame_info_length))

{
priority_delay = priority[the_message_type];
continue_at (MONITOR_BUS) }
else {
wait_event (CLIENT, MESSAGE_ARRIVAL, NEXT_PACKET);
return;
}
case MONITOR_BUS:
/* If some activity is going on in the bus then wait */
last_silence = last_eoa_sensed (BUS);
if (undef(last_silence)) {
wait_event(BUS, SILENCE, CHANNEL_ACCESS);
return;
}
case CHANNEL_ACCESS:
if (!the_station->queued_mode) {
access_delay = inter_packet_space + priority_delay + t_uniform(0,3);
}
if (the_station->queued_mode) {
```

```
access_delay = inter_packet_space + priority_delay + queueing_delay + t_uniform(0,3);

}
idle_period = minus (current_time, last_silence);
if (les(idle_period, access_delay)) {
wait_event ( TIMER, minus(access_delay, idle_period), TRANSMIT_PREAMBLE
);
wait_event (BUS, ACTIVITY, RETRY);
return;
}
```

Immediately after the Transmitter process is invoked, it calls the standard function get_packet which attempts to acquire a packet for transmission. If there is no packet awaiting transmission, the transmitter waits until a packet arrives. If there is a packet to be transmitted, it acquires the packet and attempts to transmit the packet. The priority of the packet depends upon the type of message: HIGH, STANDARD or DEFERRED for the standard CEBUS.

Before the transmitter decides to send the packet, it has to determine the status of the BUS. This is done by the standard function last_eoa_sensed which checks whether any activity is currently going on in the BUS. If any activity is going on in the BUS, the transmitter waits until the end of this activity and then attempts to access the channel by executing the CHANNEL_ACCESS event.

Before accessing the channel, the transmitter process checks to see whether its station is in the queued or unqueued state, and the corresponding access delay is calculated accordingly. The priority delays are stored in an array and t_uniform(0,3) generates a uniformly distributed random number between 0 and 3. Once the access delay is calculated, the transmitter waits until the silence period in the channel is equal to the access delay and attempts to transmit a preamble over the channel. Each station has a message queue with a large queue size.

3.3 Modified CEBUS Simulation Model

The Receiver process of the modified CEBUS protocol with two priority and non-priority scheme, is the same as that of the standard CEBUS discussed in 3.2.1. In case of the two priority scheme, only HIGH and STANDARD priorities are defined in the Transmitter process. In the non-priority scheme no priority delays are defined in the transmitter process. The rest of the transmitter process is the same as that for the Standard CEBUS model discussed in 3.2.2.

Chapter 4

Simulation Analysis

In this chapter the results obtained by performing simulation of the CEBUS network are presented. Simulation runs were made for different traffic patterns and offered loads and the results for the standard and modified CEBUS schemes are compared.

4.1 Simulation Model

In the CEBUS scheme, there are three different priority messages. HIGH priority is used for messages which cannot tolerate delay, STANDARD priority is used for messages which can tolerate some delay, and DEFERRED priority is used for messages where considerable delay can be tolerated.

CEBUS is intended primarily for home automation. In a typical home with several consumer appliances to be connected to the CEBUS, certain appliances have more stringent bounds on delay than others. For example, several seconds of delay can be tolerated for messages between a thermostat and a heater while security and alarm systems require minimum delay. Hence messages with smaller delay requirements are given higher priority when accessing the channel.

The various appliances that have to be connected to the CEBUS in a typical home, and the traffic generated by them have been taken into consideration in our simulation model, so that the model represents a reasonably realistic situation. Table 4.1 lists the various nodes and their priority allocation used in our simulation study. Devices requiring immediate response are alloted HIGH priority while the other devices are alloted STANDARD and DEFERRED priority. From the table it can be observed that the devices alloted HIGH priority are mostly operated in cases of emergency. Hence the overall average data rate of HIGH priority messages will be quite low even though these devices will be sending regular status bits. Hence the overall HIGH traffic is lower than STANDARD and DEFERRED priority traffic.

In our simulation study the number of stations was set at 15, between one and two per room in a typical large house. Further it is also assumed that all the messages from a given node have the same priority. In practice this need not be the case and a single node could send messages with different priority. For example in case of a computer, file transfers can be at lower priority whereas a phone interface should be at HIGH priority. Hence in Table 4.1 the computer priority allocation has been indicated as Mixed. The nodes with Mixed priority have been modeled as multiple nodes of different priorities in the simulation model. They are logically equivalent since the nodes are not queue size limited. CEBUS packet length can be variable upto a maximum of 256 bits, however in this model the number of bits per packet is assumed to be constant i.e. 184 bits and the ratio of one's to zero's is 2:1.

Each node to be connected to the CEBUS requires an interface to the bus, the a.c. mains in this study. This interface is electrically complex, and rather than have an interface for each device, we assume one interface could economically serve several devices. Depending on the device, local connection to a station could be implemented with wire, twisted pair or some other low cost means. The logic needed at such a node could be economically provided by a low cost 4-bit microcomputer.

4.2 Analysis of Results

The simulation for the standard CEBUS was run for different traffic patterns. Initially it was assumed that HIGH priority traffic was 20%, STANDARD and DEFERRED priority traffic 40% each, the normal traffic one would expect in a typical home environment. With this traffic pattern, the normalized offered load to the network was increased from 0.2 to 1.

4.2.1 Effect of Increased Load

Figure 4.1 and Figure 4.2 show the variation of the average message delay and the average packet delay with offered load. It can be observed from these graphs that the average packet and message delays are almost constant up to an offered load of 0.5. This is because at lower loads there is less contention, and all nodes get a fair chance to access the channel.

Beyond this load the rate of increase in delay depends upon the priority of the message. For HIGH and STANDARD priority messages, the delay increases slowly, whereas for DEFERRED priority messages, it increases very rapidly. This is because HIGH priority messages are given the first chance to access the channel. STANDARD priority messages have to wait until HIGH priority messages are transmitted. DEFERRED priority messages have to wait until both HIGH and STANDARD priority messages are transmitted resulting in their large increase in delay with load.

Figure 4.3 and Figure 4.4 show the variation of the maximum message and packet delays with offered load. These graphs have the same pattern as those of the average delay except that the delay values are larger. Figure 4.5 shows the variation of the throughput with load. It is observed that the throughput increases up to an offered load of 0.5 and then remains almost constant.

At lower loads the channel utilization is low resulting in low throughput. Increasing the offered load increases the channel utilization and hence the throughput. Increasing the load also increases the contention in the network, but the contention resolution scheme of the CEBUS is such that all collisions are resolved in the preamble interval. Thus at offered loads greater than 0.6 the throughput is almost constant as no channel time is wasted by colliding packets. It is observed from Figure 4.5 the maximum throughput is 0.65, the remaining throughput is utilized by the overhead bits and the constant channel access wait times.

4.2.2 Effect of Network Traffic Pattern

To observe the effect of the network traffic pattern on the delay, simulation runs were performed for four different traffic patterns. Traffic patterns #2 and

#3 are the patterns one would expect in home environment and traffic #4 was used to study the effect of large HIGH priority traffic. In traffic pattern #1, the HIGH, STANDARD and DEFERRED priority messages were equally distributed. In traffic pattern #2, 20% of the traffic was HIGH priority, 40% STANDARD priority and 40% DEFERRED priority. In traffic pattern #3, HIGH, STANDARD and DEFERRED priority messages constitute 20%, 30% and 50% of the network traffic respectively. In traffic pattern #4 traffic is 80% HIGH, 10% STANDARD and 10% DEFERRED.

Figure 4.6 shows the effect of the traffic pattern on the packet delay for HIGH priority messages. It is observed that at higher loads, traffic patttern #4 has a higher delay than the others. This is because in traffic pattern #4 80% of the traffic is HIGH priority, whereas in the others it is considerably lower. Increasing the HIGH priority traffic increases the average delay of these messages at higher loads, due to increased contention.

Figure 4.7 shows the effect of the traffic pattern on the packet delay for STANDARD priority messages. Here also it can be observed that traffic pattern #4 yields larger delay at higher loads. The same effect can be observed for DEFERRED priority messages in Fig 4.8. Hence increasing the percentage of HIGH priority traffic in the CEBUS network, not only increases the delay for HIGH priority messages but the delay for STANDARD and DEFERRED priority messages as well. This is because increasing the HIGH priority traffic increases the waiting times for STANDARD and DEFERRED priority messages.

It can also be observed from Figure 4.7 and Figure 4.8 that increasing the STANDARD priority traffic increases the average delay of STANDARD and DEFERRED priority messages. Hence the packet delay in a CEBUS network at a given load is also dependent upon the traffic pattern in the network.

4.2.3 Modified CEBUS two priority Scheme(2P-CEBUS)

Simulations were also run for the 2P-CEBUS scheme and compared with the standard CEBUS scheme. In the 2P-CEBUS scheme the number of stations was the same as in the standard scheme, i.e. 15, but traffic was 30% HIGH and 70% STANDARD priority. In Figure 4.9 it can be observed that the HIGH priority message delay of the 2P-CEBUS and standard CEBUS schemes are almost the same.

Further the STANDARD priority message delay of the 2P-CEBUS scheme is lower than the DEFERRED priority delay of the standard CEBUS scheme, due to the absence of DEFERRED priority level in the modified CEBUS scheme. Figure 4.10 shows similar behavior for the average packet delay of the two schemes. Further the throughput verses load characteristics of the two schemes are the same from Figure 4.11. This is because the contention resolution scheme of the CEBUS avoids collision penalties irrespective of the priority distribution of messages.

In situations where messages can be classified into two categories, one where delay cannot be tolerated and the other where delay can be tolerated, it seems advantageous to use the 2P-CEBUS protocol. It is simpler to classify only two kinds of messages, and the throughput characteristics are similar to the standard CEBUS scheme.

4.2.4 Modified CEBUS non-priority Scheme(NP-CEBUS)

The performance of the standard CEBUS protocol was compared with the NP-CEBUS scheme. Figure 4.12 and Figure 4.13 show the variation of the average message delay and the average packet delay verses load for both schemes. It is observed from these graphs that the delay for both schemes is quite low for an offered load up to 0.5. Further the delay at higher loads for the NP-CEBUS scheme is considerably lower than the DEFERRED priority delay of the standard CEBUS scheme. From Figure 4.14 it can be observed that the throughput verses load characteristics of the two schemes is almost the same.

In situations where the offered load in the network is below 0.6, it would be advantageous to use the NP-CEBUS scheme with no priorities because of its simplicity. However in a typical application as described earlier, there are significant time intervals with traffic loads greater than 0.6 (e.g during a file transfer), and important messages would be delayed excessively. Hence priorities must be used in a contention system with real-time response criteria.

4.2.5 Effect of Slot Size

In the CEBUS scheme each priority message must access the channel in its allocated time slot, and each slot duration is 4 UST. To observe the effect of the slot size on the delay, the modified non-priority CEBUS scheme was considered and simulation runs were carried for slot sizes of 2, 4, 8 and 16 respectively.

It is observed from Figure 4.15, that at lower loads, i.e. 0.3, the slot size has no effect on the delay. This is because at lower loads there is no contention, and channel access is not a problem. However at a medium offered load, i.e. 0.6, the average delay increases with the slot size. At these loads there is contention, and a wider time slot results in messages having to wait longer before accessing the channel.

4.2.6 Effect of Delay on High Priority Messages

High priority is allotted to messages where delay is crucial to reduce their average and maximum delay values. In [2] it was suggested that the average delay of messages can be reduced by sending more messages at High priority. The standard and modified CEBUS schemes were compared with the scheme of transmitting all messages at High priority in the standard CEBUS scheme ('All High'). Figure 4.16 shows the variation of the Maximum packet delay of High priority messages with load. It can be observed that by sending all messages at High priority, the maximum packet delay of High priority messages increases to a large value. 'All High' and NP-CEBUS are logically equivalent, but the channel access time durations are different.

The Throughput verses delay characteristics of High priority messages of all the schemes is shown in Figure 4.17. It is observed that at higher throughputs both the NP-CEBUS and 'All High' priority schemes yeild large values of delay compared than the other schemes.

4.3 Analytical Comparison

The CSMA/CDCR scheme of the CEBUS is quite similar to the CSMA scheme. A complete analysis of the CEBUS scheme with three priorities is quite complex. Hence we consider the NP-CEBUS scheme in our analytical analysis.

The normalized average packet delay for a message in the CSMA scheme is given in [16] as

$$D = (\frac{G}{S} - 1)R + 1 + a \tag{4.1}$$

where D = average packet delay normalized with respect to the packet transmission time

G = offered load

S = throughput

R = normalized average delay between two consecutive transmissions and

a = propagation time/transmission time

For the power line version of the CEBUS scheme, $a = 0$ since the transmission time is very large compared to the propagation time. The average interval in UST between two consecutive transmissions is given by

$$R_c = 6 + 4 + 8 + T_a + T_r \tag{4.2}$$

where 6 is the minimum wait time after an EOP symbol, 4 is the average time for a packet to begin transmission in the unqueued slot and 8 is the preamble time interval. T_a is the average packet transmission time and T_r is the average time spent waiting for channel access. In normalized time units

$$R_{cn} = 1 + \frac{18}{T_a} + \frac{T_r}{T_a} \tag{4.3}$$

Hence the normalized average packet delay for a message in the CEBUS scheme is given by

$$D = (\frac{G}{S} - 1)(1 + \frac{18}{T_a} + \frac{T_r}{T_a}) + 1 \tag{4.4}$$

Assuming the throughput can be approximated as linearly increasing with load to a maximum of 0.5, then

$$s \simeq \frac{G}{G+1} \tag{4.5}$$

The normalized average packet delay for a message in NP-CEBUS scheme will be

$$D_c = G + \frac{18G}{T_a} + \frac{GT_r}{T_a} + 1 \tag{4.6}$$

The average time spent waiting for channel access T_r, is a function of the offered load. Considering T_r to be exponentially distributed as a function of load G, i.e.

$$T_r \simeq KT_aGe^G \tag{4.7}$$

Then

$$D \simeq G + \frac{18G}{T_a} + KG^2e^G + 1 \tag{4.8}$$

where K is a constant scale factor. The analytical and simulated delay values are compared in Figure 4.18 for $K = 5.2$. It can be observed that at lower loads the values are quite close. However at loads beyond 0.6, the difference betweeen the analytical and simulated values of delay is quite large due to the simplifying assumptions made in the analytical derivation in equations 4.1, 4.2 and 4.5.

Stations and Their Priority Allocations in a Typical Home Environment

Stations	Data Rate	Priority Allocation
Light Switch	Low	High
Alarm	Low	High
Sensor	Low	High
Security Panel	Low	High
Curtain Puller	Low	High
Washing Machine	Low	Standard
Dryer	Low	Standard
Computer	Variable	Mixed
Dishwasher	Low	Deferred
Furnace Controller	Low	Deferred
Temperature Monitor	Low	Deferred
Water Heater	Low	Deferred

Table 4.1

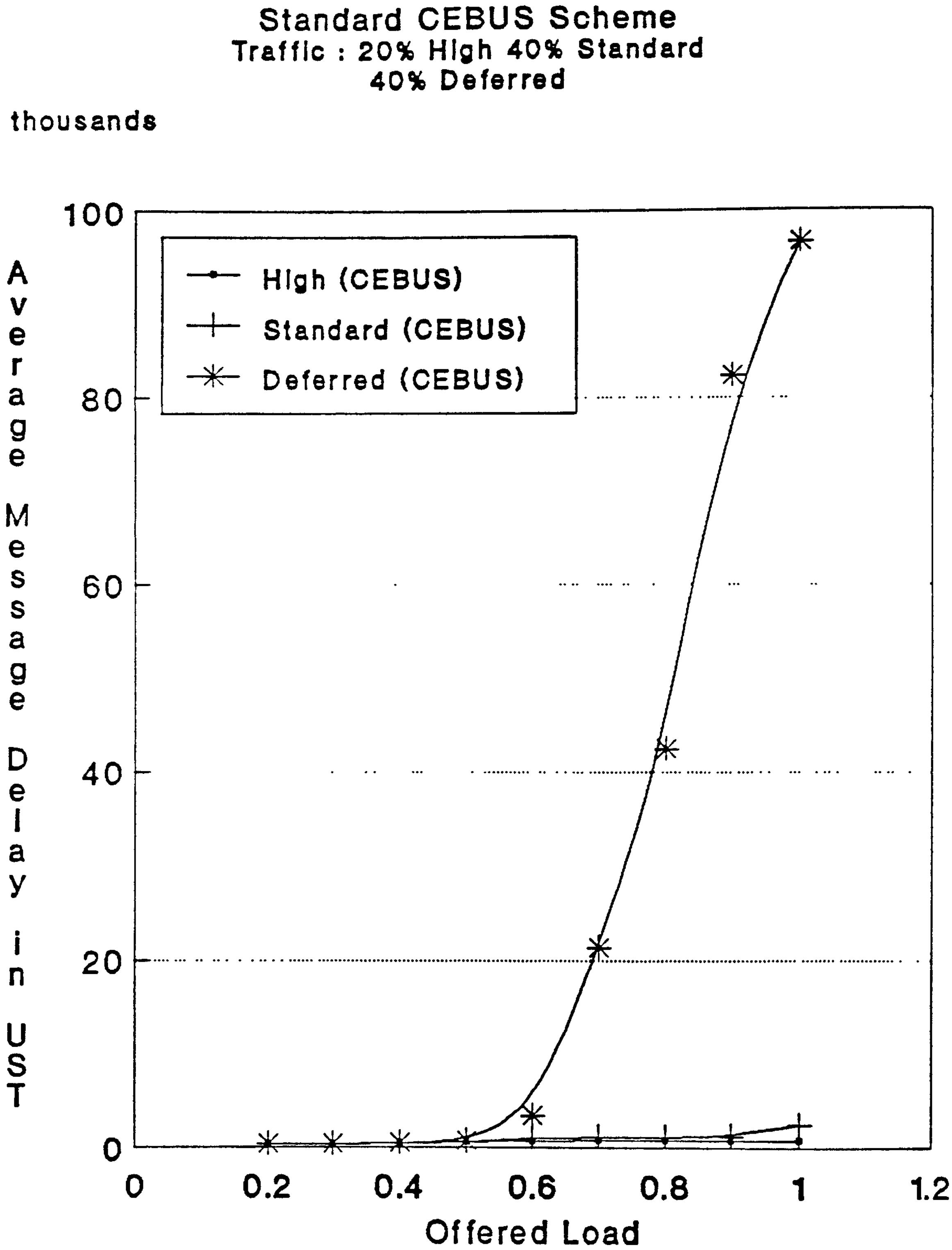

Figure 4.1 Avg. Message Delay vs Load

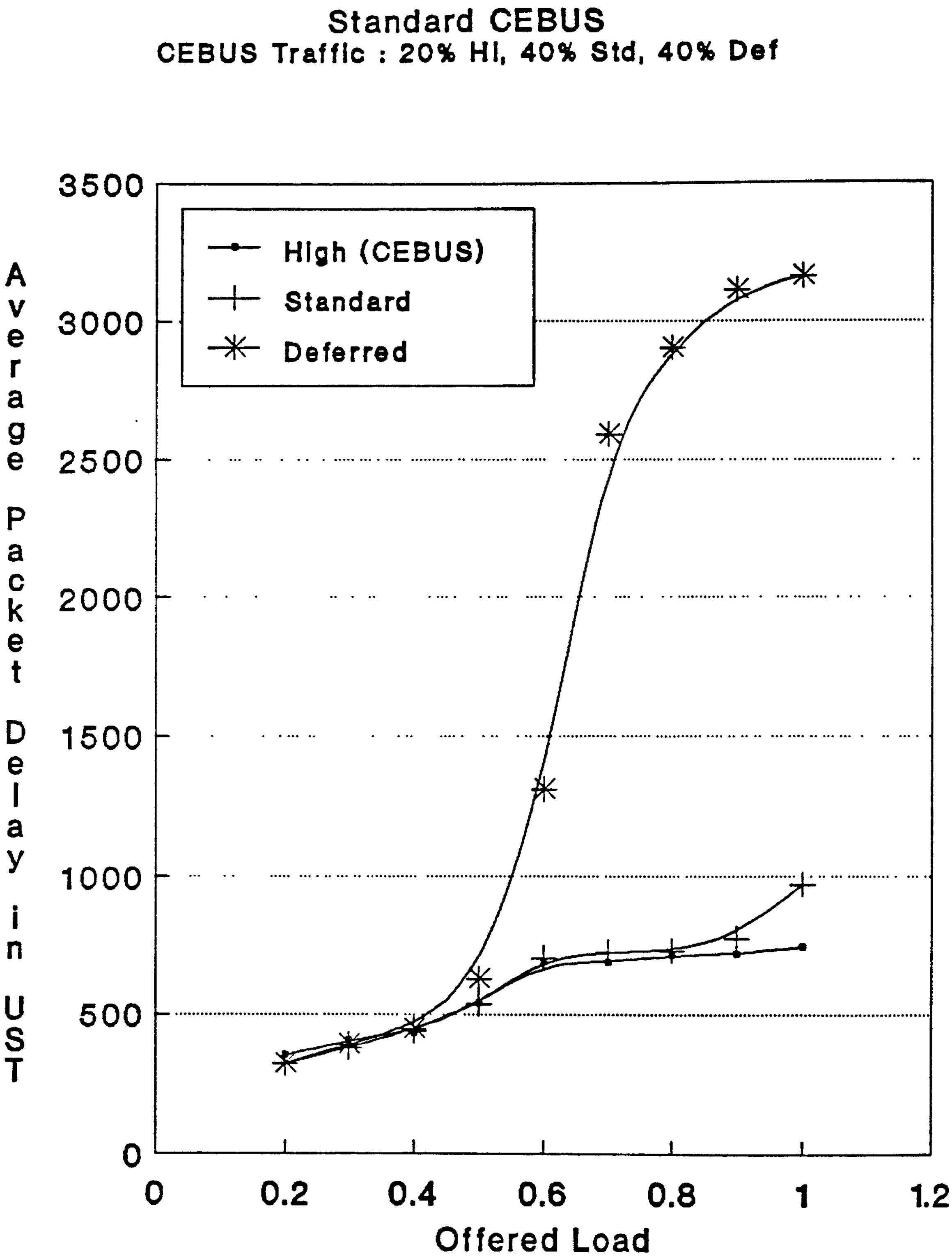

Figure 4.2 Avg. Packet Delay vs Load

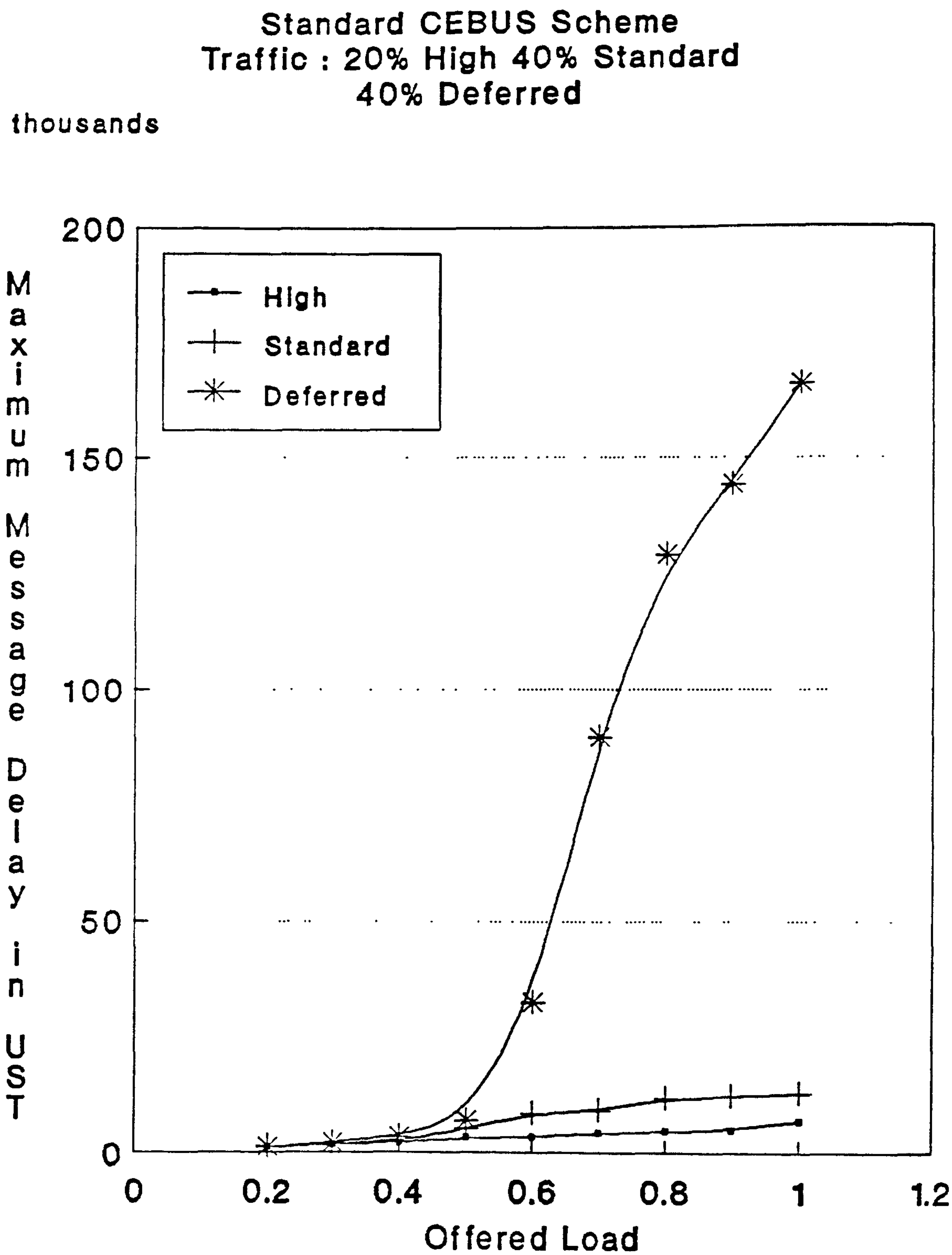

Figure 4.3 Max. Message Delay vs Load

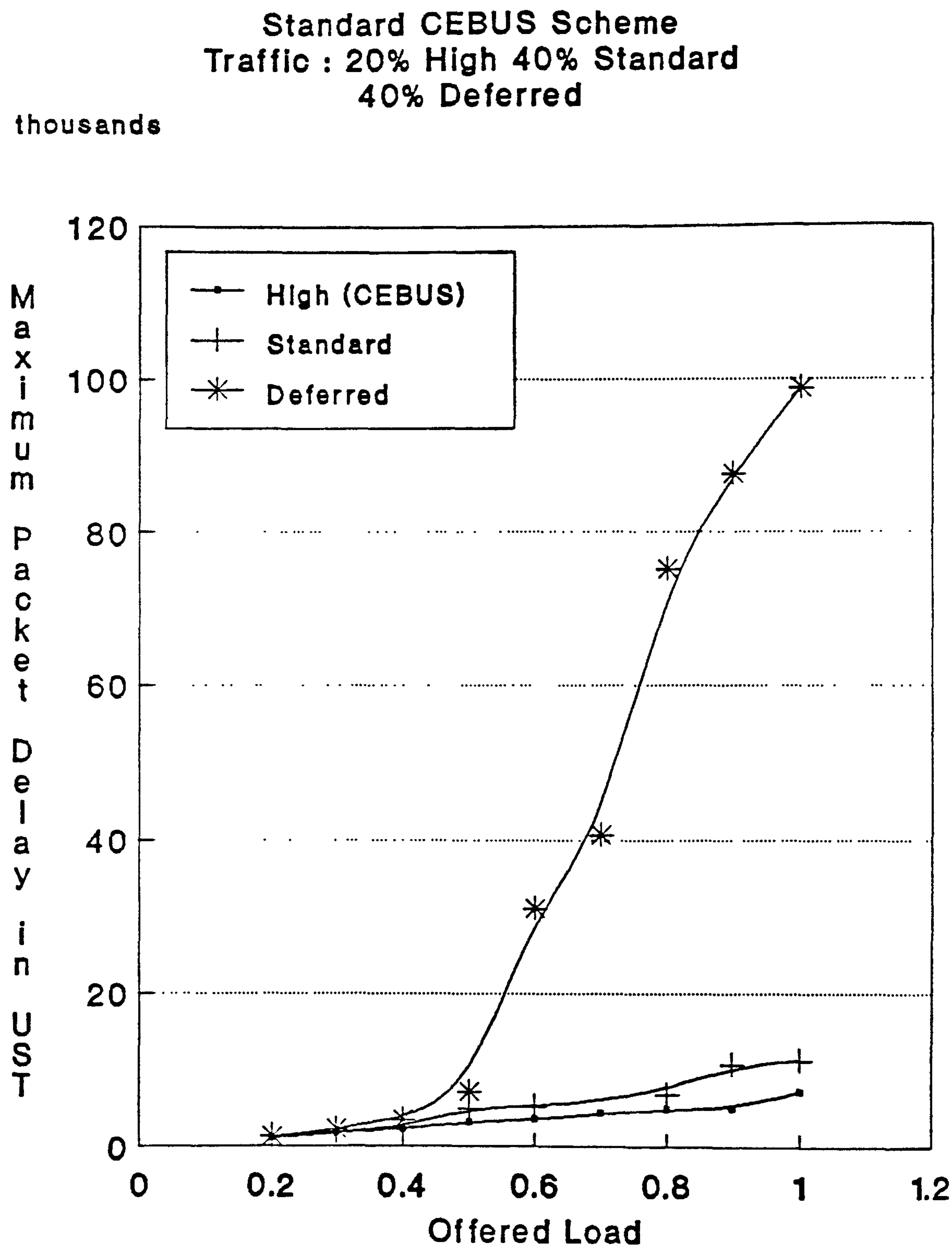

Figure 4.4 Max. Packet Delay vs Load

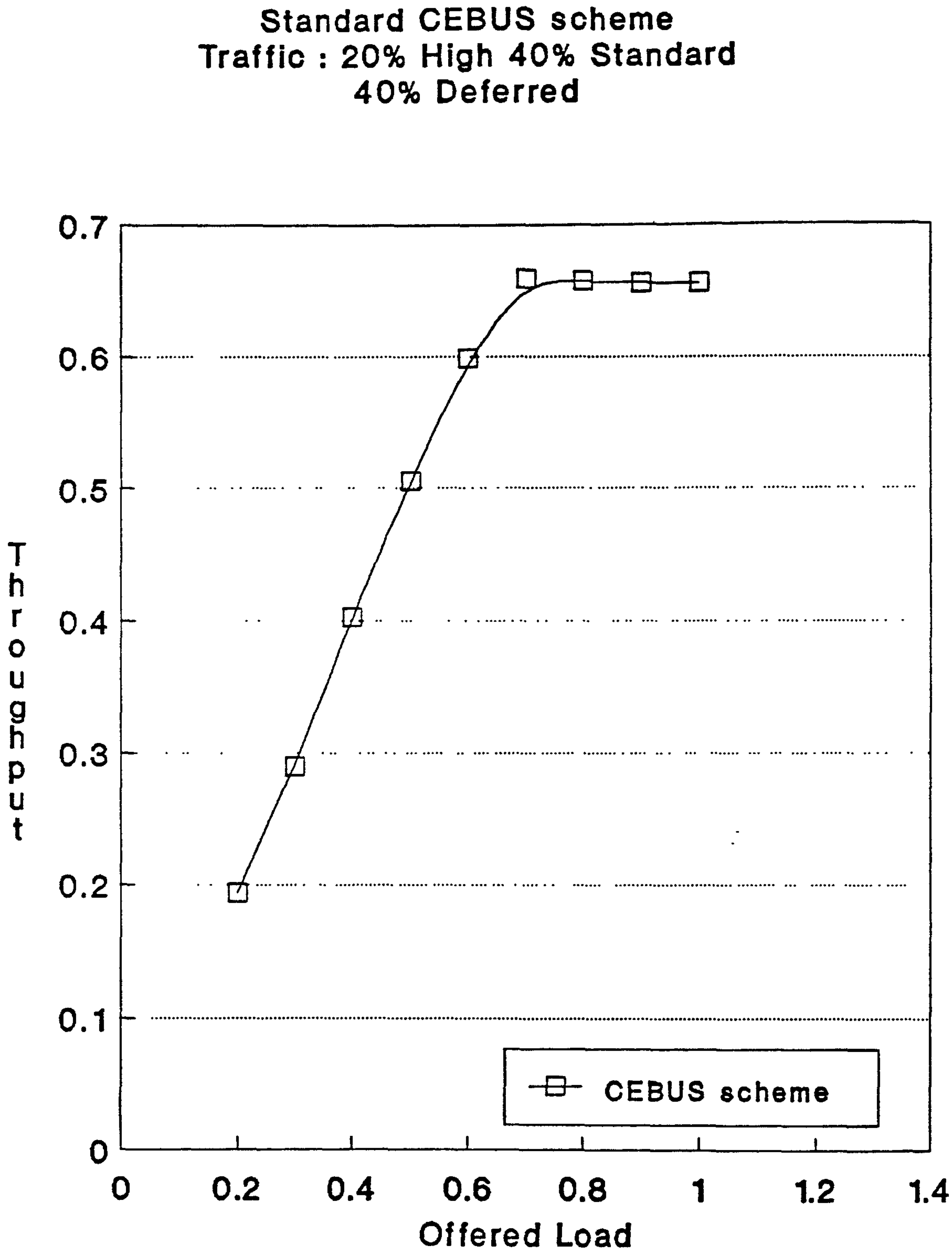

Figure 4.5 Throughput vs Offered Load

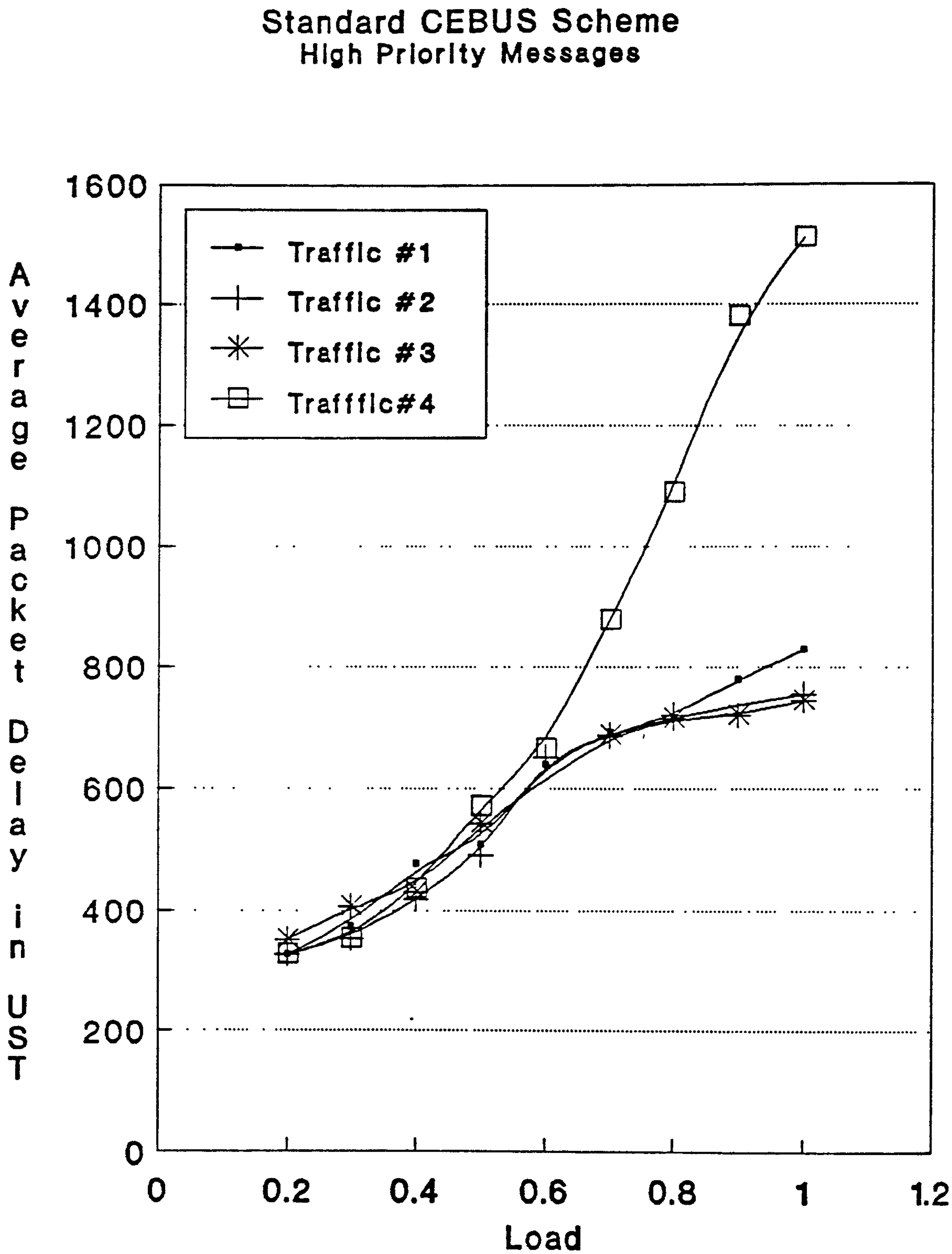

Figure 4.6 Average Packet Delay vs Load

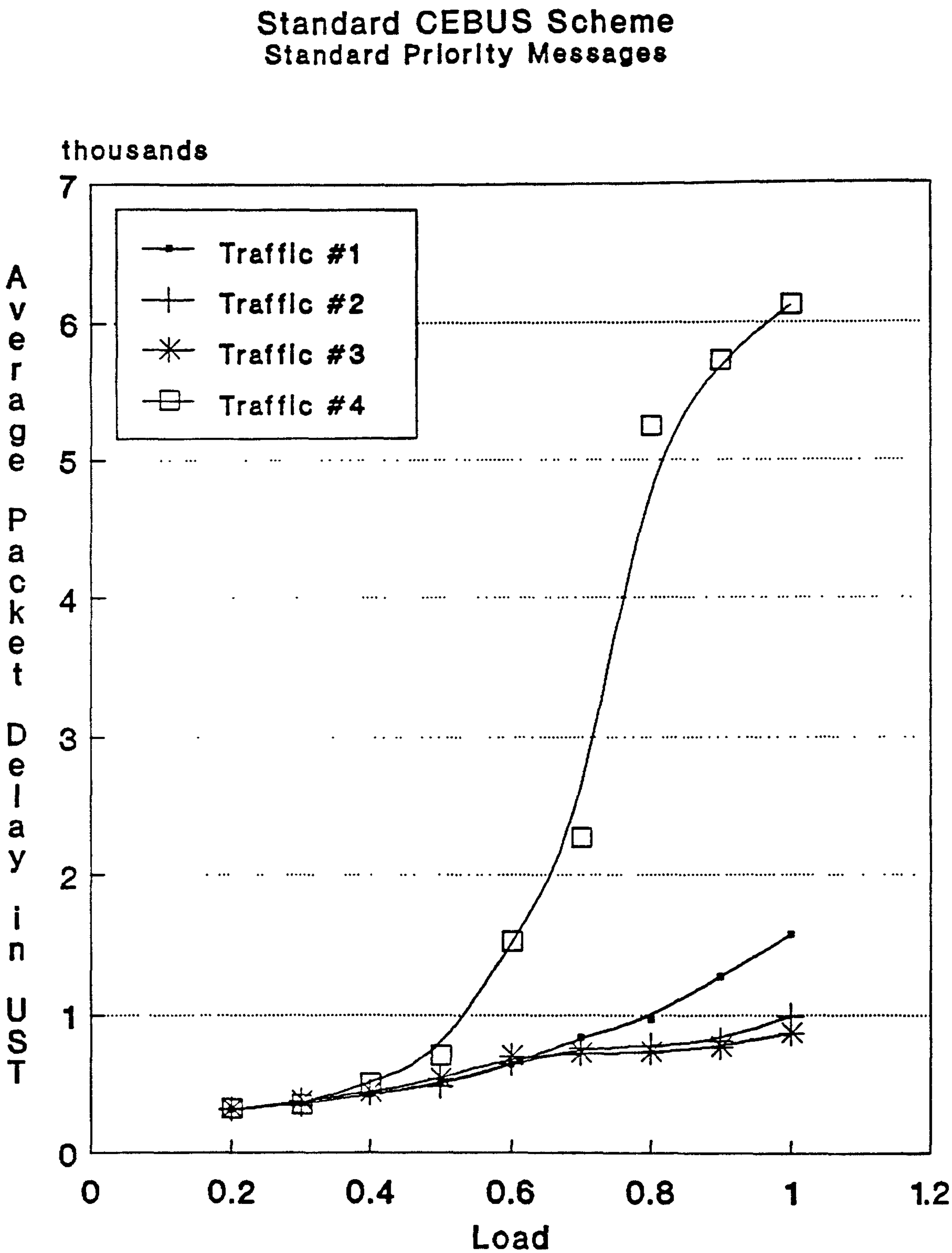

Figure 4.7 Average Packet Delay vs Load

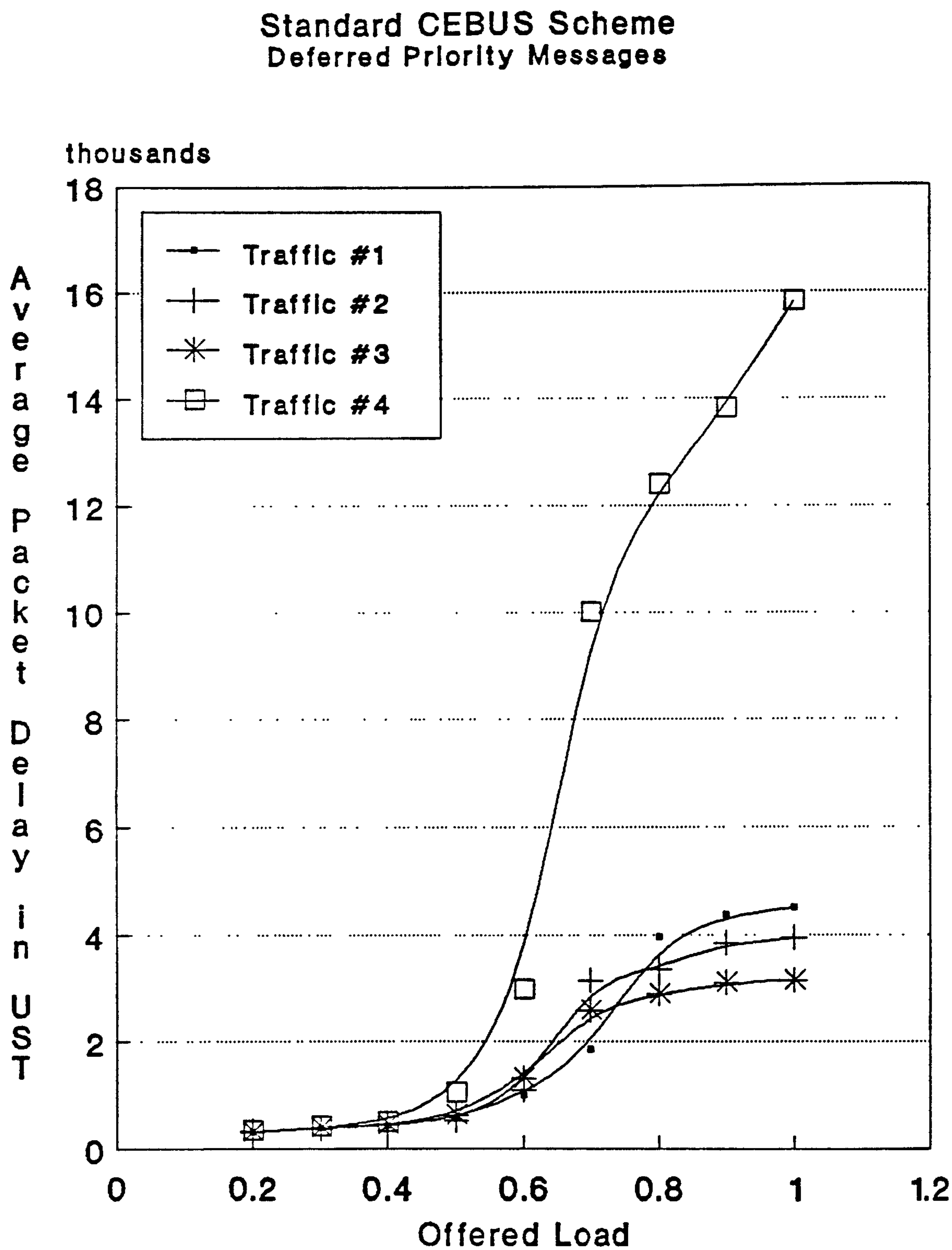

Figure 4.8 Average Packet Delay vs Load

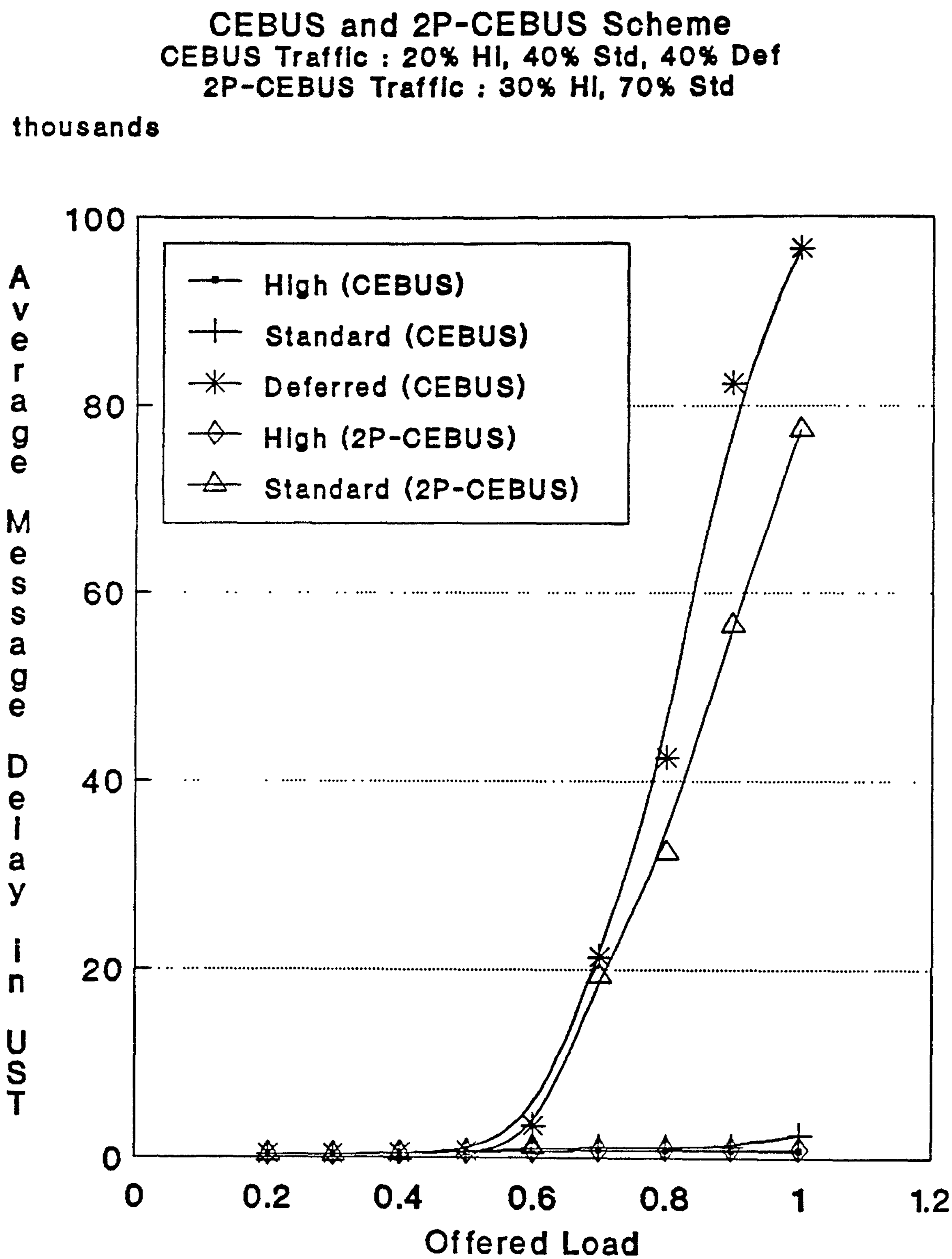

Figure 4.9 Avg. Message Delay vs Load

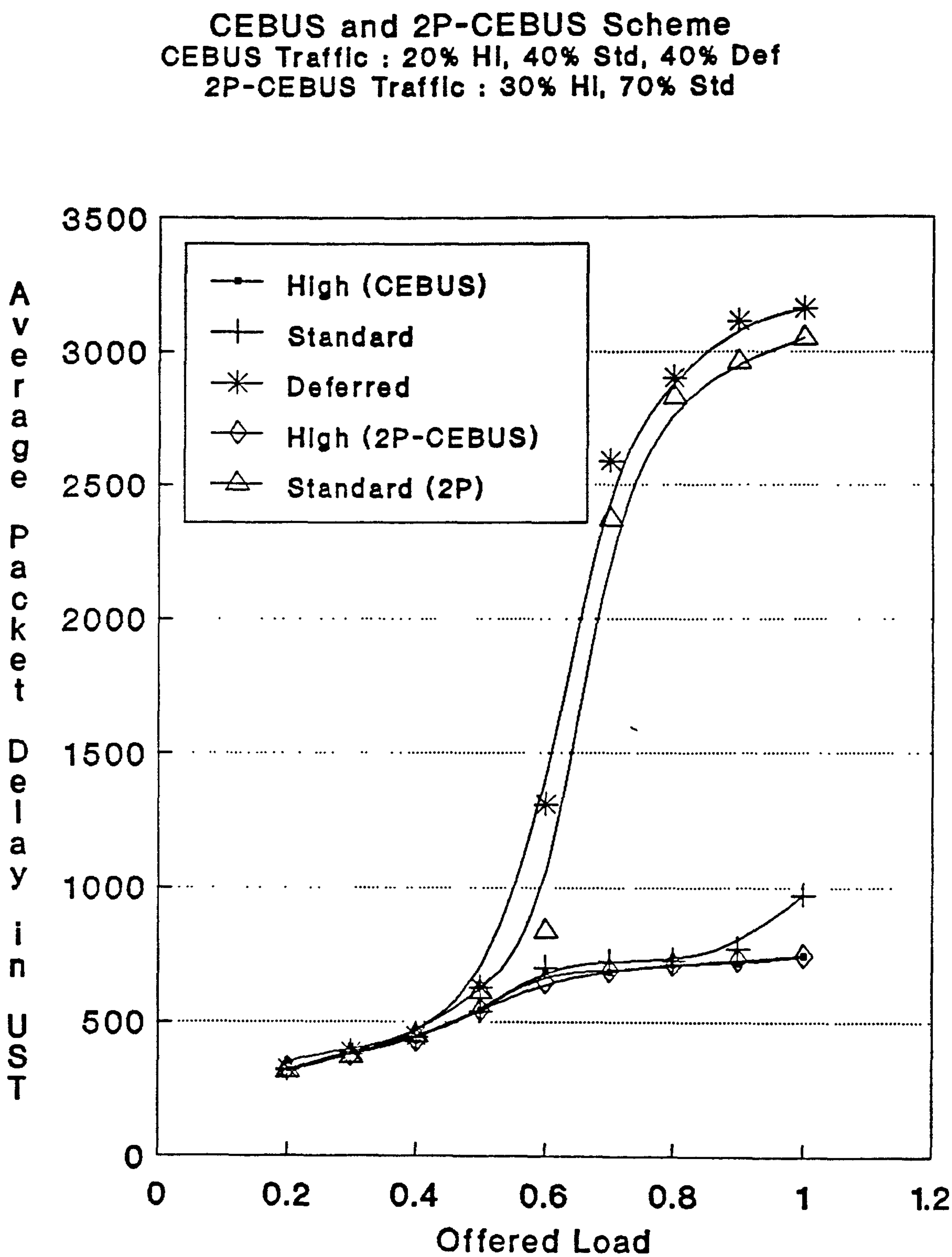

Figure 4.10 Avg. Packet Delay vs Load

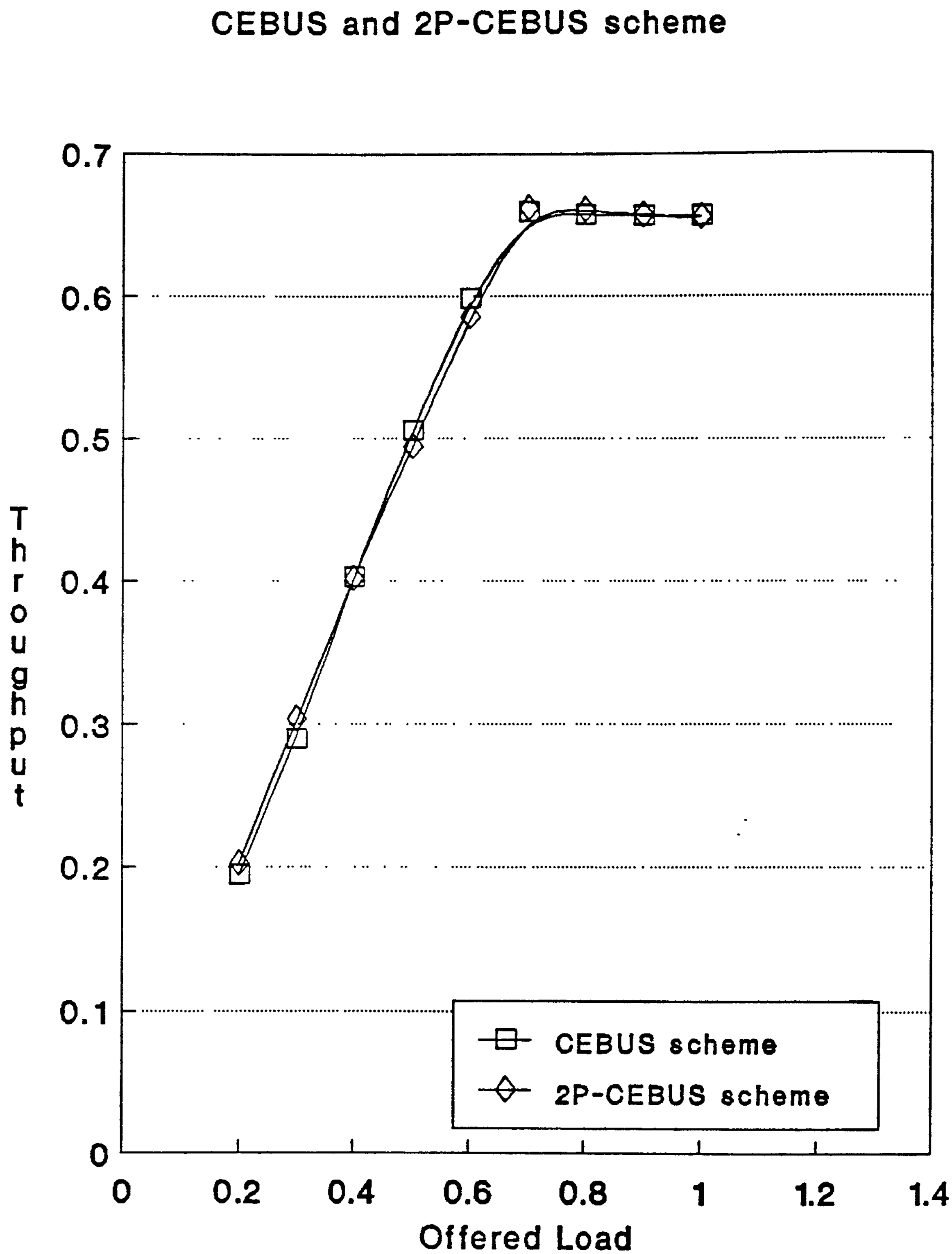

Figure 4.11 Throughput vs Offered Load

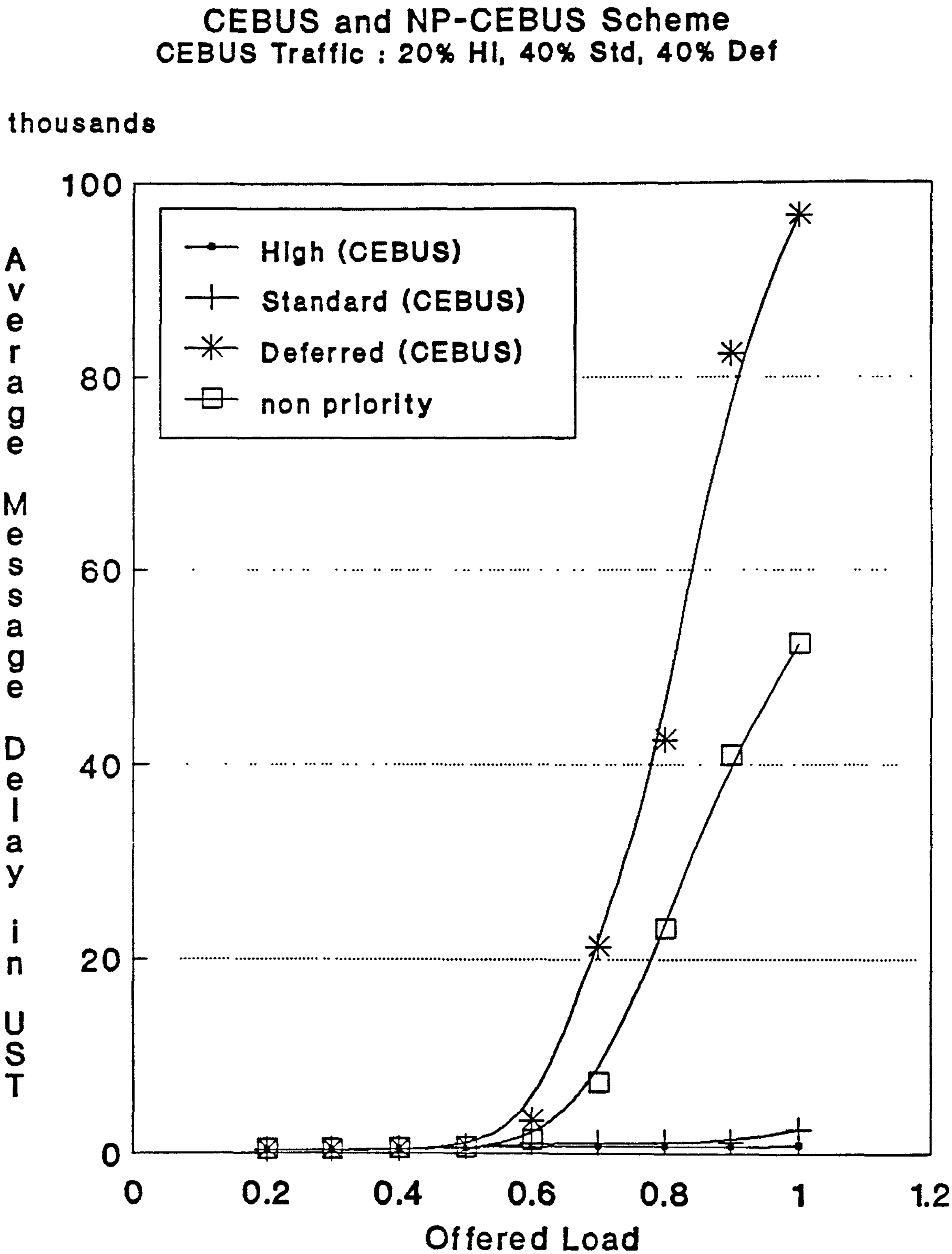

Figure 4.12 Avg. Message Delay vs Load

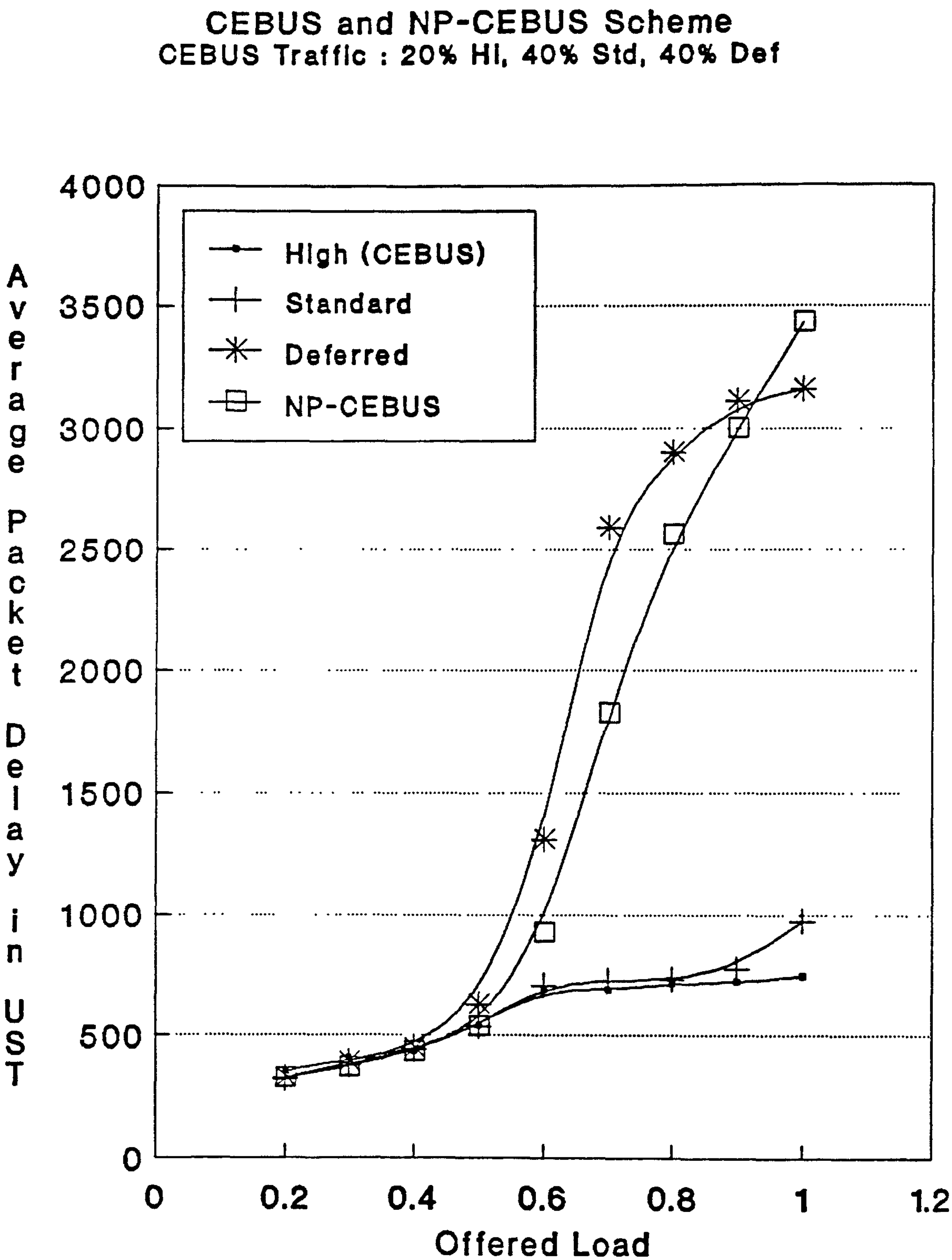

Figure 4.13 Avg. Packet Delay vs Load

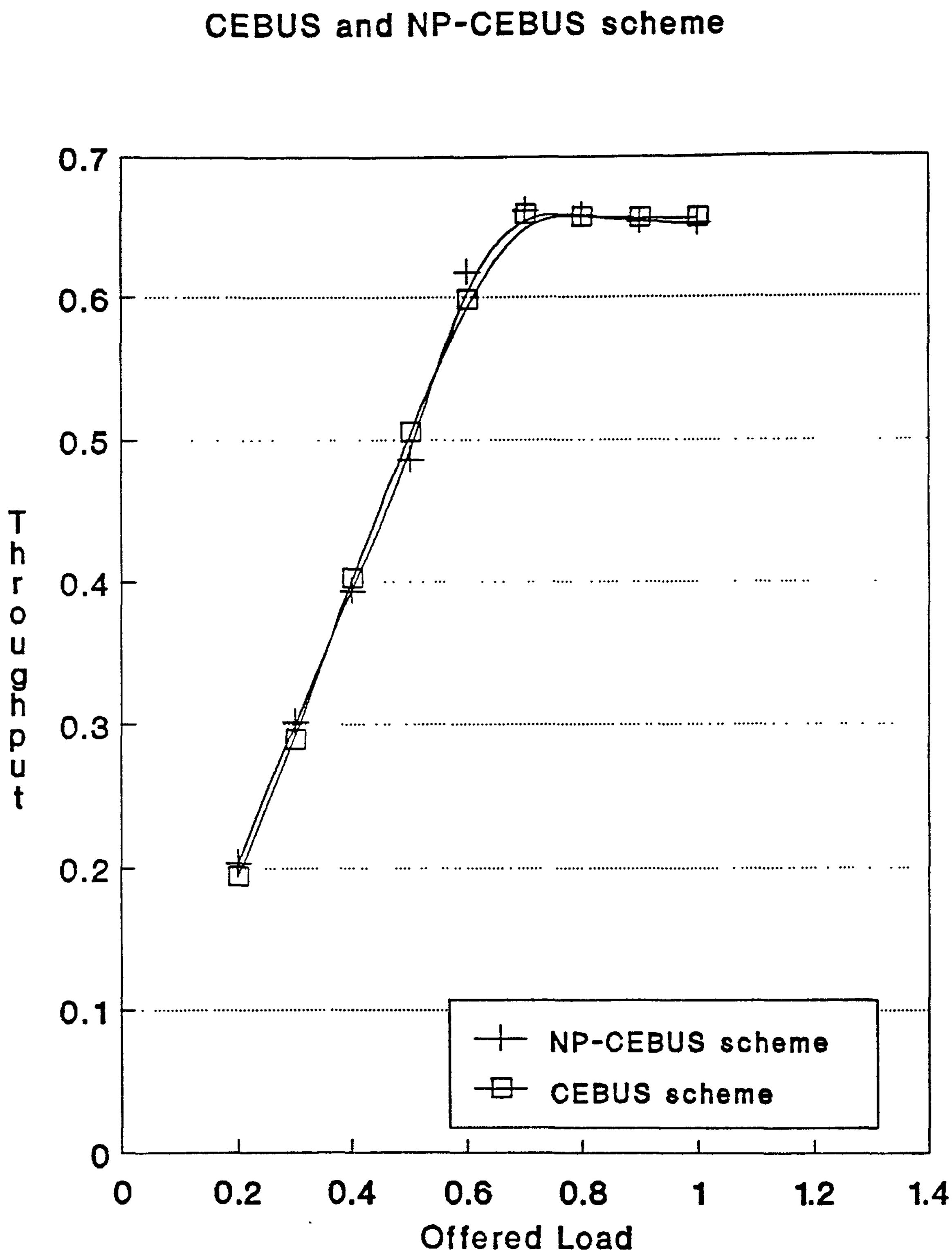

Figure 4.14 Throughput vs Offered Load

NP-CEBUS Scheme

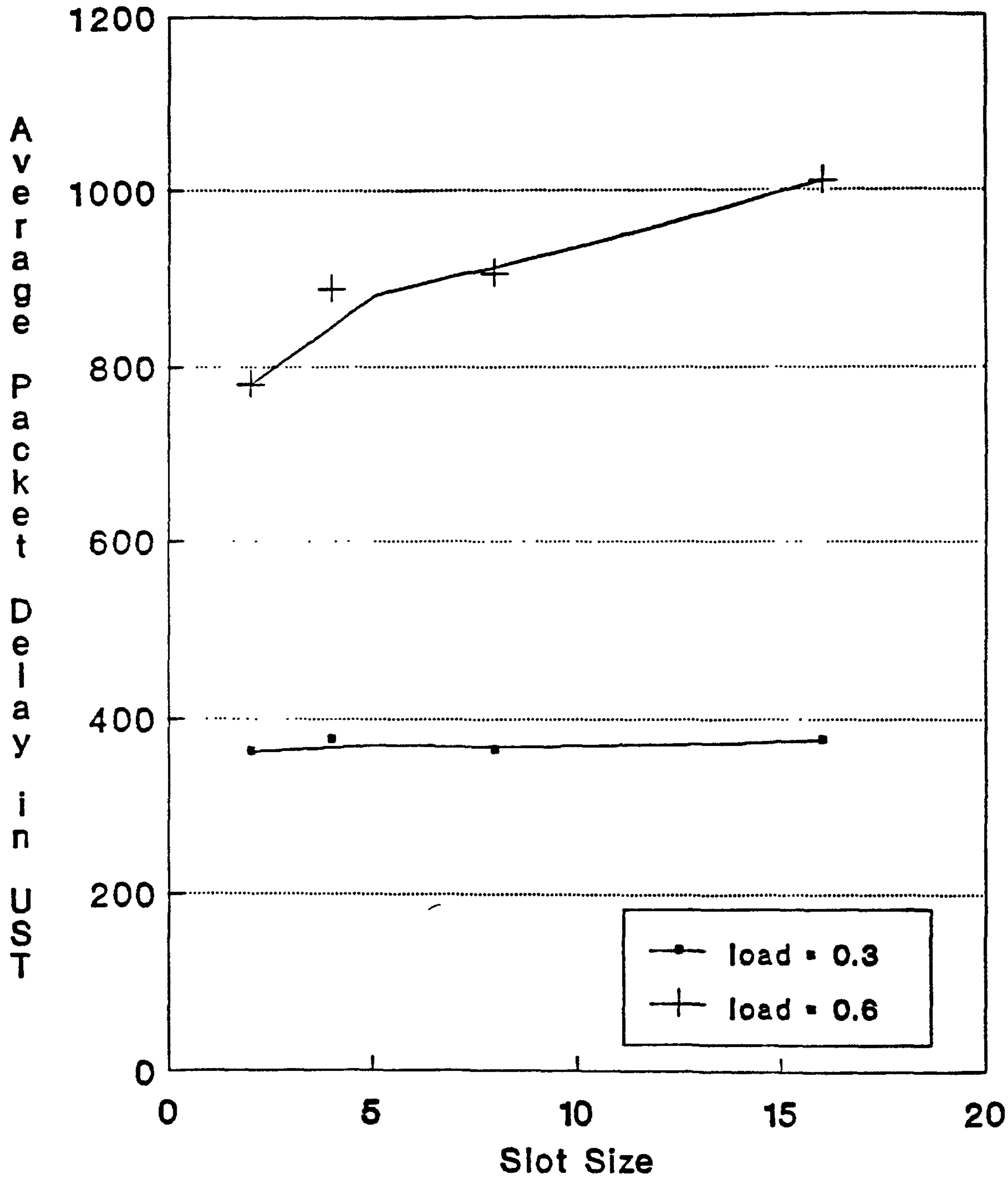

Figure 4.15 Packet Delay vs Slot Size

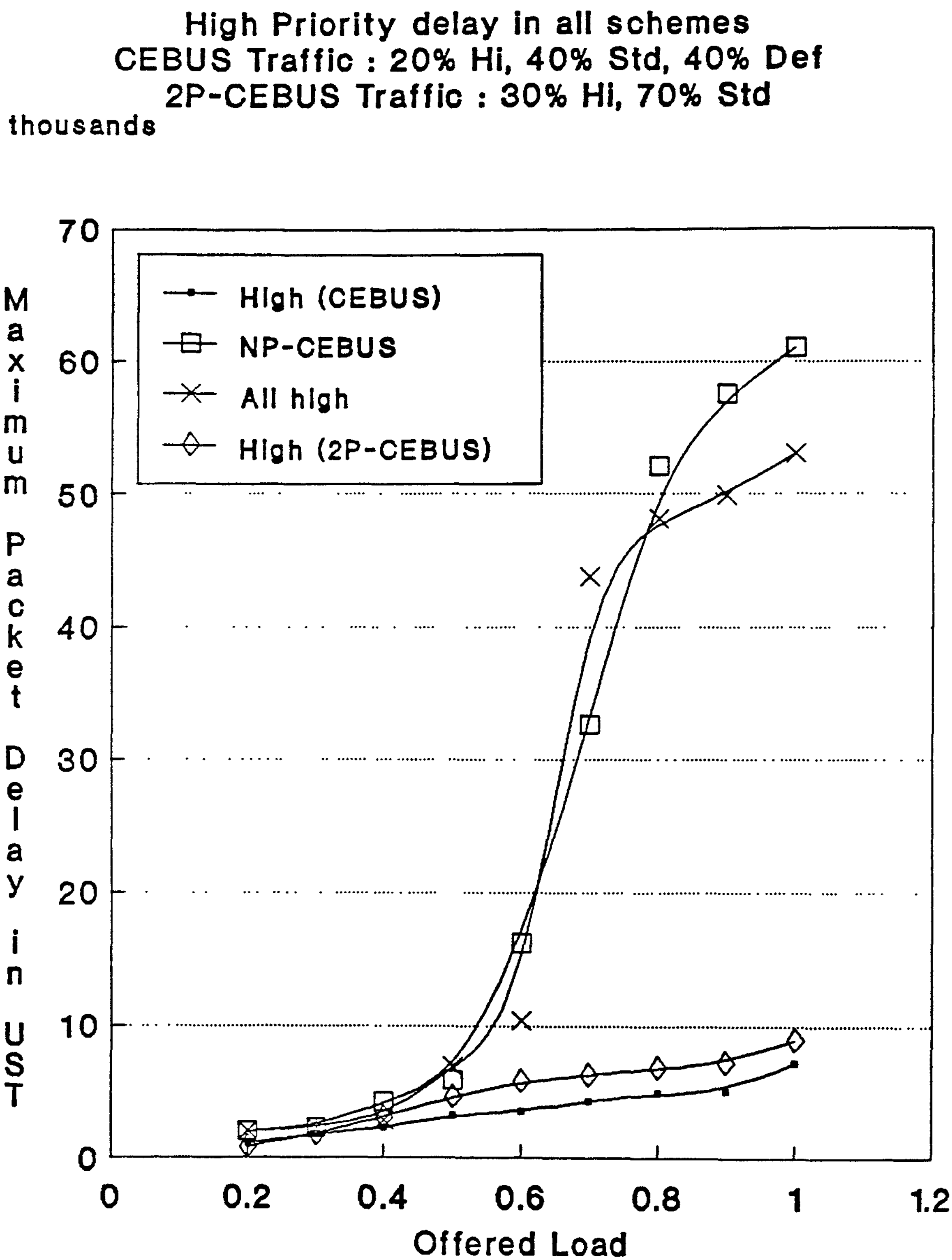

Figure 4.16 Max. Packet Delay vs Load

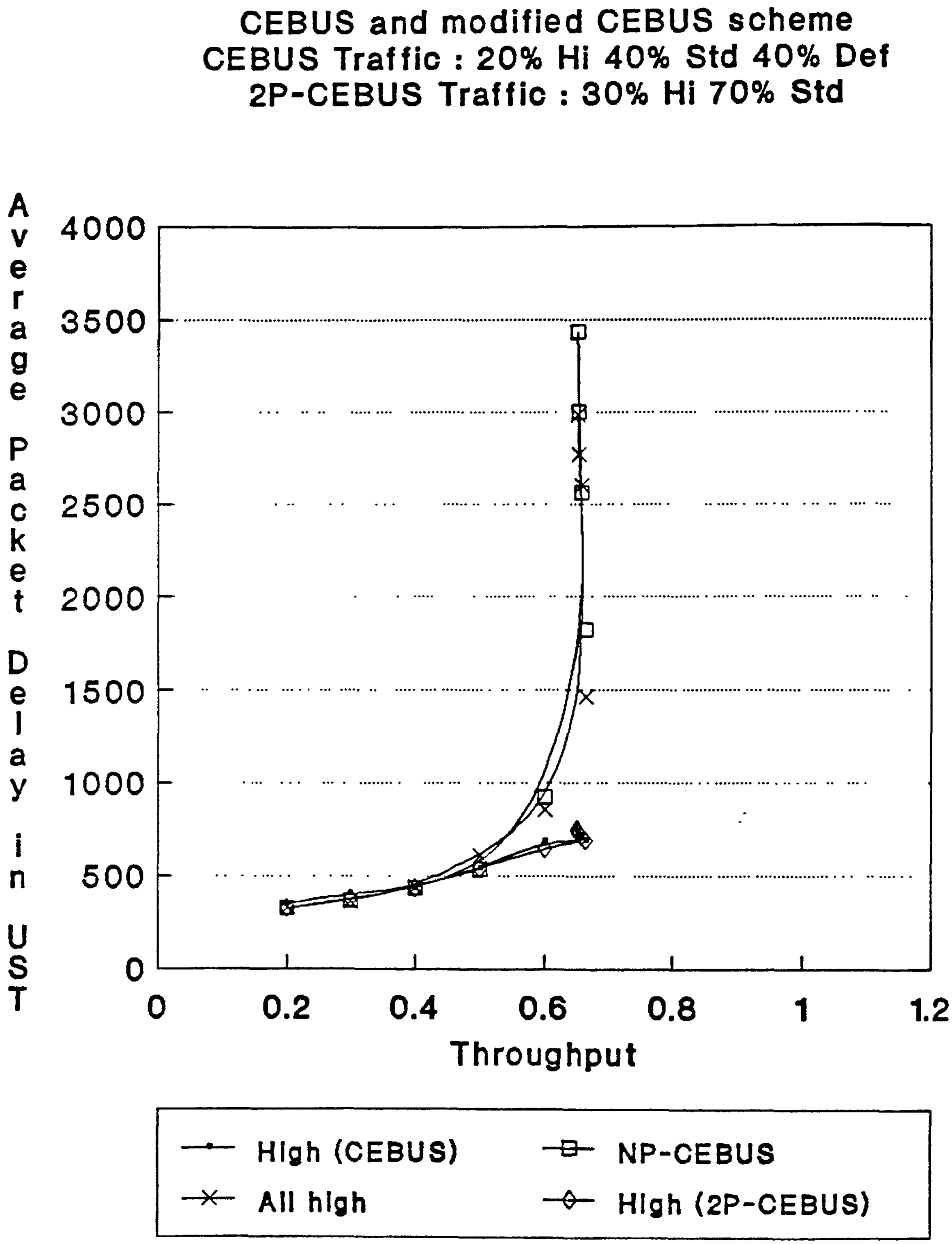

Fig.4.17 Avg. packet delay vs Throughput

Simulation and Analytical Results

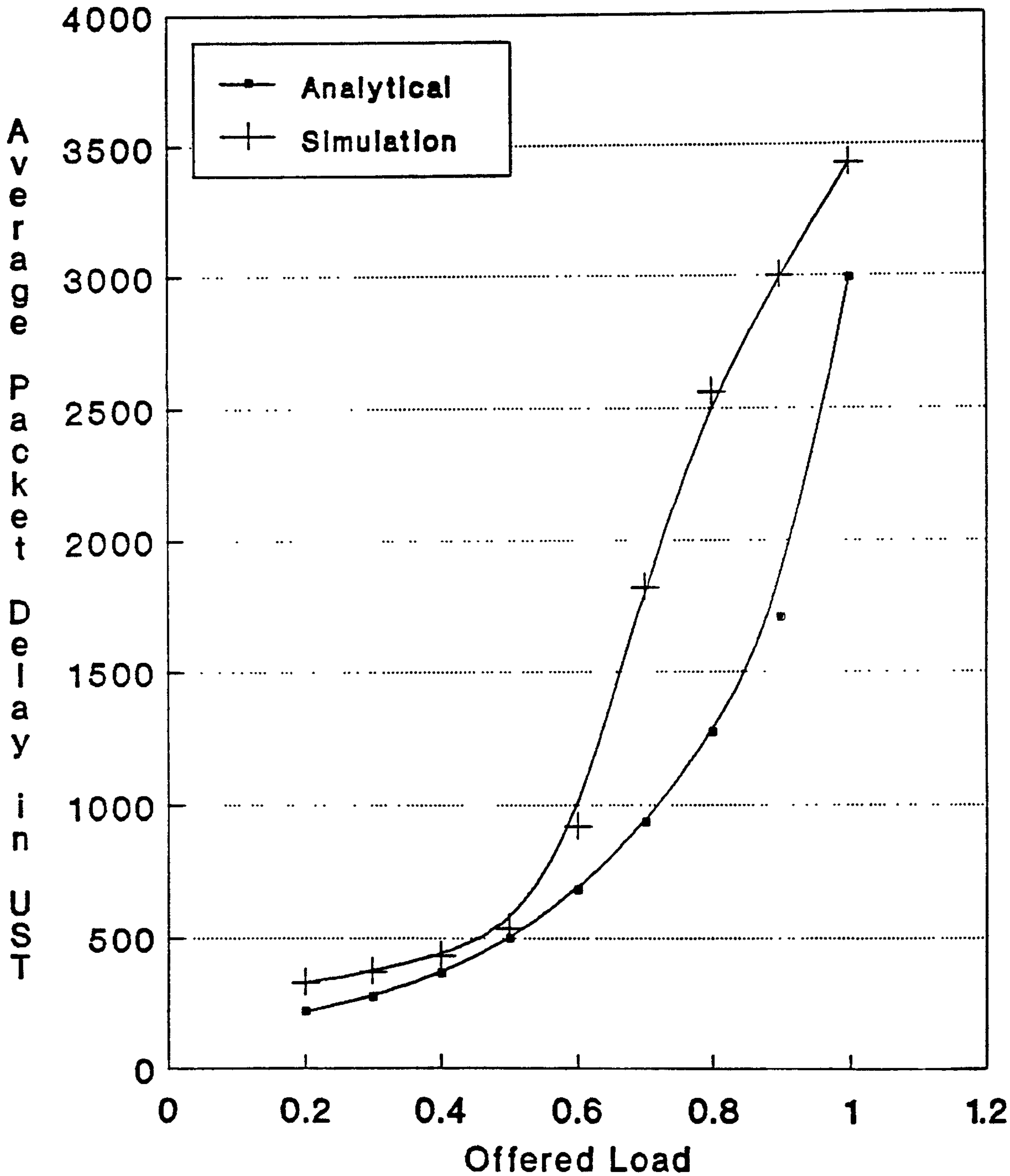

Figure 4.18 Analytical Comparison

Chapter 5

Conclusions

This chapter presents conclusions based on the results obtained from simulation analysis and results reported in the CEBUS literature.

For the standard CEBUS scheme, it was observed that at offered loads below 0.5, the average delay for all the priority messages is almost constant and also quite low. At these loads, the non-priority CEBUS scheme performs equally well. However in some applications there could be time intervals with loads greater than 0.5, and in these situations important messages could be delayed excessively.

At loads beyond 0.5, the delay depends upon the priority of the message. Comparing the performance of the standard CEBUS scheme and the modified two priority CEBUS scheme at these loads, it was observed that the high priority delay performances of the two schemes are almost the same. The standard priority delay of the modified scheme is greater than the standard priority delay but lower than the deferred priority delay of the regular CEBUS scheme. The standard priority is allotted to messages that can tolerate some delay, and this increase in delay should not be of much concern. Hence the modified CEBUS scheme has performance that is apparently comparable to that of the standard

CEBUS scheme with the advantage of reduced complexity. One would have to know more about the rationale for the distinction between STANDARD and DEFERRED priorities to suggest dropping it totally.

It was observed that increasing the proportion of high priority traffic not only increases the average and maximum delay of high priority messages but also the average maximum delays of standard and deferred priority messages. In the model of [2], most of the traffic is assumed to be high priority, and it was suggested that the average delay of messages can be reduced by assigning high priority to a large proportion of messages. This technique if adopted would decrease the overall average delay of all the messages at the expense of a large increase in the average delay of high, standard and deferred priority messages individually. In a home environment relying on power line or other slow media high priority should be allotted to messages where delay is crucial and the remaining messages should be allotted lower priority. Hence high priority message traffic should not be increased beyond the minimum required even though the overall system performance will be lower.

A scheme was suggested in [3] to reduce the delay of standard priority messages by modifying the CEBUS scheme such that one standard priority packet is allowed to transmit after all the high priority packets are transmitted. After one standard priority packet is transmitted, the cycle repeats: all high priority messages followed by one standard message and so on. This analysis was carried out under the assumption that 80-90% of the traffic is of high priority and the rest is either standard and or deferred priority. However in a normal home environment, high priority traffic should be only 20-30% of the overall traffic as shown in

Table 4.1. This is a simpler way to prevent long delays for lower priority messages.

At a given capacity, the delay in the CEBUS network depends upon the offered load, the message priority and the traffic pattern in the network. To achieve effective real-time performance the traffic pattern in the CEBUS network must be properly distributed, with high priority strictly allotted to messages where delay is important. The other messages must be allotted lower priority.

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