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Design and analysis of a medium access and control strategy for extending the ISDN services to LAN users

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Iowa State University, 1989

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Design and analysis of a medium access and control strategy for extending the ISDN services to LAN users

by

Muhammad Shafiq

A Dissertation Submitted to the
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1989

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1 INTRODUCTION

A significant portion of the contemporary research efforts in the area of data communications and computer networking is devoted to Local Area Networks (LANs) and Integrated Services Digital Networks (ISDNs). Both, ISDN and LAN, are being developed to satisfy the the key requirements of their specific applications.[1] This application specific development has created a large semantic gap between ISDN and LAN. Consequently, an extensive mapping is required to interface an ISDN with a LAN. Obviously, such mapping may limit the overall performance of a LAN [37].

In the next section, a brief overview of the ISDN services and ISDN user-network interfaces is presented which is followed by the requirements of a medium access and control strategy that can be used to extend the ISDN services to a LAN user.

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[1] LANs are used primarily for connecting the users located in a closed proximity by using, generally, a high bandwidth shared transmission medium. On the contrary, ISDNs are primarily intended for worldwide extension of communication services.

1.1 ISDN

An ISDN is a network, in general evolving from a telephony Integrated Digital Network (IDN), that provides end to end digital connectivity for supporting a wide range of services as shown in Table 1.1 . Users can access these services, termed as ISDN services, through a limited set of standard multi purpose user–network interfaces which are specified by the International Telegraph and Telephone Consultative Committee (CCITT) in its I series recommendations [7].

The ISDN services are described by a set of service attributes and are divided into two broad categories: bearer services and teleservices. Table 1.2 and Table 1.3 list the service attributes of bearer services and teleservices, respectively. A user can tailor an ISDN service or can create a service by selecting appropriate values of the service attributes.

1.1.1 ISDN user-network interface

To assist in developing worldwide compatible ISDN user-network interfaces, the CCITT recommendations I.412 specify two access capabilities [7]:

1.1.1.1 Preferred basic access capability The preferred basic access capability provides the following options to a user:[2]

- 2B + D
- B + D

---

[2] In these options, a B channel provides a bandwidth of 64 Kbps and a D channel supports a bandwidth of 16 Kbps.

Table 1.1: Emerging ISDN Services

- I LOW RATE DATA TRANSMISSION
  - TELEMETRY 10-100 BPS
    - METER READING
    - SECURITY ALARMS
    - OPINION POLLING
    - TELECONTROL E.G. ENERGY MANAGEMENT
- II HOME AND BUSINESS SERVICES 1K-10K BPS
  - TELETEX
  - HOME COMPUTER
  - VIDEOTEX
  - HOME FACSIMILE
  - LOW SPEED DATA
- III INTEGRATED MULTI-SERVICES 10K-100K BPS
  - LOW BIT RATE VOICE
  - HIGH SPEED DATA
  - PCM TELEPHONY/WIDEBAND TELEPHONY
  - FACSIMILE
  - SLOW SCAN VIDEO
- IV BULK SERVICES
  - I. 100K-1M BPS
    - HIGH SPEED FACSIMILE
    - WIDE BAND MUSIC
  - II. 1M-10M BPS
    - VIDEO CONFERENCE
    - INTERACTIVE VIDEO RETRIEVAL
  - III. 10M-100M BPS
    - TELEVISION
  - IV. 100M-1000M BPS
    - HIGH DEFINITION TELEVISION

Table 1.2: Values for Bearer Services Attributes

Possible values of attributes								Attributes (Note 6)
								Information transfer attributes
Circuit	Packet							1. Information transfer mode
Bit rate (kbit/s)	Throughput							2. Information transfer rate
64	384	1536	1920	Other values for further study	Options for further study			
Unrestricted digital information	Speech	3.1 kHz audio	7 kHz audio	15 kHz audio	Video	Others for further study		3. Information transfer capability
8 kHz integrity	Service data unit integrity (Note 2)	Unstructured						4. Structure
Demand	Reserved	Permanent						5. Establishment of communication (Note 5)
Point-to-point	Multipoint	Broadcast (Note 1)						6. Communication configuration
Unidirectional	Bidirectional symmetric	Bidirectional asymmetric						7. Symmetry
D(16)	D(64)	E	B	H0	H11	H12	Others for further study	*Access attributes* 8. Access channel and rate
1.440	1.451	CCITT No. 7	1.462	Others for further study				9.1 Signalling access protocol
G.711	G.721 (Note 3)	1.460	1.451 (Note 4)	X.25	Others for further study			9.2 Information access protocol
Under study								*General attributes* 10. Supplementary services provided 11. Quality of service 12. Interworking possibilities 13. Operational and commercial

Note 1 **– The characterization of the information transfer configuration attribute "broadcast" is for further study.**

Note 2 **– The need for a "data sequence integrity" attribute is for further study.**

Note 3 **– The use of Recommendation G.721 as an information access protocol is for further study.**

Note 4 **– The use of Recommendation 1.451 as an information access protocol is for further study.**

Note 5 **– A provisional definition of the establishment of communication is given in Recommendation 1.130 Further clarification is required.**

Note 6 **– The attributes are intended to be independent of each other.**

Table 1.3: Values for Teleservices Attributes

Possible values of attributes								Service attributes
Refer to Recommendation I.211								Information transfer attributes and access attributes
Speech	Sound	Text	Fac-simile	Text-fac-simile	Video-tex	Video	Others	Type of user information
X.224		T.70		Others				Layer 4 protocol
X.225		T.62		Others				Layer 5 protocol
T.73		T.61		T.6	T.100		Others	Layer 6 protocol
200	240	300	400	Others				Resolution (Note)
Alpha-mosaic		Geometric		Photographic		Others		Graphic mode (Note)
T.60		T.5	T.72	Others				Layer 7 protocol.
Under study								General attributes

Note - If applicable.

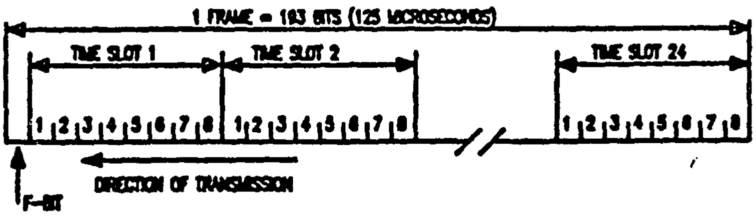


Figure 1.1: Frame Format of 1544 Kbps Primary Interface

- D

1.1.1.2 Primary rate B channel access capability The primary rate B channel access capability provides one D and multiple B channels—each with a capacity of 64 Kbps. The total bandwidth available to a user is equal to $nB + D$, where n is less than or equal to 23 for 1544 Kbps interface[3] and n is less than or equal to 30 for 2048 Kbps interface.[4]

The frame format of the primary interface of 1544 Kbps is shown in Figure 1.1. All the channels of the primary interface are time multiplexed, and channel number 24 is used for signalling and control information transfer using Link Access Procedure D (LAPD).

---

[3] If signalling is provided in another physical ISDN user–network interface, then n=24.

[4] If signalling is provided in another physical ISDN user-network interface, then n=31.

1.1.2 LAPD

LAPD is defined in the CCITT recommendation I.441. The procedure—a subset of HDLC [14],[15]—provides the following functions:

- One or more data link connections on a D channel.
- Distinction between data link connections.
- Frame delimiting, recognition, aligning, and transparent reception and transmission.
- Recovery
- Flow control

LAPD ensures that, even in cases where two or more terminals attempt to access the D channel simultaneously, one terminal will always be successful. When an active Terminal Equipment (TE) has no frame to send, it sends on this channel binary ones signal which corresponds to the absence of the line signal. Collisions on D channels are sensed by monitoring the D echo channel and resolved using the *deterministic back-off procedure* of LAPD. The procedure supports acknowledged (only for point-to-point operation) and unacknowledged transfer mode using single or multiple frame operation.

1.2 Requirements Specifications

In this section, we will discuss the key requirements for a Medium Access and Control Strategy (MACS) which can be used to extend the telecommunication services, supported by an ISDN, to a LAN user.

1.2.1 Information transfer modes

The MACS must support circuit switched and packet switched transfer modes and it should satisfy fairly the bandwidth demands of LAN users.

1.2.2 Information transfer capability

The bandwidth allotted to a user must be large enough to transmit the following unrestricted digital information:

- Speech
- 3.1 KHz Audio
- 7 KHz Audio
- 15 KHz Audio
- Video

1.2.3 Communication establishment modes

The MACS strategy should support the following communication establishment modes:

- Demand
- Reserved
- Permanent

1.2.4 Symmetry

The information transfer mode between two or more than two access points can be:

- Unidirectional
- Bidirectional symmetric
- Bidirectional asymmetric

The MACS should not only support end to end unidirectional and bidirectional information transfer, it should also exploit the unidirectional information transfer mode to improve the performance of the LAN.[5]

1.2.5 Communication configurations

The MACS should support the following communication configurations:

- Point-to-point
- Multipoint
- Broadcast

1.2.6 Effective transfer rates

The MAC should support 64, 384 and 1536 KBPS information transfer rates. This is necessary to establish a symmetrical communication mode with a remote

---

[5] Example: In case of the token ring, the receiver may remove the data transmitted by the sender, and at the same time, the receiver can also transmit its own data which can be removed by the sender.

end user.

1.2.7 Prioritized traffic

The MACS must support the prioritized traffic without degrading the overall performance of the network , and it should guarantee network–wide fairness among all the stations contending for *the right of transmission* at the same priority level.

1.2.8 Interfacing

The MACS should provide required functionality to support an efficient interface. The performance of the network must not be limited by the performance of the interface. *Any modification at the upper layers of a LAN must not require a modification in the interface.*

1.2.9 Access control

The MACS should not depend upon a central controller for controlling access to the shared transmission medium.[6] The access control should be simple, distributed, and robust.

1.3 Format of the Dissertation

The format of the rest of the dissertation is as follows: MACSs of the contemporary LANs are discussed in Chapter 2. Chapter 3 describes and Chapter 4 specifies a MACS that can be used on a ring topology to extend the ISDN services

---

[6] This requirement ensures higher reliability.

to a LAN user. The performance of the proposed strategy is evaluated—using simulation and analytical modeling— and discussed in Chapter 5. Finally, conclusions are stated in Chapter 6.

2 ISDN AND MEDIUM ACCESS STRATEGIES

The MACSs of contemporary LANs can be divided into two broad categories: random access strategies and controlled access strategies. Both categories have their intrinsic advantages and disadvantages[1] which are discussed in this section—with respect to for supporting the ISDN services.

2.1 Random Access Strategies

In random access strategies [1], [11], [19], [29], a station is allowed to transmit on a shared transmission medium when the medium is sensed idle by the station.[2] The success or the failure of a transmission depends upon the state of the other stations—connected on the same transmission medium. In case of a failure, which is detected either by sensing a collision [11] or by the absence of an acknowledgement

---

[1] A random access strategy is very suitable for *low intensity, non-realtime data traffic*, but a controlled access strategy is more convenient for *high intensity data traffic*.

[2] An exception to this rule is ALOHA network [1], in which a station is allowed to transmit even though the medium is still busy.

[1],[3] the contending stations retransmit after a short delay.[4]

2.1.1 Problems

Random access strategies are simple to implement[5] but provide limited support for realtime applications because of the following two major problems:

- High variance of network-access-delay
- Possibility of starvation under high intensity data traffic

Moreover, it is not easy to allocate a portion of the shared bandwidth of a transmission medium to a station without altering the fundamental structure of the random access strategies. Though an implicit priority order can be implemented easily,[6] the strategies lack the required capabilities for supporting the circuit switching facilities. Because of all these drawbacks, these strategies are not further considered.

2.2 Controlled Access Strategies

In the controlled access strategies [2], [9], [12], [13], [43], the access to the shared transmission medium is granted by passing a token explicitly [2], [12], [13],

---

[3] A timer is initiated when a packet is transmitted. If the timer times out and the acknowledgement of the transmitted packet is not received, the packet is retransmitted.

[4] The back-off delay is an important performance controlling parameter and is discussed by Tannenbaum [41].

[5] The is the prime reason of the wide-spread use of Ethernet—a random access strategy based, baseband LAN [11].

[6] One way of obtaining this objective is to assign short back-off delay to high priority stations and long back-off delay to low priority stations.

or implicitly [10], [43]. The token is passed on either in the physical order of the stations [2], [13], or in a user defined logical order [12]. The monopolization of the *right to transmit* is prevented by defining a token hold timer [13] or a token rotation timer [3]. The prioritized traffic is supported by dynamically changing the token priority and disallowing a station to transmit if the current token priority is more than the pending Protocol Data Unit (PDU) [16]. In the following section, a few representative controlled access strategies are discussed.

2.2.1 Token ring

The IEEE token ring [13] is based upon a medium access strategy in which an explicit token is passed from station to station in the order determined by the ring topology. A station can start transmission of a pending PDU after receiving a token whose priority is not greater than the priority of the pending PDU. Stations are not allowed to hold the token for more than a user defined token hold time; thus, the fairness is ensured among the stations contending for the right of transmission at the current priority level of the ring. The strategy is simple, but it possesses the following drawbacks:

- A large variance of network-access-delay
- No support for a circuit switching facility. Consequently, realtime services with unpredictable characteristics[7] cannot be supported.

---

[7] The bandwidth requirements for such services are assumed to be known.

2.2.2 Cambridge fast ring

The cambridge fast ring [38], a derivative of cambridge ring, is a 50 Mbps slotted LAN. A fixed format train of slots circulates indefinitely in the ring. A station willing to transmit waits for an empty slot,[8] marks it occupied, and transmits in the slot. The receiving station, indicated by an address field in the header of the slot, sends an acknowledgement by placing a marker in the same slot. To ensure fairness among all contending stations, a station is not allowed to transmit in more than one slot in one round trip delay.

A block transfer protocol, tailored to support the ISDN services, is defined for cambridge fast ring [37]. The protocol can handle varying size of blocks without introducing complex segmentation and assembly of the packets. The Information such as start of block, end of block, tag, and length of block is included in the header of the block.

Unlike the IEEE token ring, the cambridge fast ring provides necessary support for a circuit switching facility.[9] But, the cambridge ring still is not an ideal approach for supporting the ISDN services because of the following reasons:

- A large portion of the bandwidth is wasted in the management and control of slots.
- The bandwidth available to a station is restricted to one slot per roundtrip delay[10]

---

[8] The state of the slot, empty or occupied, is indicated in the header of the slot.

[9] A station can occupy a slot which will be accessible to this station after a deterministic delay.

[10] A possible solution could be to allow a station to occupy more than one slot in

- The proposed ISDN/Cambridge fast ring interface [39] require complex control procedures to extend the ISDN services to LAN users, which will degrade the overall performance of the LAN.

2.2.3 FDDI-II

FDDI-II [2], [3] is 100 Mbps/125 baud rate, double ring, multiple frame transmission in a single access protocol. Both, circuit switching (with 6.144 Mbps isochronous channels) and packet switching techniques are supported on a fiber optic based transmission medium. Upto 16 circuit switched channels, with a total capacity of 98.304 Mbps, can be used. Like the ISDN channels, these channels are full duplex and can be subdivided into 2.048 or 1.536 Mbps data highways. The Isochronous channels can be dynamically assigned and deassigned[11] on real-time basis—with the remaining channels available for packet switching. Circuit switched data are injected into the ring by means of a cycle, which is initiated[12] by a *cycle master* using an internal or an external clock..

A study of FDDI, a subset of FDDI-II, was conducted by Marjory [26], in which the reliability mechanism of FDDI and its suitability for the future space station was analyzed. The author concludes that the FDDI design represents an extensive effort to incorporate reliability mechanism as an integral part of the design. The mechanism provides fault isolation, monitoring, and reconfiguration functions.

Interfacing of the ISDN to FDDI-II is yet to be studied. However, it can be

---

one round trip delay. But this may create a possibility of starvation. Also, it will increase the variance of network-access-delay.

[11] This is accomplished by negotiating with the master station.

[12] These cycles are created at a frequency of 8 KHZ.

easily visualized that FDDI-II is primarily designed for intra-network traffic; thus, inter-network traffic can face serious problems, such as:

- No support for slow, realtime data traffic, such as voice.
- Bandwidth allocation is centrally controlled which will create an unnecessary delay in connection establishment. Because of this, an extensive mapping is required between an ISDN and FDDI-II to extend the ISDN services to a LAN user.

2.2.4 Token passing bus

The medium access strategy used in the token passing bus has the same semantic as that of the token ring access strategy. Like the token ring, a token is passed from station to station[13] in a logical order. Upon reception of the token, a station is allowed to transmit. The station must surrender the token to the *logical next station* before the token hold timer expires.

The strategy suffers with the same drawbacks as discussed under the token ring. Moreover, a lengthy header of the token passing bus is expected to further degrade the network performance while transferring short signalling and control information.

---

[13] The main difference between the token passing bus and the token ring is the structure of the ring. In the token passing bus a logical ring is constructed which implies that a *logical next station* may not be the *physical next station.* On the contrary, in the token ring there is no distinction between a logical next and a physical next station.

2.3 Recent Trends

Recently, researchers have proposed hybrid, medium access strategies, in which controlled access and random access techniques are combined to increase the overall performance of the networks [8], [10], [39]. Stewart and Boulton [39] developed a prototype 50 Mbps glass fiber LAN which provides an end-to-end path between two stations using a rooted tree topology. Thus, the medium access and control strategy of the LAN is simple, but the central hub is a bottleneck and limits the performance of the network. Further, the expected delay encountered by a user also depends upon the physical location of the user.

A distributed MACS which achieves a conflict free round robin scheduling using an implicit token passing technique is used in Expressnet [43]. A variant of this strategy is used in Fastnet [23]. Both, Expressnet and Fastnet, approximate the behavior of the token ring using a folded bus configuration; thus, contain all drawbacks of the token ring. The implicit token passing scheme improves the performance of these networks but also introduces additional complexity to interface these networks to an ISDN.

A distributed MACS for a multi channel LAN with global and local transceiving channels using a look-ahead reservation protocol is proposed by Yum and Wong [46]. The network is capable of message switching, packet switching, and circuit switching. The available bandwidth is divided into local and global channels to support telephone calls, conference calls, facsimile and customized data rates. The local channels are used for transmission between a preassigned set of stations using CSMA/CD based bus access protocol. The global channels are accessed using a reservation scheme and are used primarily for communication between different sets. A separate global channel is reserved to implement the reservation scheme. The channel is known as a reservation channel and employs the slotted ALOHA medium access protocol for arbitration between the contending stations.

The proposed strategy is intended primarily to reduce the back-off delay of CSMA/CD. However, the strategy suffers from all the flaws of a random access strategy. Also, the contention on the reservation channel will reduce the overall performance of the network, and it will introduce delay in the connection establishment. The prioritized access is not allowed in this strategy. And dynamic expansion of the bandwidth is not supported.

3 DESCRIPTION

In this chapter, a MACS is proposed that will not require a complex ISDN/LAN interface and will extend the ISDN services to a LAN user without degrading the performance of the LAN. The proposed MACS is distributed in nature and can be implemented on a ring topology.

3.1 Frame Format

A frame whose format is shown in Figure 3.1 is inserted by the master station[1] after every 125 *μsec.*[2] The *available bandwidth* of a frame is divided as follows:

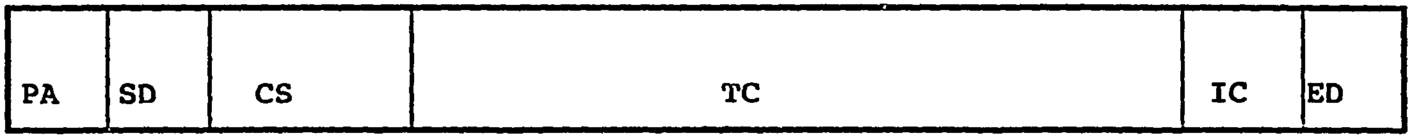
- Status channel (24 bits per frame)
- Token channel (2256 bits per frame[3])
- ISDN channels (192 bits per frame)

---

[1] Every station has the ability to act as a master station.

[2] This implies that the cycle will be inserted at a frequency of 8KHz which may help in optimizing the voice transmission.

[3] This value is computed for a 20 Mbps LAN and could be different for different bandwidth LANs.



PA	Preamble
SD	Start Delimiter
CS	ISDN Channels Status
TC	Token Channel
IC	ISDN Channels
ED	End Delimiter

Figure 3.1: Frame Format

3.1.1 Status channel

The first 24 bits of the frame[4] are reserved for the status channel. A binary 0 in the status channel indicates that the corresponding ISDN channel is free; otherwise, the channel is occupied by a station.

3.1.2 Token channel

The status channel is followed by the token channel[5] which is large enough to support a modified token ring protocol. The token channel is used for intra-LAN data traffic. All free ISDN channels, except the D channel, are merged with the token channel. Thus, a free ISDN channel will not degrade the overall performance of the network.

3.1.3 ISDN channels

In every frame, there are 24, 8 bit ISDN channels whose status is indicated by the status channel. The format of the ISDN channels is consistent to the CCITT specifications [7].

3.2 Access Protocols

Two access protocols are defined to regulate the access to the shared transmission medium. These are :

- Token channel access protocol

---

[4] SD and Preamble fields are not considered here.

[5] This position of the token channel in a frame will facilitate to merge the token channel with the free ISDN channels.

- ISDN channel access protocol

3.2.1 Token channel access protocol

3.2.1.1 Frame format of the token channel The frame format of the token channel is shown in Figure 3.2. The format is an extension of the IEEE token ring frame [13]. A new sub-field known as timer subfield is specified which will allow a user to dynamically control the Target Token Rotation Time (TTRT).[6]

3.2.1.2 Access control In this protocol, the access to the token channel and all free ISDN channels is regulated by explicitly passing a token from station to station. A station can transmit a pending PDU if the following conditions are satisfied:

- The station has received a token.[7]
- For *realtime pending* PDU, the time elapsed between the last and current token arrivals is less than the current TTRT.
- For an *ordinary pending* PDU, the time elapsed between the last and current token arrivals plus the transmission time of the pending PDU will be less than the current TTRT.

---

[6] This is an enhancement of the timed token rotation protocol [44], which allows to change the TTRT statically, not dynamically.

[7] This restriction is not rigid. A station can transmit even without holding a token, provided it has established a full duplex communication with the current token holding station.

SD_TKN	AC	FC	DA	SA	INF	FCS	ED_TKN	FS

SD_TKN	Start Delimiter of Token Channel
AC	Access Control
FC	Frame Control
DA	Destination Address
SA	Source Address
INF	Information Field
FCS	Frame Check Sequence
ED_TKN	End Delimiter of Token Channel
FS	Frame Status

Figure 3.2: Token Channel Format

- The token hold timer of the station will not expire during or before the transmission of the pending PDU.[8]

3.2.1.3 TTRT control The LAN will generally operate on a mutually agreed TTRT value. Any active station can request to reduce the TTRT by setting the TIMR subfield to an appropriate value,[9] as it repeats the AC field. The current token holding station acknowledge this request by modifying the TIM subfield[10] according to the requested value and setting TIMR to the value which correspond to the highest, prespecified TTRT value. The station then becomes a *stacking station.* The operation of the stacking station is the same as the token ring stacking station operation—defined in the IEEE token ring standard for controlling the priority of the ring.[11] The stacking station is responsible for restoring the previous value of the TTRT by using the same procedure as specified for the IEEE token ring to restore the ring priority.[12]

---

[8] This can be checked by using the size of the pending PDU to be transmitted and the remaining token hold time.

[9] Since the TIMR subfield is 2 bit in length, a station can request one of the 4 possible TTRT values which should be mutually selected at the LAN initialization time.

[10] The subfield is modified when token is placed on the ring.

[11] The IEEE token ring priority control procedure is selected for its flawless operation.

[12] This implies that the TTRT can be reduced by any *active station* but can be increased only with the mutual consent of all the *active stations.*

Start/End Delimiter of Token Channel

J	K	1	J	K	1	K	X

X=1 : Token Channel Start
X=0 : Token Channel End

Start/End Delimiter of Frame

J	K	X	J	K	X	X	X

X=1 : End Delimiter
X=0 : Start Delimiter

Token Channel End Delimiter Format

J	K	1	J	K	1	1	0

Access Control

RTIM	TIM

RTIM	Requested Target Token Rotation Timer
TIM	Current Target Token Rotation Timer

Token Format

SD_TKN	AC	ED_TKNI

SD_TKN	Start Delimiter of Token Channel
AC	Access Control
ED_TKNI	End Delimiter of Token

Figure 3.3: Token Channel Start Delimiter, End Delimiter, and Access Control Field Formats

3.2.2 ISDN channel access protocol

Access to the ISDN channels is regulated by the status channel. A station willing to transfer on a channel can do so by reserving the channel access bit.[13] Once a channel is reserved, no other station can transmit through this channel. It is the responsibility of a station to release the ISDN channels occupied by it.[14] The users have complete freedom to define their own protocols for transferring data in the ISDN channels. The network transparently transmits the user data through the interface.

3.2.2.1 Data consistency Since all the free ISDN channels are merged with the token channel, an ISDN channel which was free for a station transmitting in the token channel may be occupied by another downstream station which may insert its data in the channel and destroy, partially or completely, the token channel data. To overcome this problem, a station is not allowed to transmit in the very same cycle in which it reserves the ISDN channel. Instead, it waits for the next cycle and then transmits its data.[15]

---

[13] This can be accomplished by setting the appropriate status bit to 1, if it was previously 0.

[14] Obviously, this will complicate the recovery procedures.

[15] It appears that this may degrade the performance of the network but a closer look on ISDN data transfer mechanism reveals otherwise: since the ISDN cannot instantly respond to a D channel signalling and control information, the station will not start transmission immediately after reserving the ISDN channel. The token channel can use this delayed response to improve its throughput. Further improvement is possible if the channel is considered free until the occupying station actually starts transmission.

3.2.2.2 Recovery procedures The token channel access protocol can utilize the recovery and maintenance procedures defined for the IEEE token ring, with the exception of the recovery of the ISDN channels occupied by the failed stations. Since there is no station that knows the current owners of the occupied ISDN channels, the station initiating the recovery must inquire the status of the ISDN channels reserved by other stations and set those channels free which are not occupied by the responding stations. Upon recovery, the station should contend for the channels and should assume that all of its previously occupied ISDN channels are released.[16] It is assumed that the failure of a station which has occupied some ISDN channels will be detected when a token will be passed on to the failed station.[17]

3.3 Interface Operation

The interface is simple, mostly, limited to the frequency conversion from ISDN signalling [7] to the LAN signalling [13], and is comprise of primarily two receiver/transmitter pairs: one on the network side and the other on the ISDN side.

3.3.1 Status channel interface

Status channel bits are neither modified nor transmitted towards the ISDN. The bits received from the *network receiver* are transmitted by the *network transmitter*.

---

[16] To make sure that the procedure works, the failed station should wait for a user defined time before becoming part of the ring.

[17] At this time the token will be lost and the lost token recovery procedure—similar to the IEEE token ring, lost token recovery procedure—will be initiated by the network monitor station.

3.3.2 B channels interface

To avoid any ambiguity, in the rest of this chapter, the ISDN channels of the LAN side of the interface will be called *LAN-ISDN* channels and ISDN channels of the ISDN side of the interface will be simply called ISDN channels. We will return to our previous definition of ISDN channels in the next chapter.

The interface transfers data from LAN to ISDN and vice versa by using the following algorithms:

3.3.2.1 Network to ISDN data transfer

- The data received in a LAN-ISDN channel, whose status bit is not set, are transmitted back in the ring. The received data are not transmitted in the corresponding ISDN channel.
- If a status bit is set and this is not the first cycle in which this bit is found set, the received data, from the corresponding LAN-ISDN channel, are transmitted through the corresponding ISDN channel, and the received data are not inserted back in the ring. If no data are received, fill characters will be transmitted through the corresponding ISDN channel.
- If a status bit is set and this is the first cycle in which the bit is found set, the data received in the corresponding LAN-ISDN channel will be considered as a part of the token channel and will be transmitted back in the ring without any further action.

3.3.2.2 ISDN to network data transfer

- If data are received in an ISDN channel and the status bit of the corresponding LAN-ISDN channel is set in the current cycle and this is not the first cycle in which the status bit is found set, the interface first waits for the beginning of the corresponding LAN-ISDN channel and then transmits the received data in the LAN-ISDN channel.

- If data are received in an ISDN channel and the corresponding status bit is free, the received data are simply discarded.[18]

- If no data are received for a LAN-ISDN channel whose status bit is set, the fill characters are transmitted in that channel.

3.3.2.3 D channel interface The LAN-ISDN D channel is permanently connected to the ISDN D channel and vice versa. The data received in the LAN-ISDN D channel are transmitted through the ISDN D channel and is also echoed back without any alteration. If no data are received—from the network or from the ISDN—the fill characters are transmitted towards the opposite side. The LAN-ISDN D channel is always monitored by all the stations all the time and only used for signalling and control information transfer.

---

[18] In normal operation, this situation cannot occur. Because, a remote station must establish a connection, reserve free B channel and only then start transmission.

3.3.3 Token channel interface

The data received in the token channel are simply transmitted back, without any alteration, in the ring.

4 SPECIFICATIONS

The key aspects of the proposed MACS are specified in Functional Specification Description Language (SDL). A brief overview of the specifications is presented in this chapter following an introduction to SDL.

4.1 SDL

SDL is defined by the CCITT in the CCITT recommendations Z.100 to Z104 [5], [6]. The language has single semantic-model based two different syntaxes: SDL/PR and SDL/GR. SDL extends the Finite State Machine (FSM) by introducing two auxiliary operations: decision and task. Both, decision and task, reduce the number of explicit states required to represent a protocol.

In SDL/PR, a system is represented by program-like statements. Whereas in SDL/GR, a system is specified by a set of rules and standardized graphical symbols (described below). The SDL/GR is selected to specify the MACS for two reasons: First, it is more readable than SDL/PR and can be understood without knowing all the pros and cons of the language. Second, it is possible to translate SDL/GR into SDL/PR, whereas the converse is not true.

4.1.1 SDL constructs

In this section, some important SDL constructs required to specify a system are discussed. The graphical symbols for some of these constructs are shown in Figure 4.1.

4.1.1.1 System A system is a concrete entity separated from its environments by a system boundary and contains a set of blocks communicating through interconnecting channels and processes.

4.1.1.2 Channel A channel is a unidirectional transparent route for the signals.

4.1.1.3 Blocks A block is an object of manageable size in which one or more processes can be interpreted.

4.1.1.4 Signal A signal is a flow of data conveying information between processes and represented either by output or by input symbols.

4.1.1.5 Process A process is a communicating FSM which defines the dynamic behavior of the system and possesses four predefined variables of process identifier type SELF, PARENT, OFFSPRING, and SENDER.

4.1.1.6 Procedure A procedure is a way of giving name to an assembly of items. It permits the structuring of the process graph, maintains the compactness of the specifications, and allows assembly of the items for repeated use.

4.1.1.7 State

A state is a representation of the logical situation of a process in which no action is performed other than monitoring the input queue.

4.1.1.8 Task

A task is a representation of a set of actions not having a direct effect outside the process.

Other than these constructs, SDL specifies symbols, for developing a process graph, such as:

- decision: indicates the sequencing of the process upon storage modification.
- save: indicates that an arriving signal will be saved.
- con: indicates the interconnection of the process graph.
- call: indicates the calling of a procedure.
- return: indicates the termination of a procedure.
- input: indicates the input signal the process might be waiting for.[1]
- output: indicates the output signals sent by the process—subject to the sequencing of the process.[2]

---

[1] Two input signals are shown in Figure 4.1. In the specifications, these signals are used to categorize the senders of the signals.

[2] Two output signals are shown in Figure 4.1. In the specifications, these signals are used to categorize, if possible, recipients of the signals.

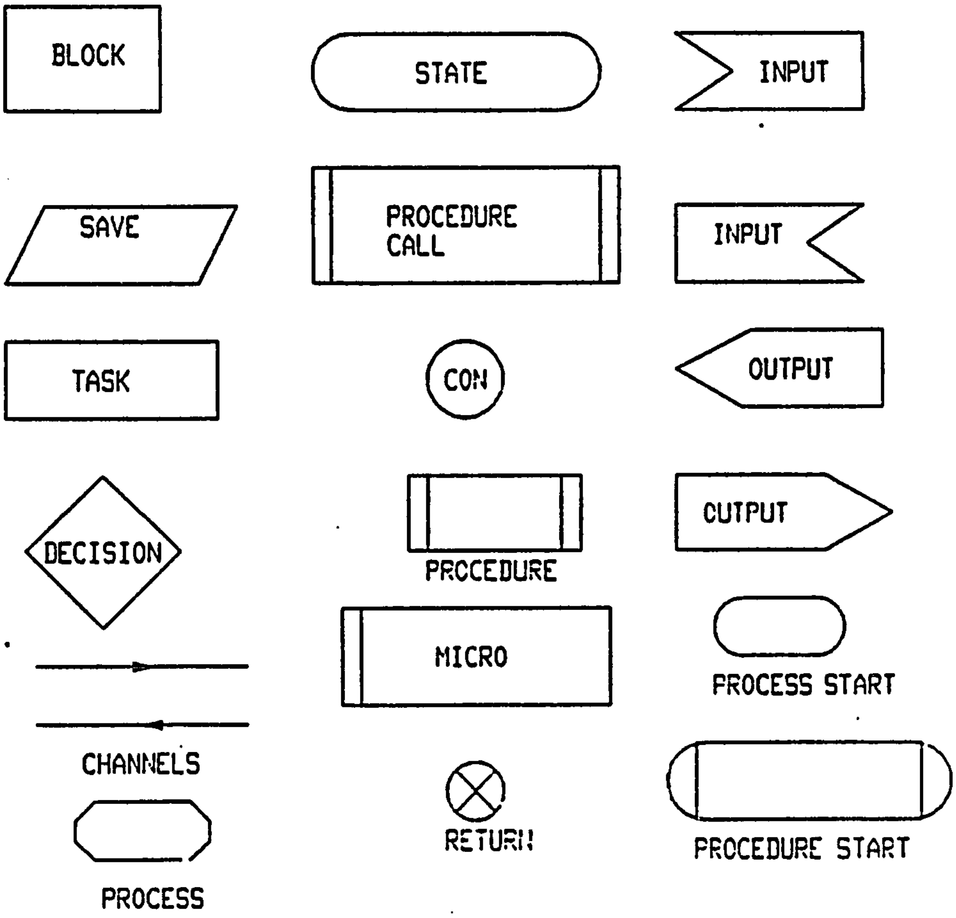


Figure 4.1: SDL Constructs

4.2 Overview of the Specifications

The system is decomposed into two blocks: a station block and an interface block. A station block specifies the behavior of a LAN station, and an interface block specifies the behavior of the ISDN/LAN interface.

4.2.1 Station Block

As shown in Figure 4.2, the station block possesses 14 processes. Five of these, *RINF_MNG*,*C_STS_MNG*,*TRINF_MNG*,*TKN_MNG*, and a user-defined process specify management and interface activities of a LAN station. RCV and TR, as their names imply, specify receive transmit functions of the network, respectively, and they also act as an interface between the network and the other processes. RCV also detects the flags, such as: SD and ED. *RCV_MNTR* monitors the data received from RCV and informs *LLC_INTF_RCV* that a data packet is received form the physical layer and also conveys the control and signalling information to *C_A_C* process, which is responsible for regulating the access to the ISDN channels by using information received from *RCV_MNTR* and *C_STS_MNG*. Packets received from other stations are transferred to LLC layer through *RINF_MNG*.

The token channel can be implemented with *PKT_TR*,*TKN_CNT*, *LLC_INTF_RCV*, and *LLC_INTF_TR*. *PKT_TR* manages the transfer of the PDU received from the uppper layer to MPXR, subject to the permission of *TKN_MNG*, which monitors the information received form *TKN_CNT* and decides to transfer or delay the token.

MPXR is the heart of the transmission control of the network. It receives data

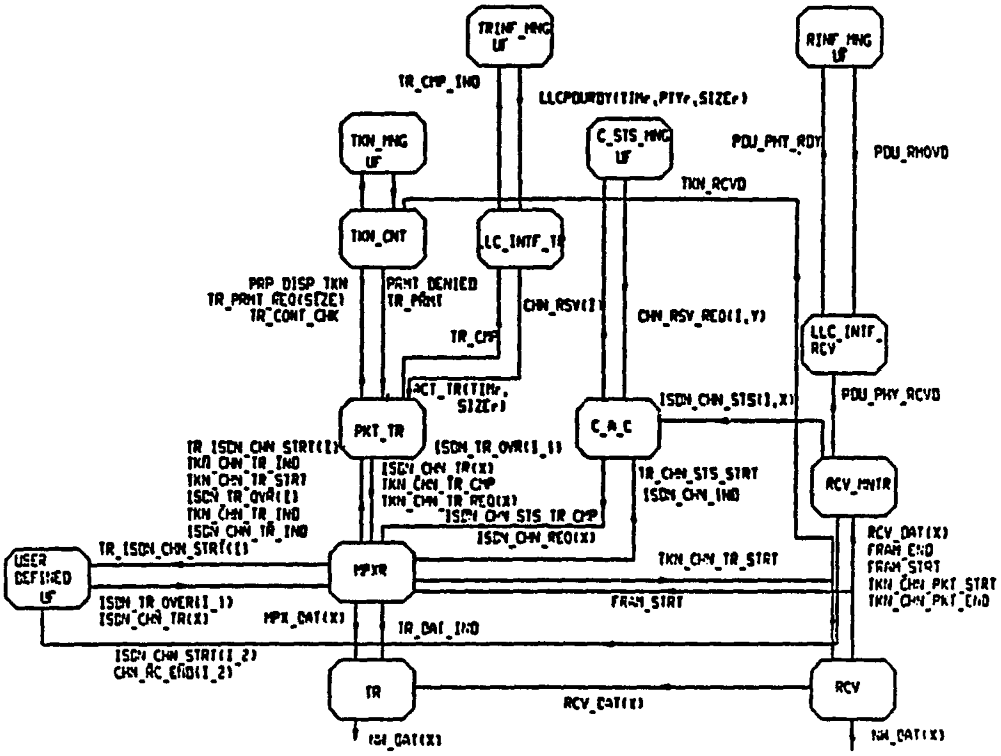


Figure 4.2: Process Interaction Diagram of a Station Block

from *PKT_TR*, *USER_DEFINED*, *C_A_C*, and *RCV* and synchronizes all the transmission activities. The specifications of the key, station block processes are given in APPENDIX.

4.2.2 ISDN/LAN interface specifications

The ISDN/LAN interface is specified with the help of five processes. Three of which *LAN_RCV_M*, *LAN_RCV* and *LAN_TR* are synonyms of *RCV_MNTR*, RCV, and TR respectively.

The *ISDN_RC* is responsible for detecting flags and then transmitting the received signals to TR through *I_N_TR*. The *ISDN_TR* inspects the flags and then transmits the previously received signals from *N_I_TR*, into the ISDN. If the required signals are not received within the prespecified duration, *ISDN_TR* will transmit fill characters into the ISDN.[3] The specifications of the key ISDN/LAN interface processes are given in the APPENDIX.

4.3 Complexity Analysis

Though a broadly acceptable meter to compare the complexity of widely varying protocols is yet to be discovered, number of states and I/O signals are generally used to quantify the complexity of the protocols. Table 4.1 lists the number of signals and states of the key, interface processes.

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[3] The format of the fill characters is not discussed here.

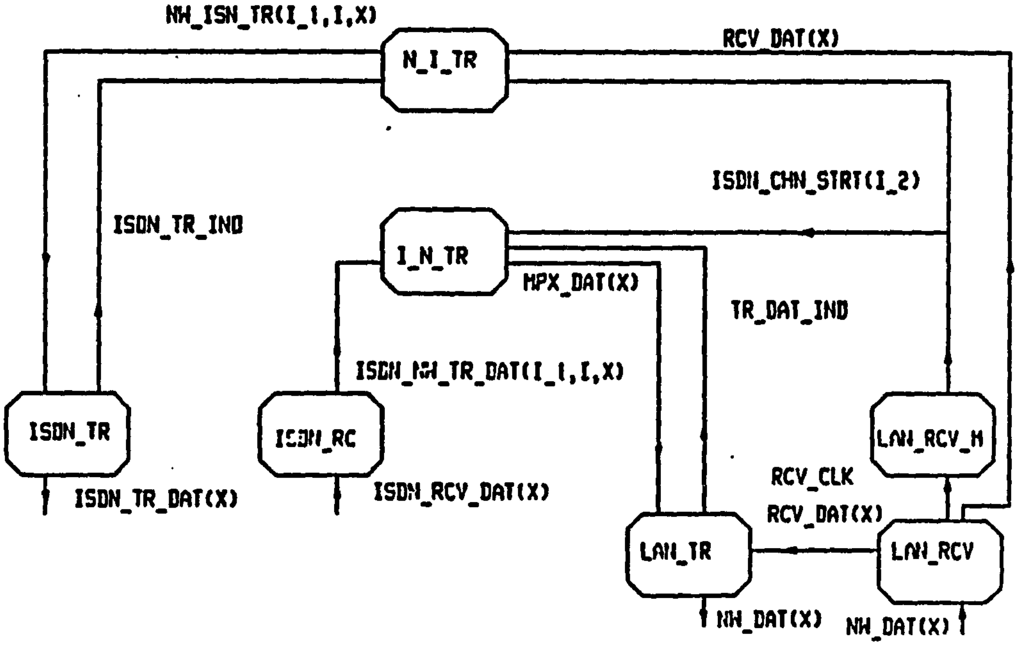

Figure 4.3: Process Interaction Diagram of ISDN/LAN Interface

Table 4.1: Complexity of Interface

Process	States	Input	Output
Interface	6	7	2
ISO Transport	8	11	8

Process	States	Input	Output
N_I_TR	3	3	1
I_N_TR	3	4	1

5 SIMULATION AND ANALYTICAL MODELING

Simulation models were developed, in SLAM [33], for analyzing the following aspects of the proposed MACS:

- The behavior of the D channel under varying, control messages traffic.
- The token channel behavior under varying, data traffic.
- The impact of the TTRT on the token channel performance.

In the following sections we will look into the details of these models and the performance of the network under different loading conditions.

5.1 Network Parameters

5.1.1 LAN Characteristics

- Bit rate: 20 Mbps
- Stations: 100
- Inter-station gap: 10 meters (constant)
- Cycle insertion rate: 8KHz
- Topology: Ring

5.1.2 ISDN interface

Primary interface with 1 D and 23 B channels.

5.2 D Channel Model

A simulation model was developed to analyze the behavior of the D channel for:

- Transferring short control messages.
- Establishing and de-establishing a circuit switched call.

5.2.1 Control message transfer model

The D channel is modeled as a cyclic server which can remove and then transfer one byte of information, in every cycle, until the queue under service is exhausted. The operation of the D channel is depicted in Figure 5.1.

5.2.1.1 Traffic characteristics

- The arrival process is Poisson.
- The number of bytes in a message are geometrically distributed.[1]
- Data traffic on every station is identical and independent from the rest of the stations.

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[1] This will not restrict our analysis for continuous message length.

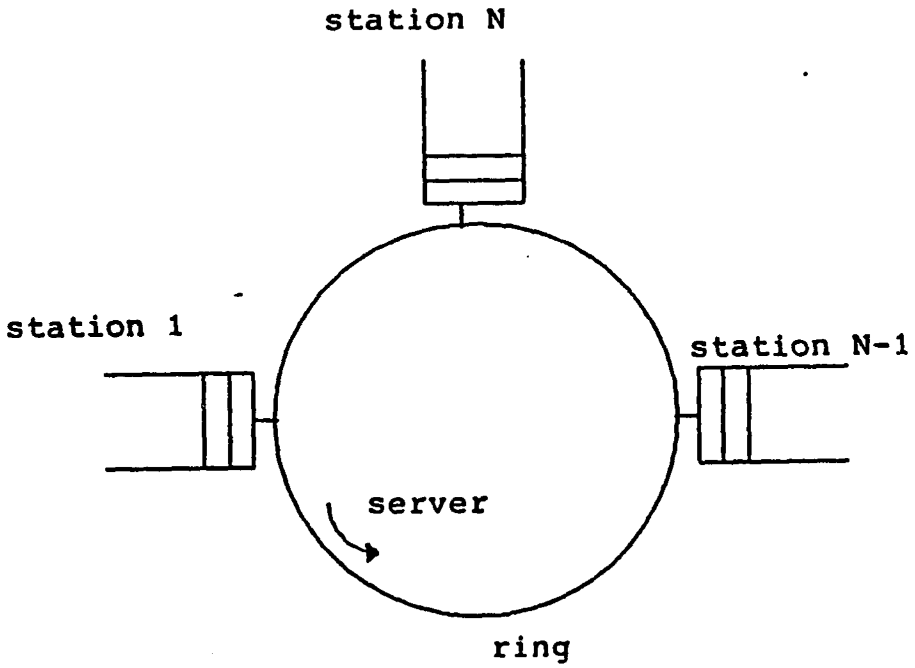


Figure 5.1: D channel as a Cyclic Server (non-prioritized case)

5.2.1.2 Analytical model The notations described in this section will be used throughout this chapter to represent different parameters of the mathematical models.

W = Waiting time of a packet

δ^2 = Variance of propagation delay

r = Expected propagation delay

N = Number of stations

λ = Number of packets arriving in one cycle time

b = Expected number of bytes in a packet

$b^{(2)}$ = Second moment of number of bytes in a packet

b^2 = Variance of number of bytes in a packet

γ^2 = Variance of number of packets arriving in one cycle time

σ^2 = Variance of number of bytes arriving in one cycle time

μ = Expected number of bytes arriving in one cycle time[2]

R = Rotation time[3]

For symmetrical stations the expected rotation time is given by Takagi [40],

$$E[R] = \frac{Nr}{1 - N\mu} \tag{5.1}$$

The variance of the rotation time is computed as:

$$Var[R] = \frac{\delta^2 N}{(1-\mu)(1-N\mu)} + \frac{\sigma^2 r N^2}{(1-\mu)(1-N\mu)^2} \tag{5.2}$$

The waiting time for a packet for the exhaustive discrete (G/G/1): (FCFS/∞/∞) queuing system:

$$E[W] = \frac{\delta^2}{2r} + \frac{N[\lambda b^{(2)} + r(1-\lambda b)]}{2(1-N\lambda b)} + \frac{(\gamma^2 - \lambda)b}{2\lambda(1-N\lambda b)} - \frac{1}{2} \tag{5.3}$$

and the expected queue length in terms of number of bytes is given as:

$$E[L] = \frac{\delta^2 \mu}{2r} + \frac{\sigma^2}{2(1-N\mu)} + \frac{Nr\mu(1-\mu)}{2(1-N\mu)} \tag{5.4}$$

Since we are primarily interested in the mean queue length of the packets, the expected queue length of the packets (L_P)is computed by exploiting the independence between the number of packets arriving in a cycle time and the number of bytes in a packet: for such cases the expected queue length is computed as,

$$E[L_P] = \frac{\delta^2 \lambda}{2r} + \frac{\sigma 2}{2b(1-N\mu)} + \frac{Nr\lambda(1-\mu)}{2(1-N\mu)} \tag{5.5}$$

---

[2] If the number of packets arriving in a cycle time and the number of bytes in a frame are independent then $\mu = b\lambda$.

[3] The rotation time is defined as the interval between two consecutive events in which the D channel is observed free by a station.

5.2.1.3 Simulation model

5.2.1.3.1 Modeling difficulties Since the number of stations to be modeled are 100 and bit rate is 20Mbps, the number of events to be simulated is exceptionally large.[4] A few optimizing techniques were used to reduce the number of events to be simulated.

The cycle was not simulated on all stations. A station who is currently holding the D channel will stop the scheduling of the cycle arrival on all other stations and will compute the time it takes to transfer the packet which is:

$$PKTr = \lceil \frac{PKTs}{SLSIZ} \rceil * CYCTIM$$

PKTr = Packet transfer time

PKTs = Packet size

SLSIZ = Slot size (D channel capacity)

CYCTIM = Cycle time

The cycle will be inserted after PKTr seconds.

It was also observed that under low intensity traffic the simulation model execution time is large.[5]

This counter intuitive behavior of the D channel simulation model[6] is explained

---

[4] For example, to simulate one hour control message traffic, 28.8 million cycle arrival events are required to be simulated. It was observed on AT&T 3B15 computer that the simulation time for such traffic is more than 2000 CPU minutes.

[5] For example, the model was executed to simulate 60 minutes data traffic of 30 calls/hour. It took more than 5000 CPU minutes on AT&T 3B15 computer and could not simulate even 30 minutes traffic. The process was finally killed.

[6] Since under low intensity traffic the number of events to be scheduled are reduced, the simulation model execution time is expected to be reduced.

as: the low intensity traffic implies that a frame, with no D channel data will circulate in the ring and will simulate, after a station to station propagation delay,[7] a frame arrival event on every station and will fill the event calendar with a large number of cycle arrival events. However, under high intensity data traffic, the chances of a station having a packet to transfer and stopping the scheduling of the cycle arrival—using the previously stated optimizing technique—on other stations are relatively more. Thus, the net simulation model execution time, under high intensity data traffic, will reduce.

To get rid of this problem, the model was modified for low intensity data traffic. Under low intensity data traffic, a station monitors the queues of the stations, and if they are all empty, the cycle is stopped. Otherwise, the cycle is continued. When a call is generated and the cycle is stopped, the following algorithm is used to compute the position of the frame in the ring:

```
$TimDiff = CurTim - StopTim$;
while (TimDiff $\geq$ 0) do
{
  $TimDiff = TimDiff - PRPDLY$;
  $Posit = (Posit\%NSTN) + 1$;
  If (Posit == 1 )
    $TimDiff = TimDiff - FramTim$; }
```

In the above algorithm, the Posit indicates the station that stopped the cycle last

---

[7] The master station will follow a slightly different rule.

time. NSTN indicates the number of the stations—100 in our case. FramTim is the transmission time of the frame, and PRPDLY indicates the propagation delay between two consecutive stations. StopTim and CurTim represent the the time at which the cycle was stopped and the current simulation time, respectively. The cycle arrival event will be scheduled after the ABS(TimDiff) time at the station indicated by the Posit.

5.2.1.4 Results The relation between normalized load and normalized, expected, waiting time (NE[W]) is shown in Figure 5.2 , where

$$\text{Normalize Load} = \frac{N\lambda b}{channel\ capacity}$$

and

$$NE[W] = \frac{queuing\ delay + service\ time}{service\ time}$$

The simulation as well as the analytical model results indicate that:

- The queue length and also the maximum buffer occupancy is not proportionally reduced as the packet arrival rate is reduced and the size of the packet is proportionally increased.[8]
- The packet size has no statistically significant impact on the waiting time.[9]

---

[8] The reason of this counter intuitive results can be explained with the help of the equation 5.5. when the packet size increases the second moment of the packet size—a random variable—also proportionally increases and offsets the reduction in the queue length—caused by the lower arrival rate of the packets.

[9] This statement is not valid for all cases.

Since the channel is used for realtime data traffic, the peak queuing times[10], under different loading conditions, are computed for the packets of 50 and 100 bytes lengths (shown in Figure 5.5). The expected queue length and the required buffer capacity, under varying loading conditions, are shown in Figure 5.3 and figure 5.4, respectively.

5.2.2 Call establishment and de-establishment

A prioritized multi-queue simulation model of the D channel—depicted in Figure 5.6— is developed to monitor the channel performance for call establishment and de-establishment procedure—shown in Figure 5.7 [7].

5.2.2.1 Call control messages The D channel is assumed to support the messages shown in Table 5.1. But in our case only a small subset of the call control messages is required to be simulated.[11] Further, to reduce the tariff charged by the carriers the following priority order is proposed.[12]

1. DIS: a disconnect message from the calling party
2. RL: a release complete message from the calling party
3. SETUP: a connection set up message from the calling party
4. ALRT: an alert message from the called party

---

[10] The queuing time is equal to the waiting time minus the service time.

[11] The reduction in number of the control messages is a direct consequence of the simplifying assumptions—will be discussed shortly.

[12] The control messages are listed in descending priority order.

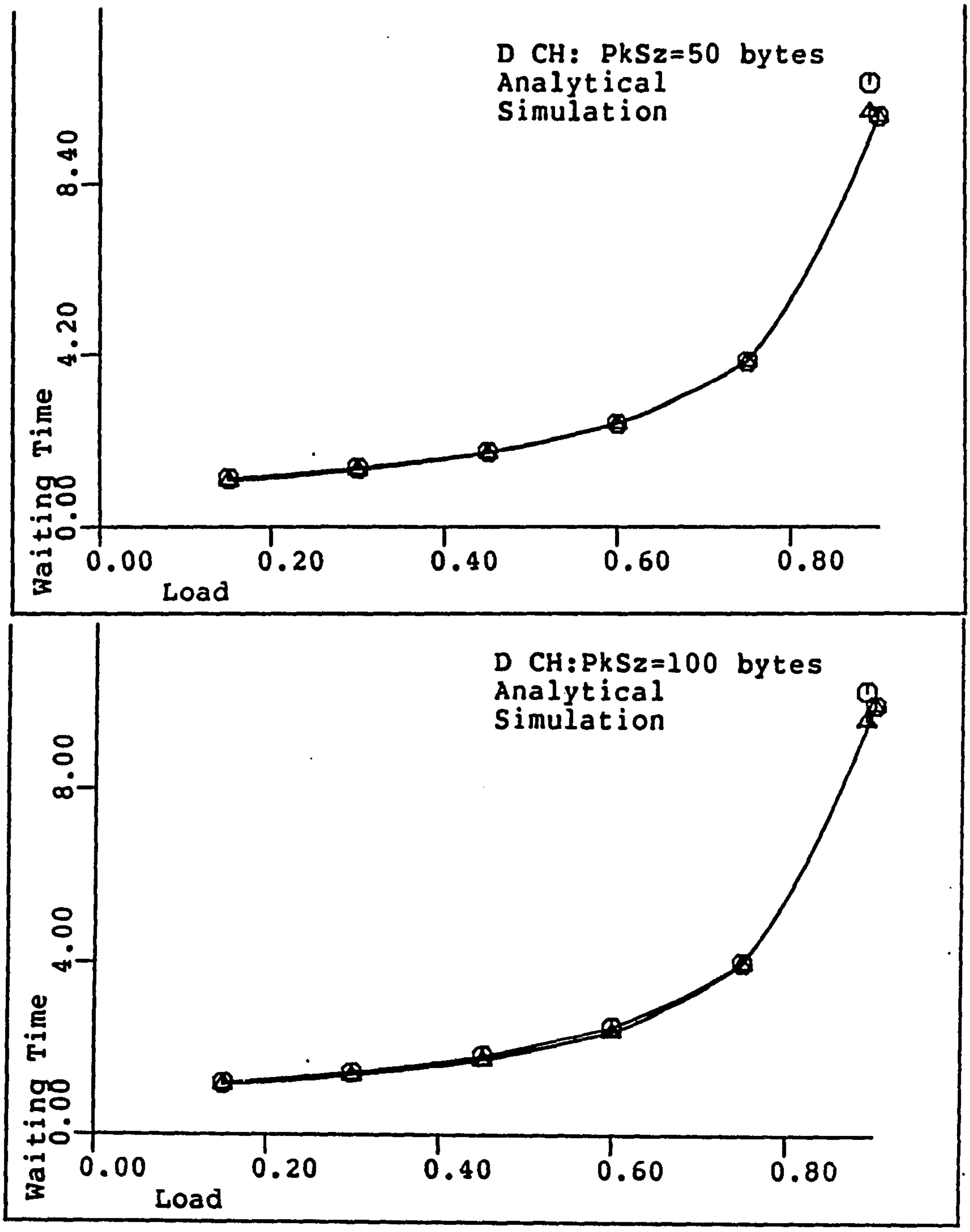


Figure 5.2: Expected Waiting Time of the D Channel Control Messages as a Function of Normalize Load

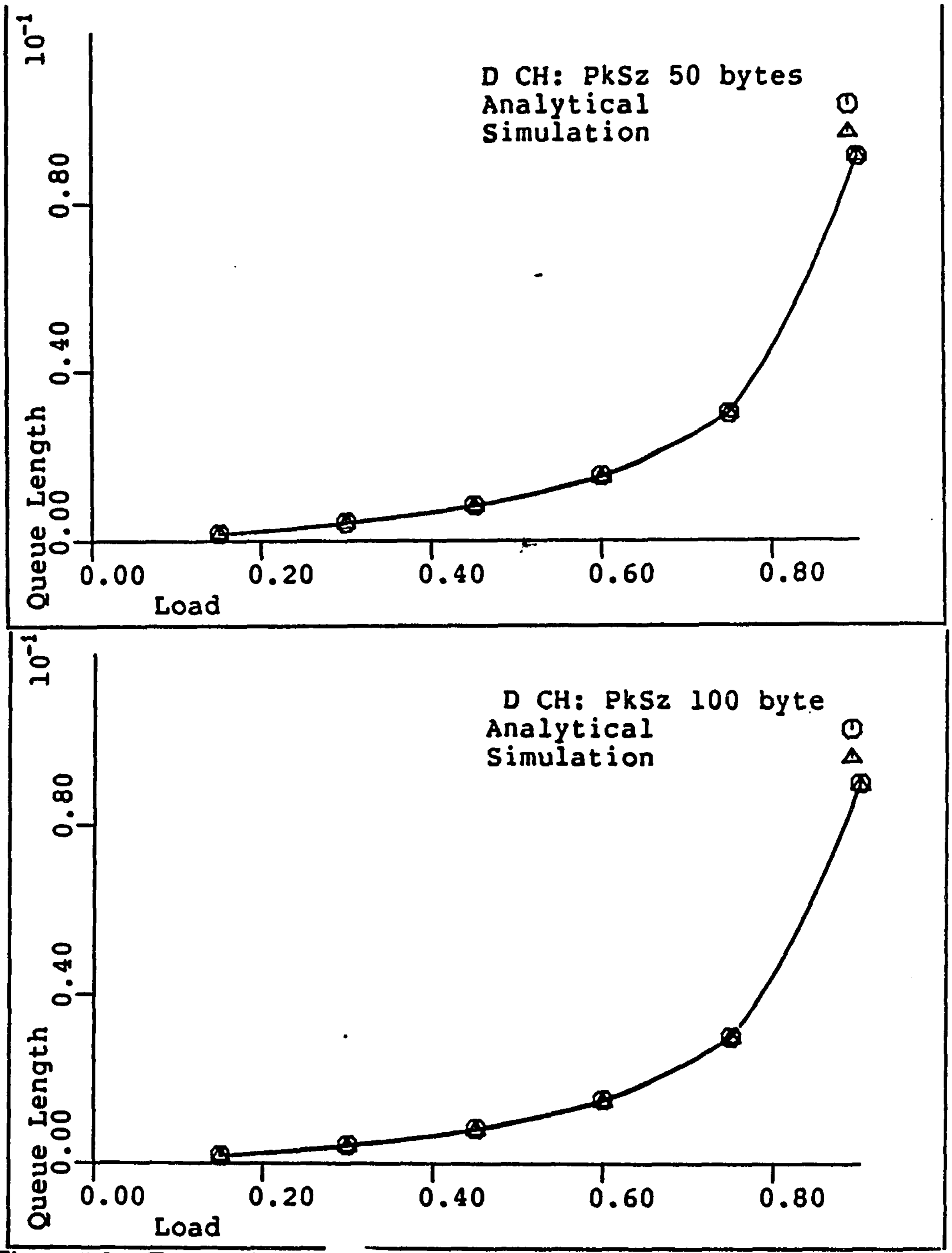


Figure 5.3: Expected Queue Length of the D Channel Control Messages as a Function of Normalize Load

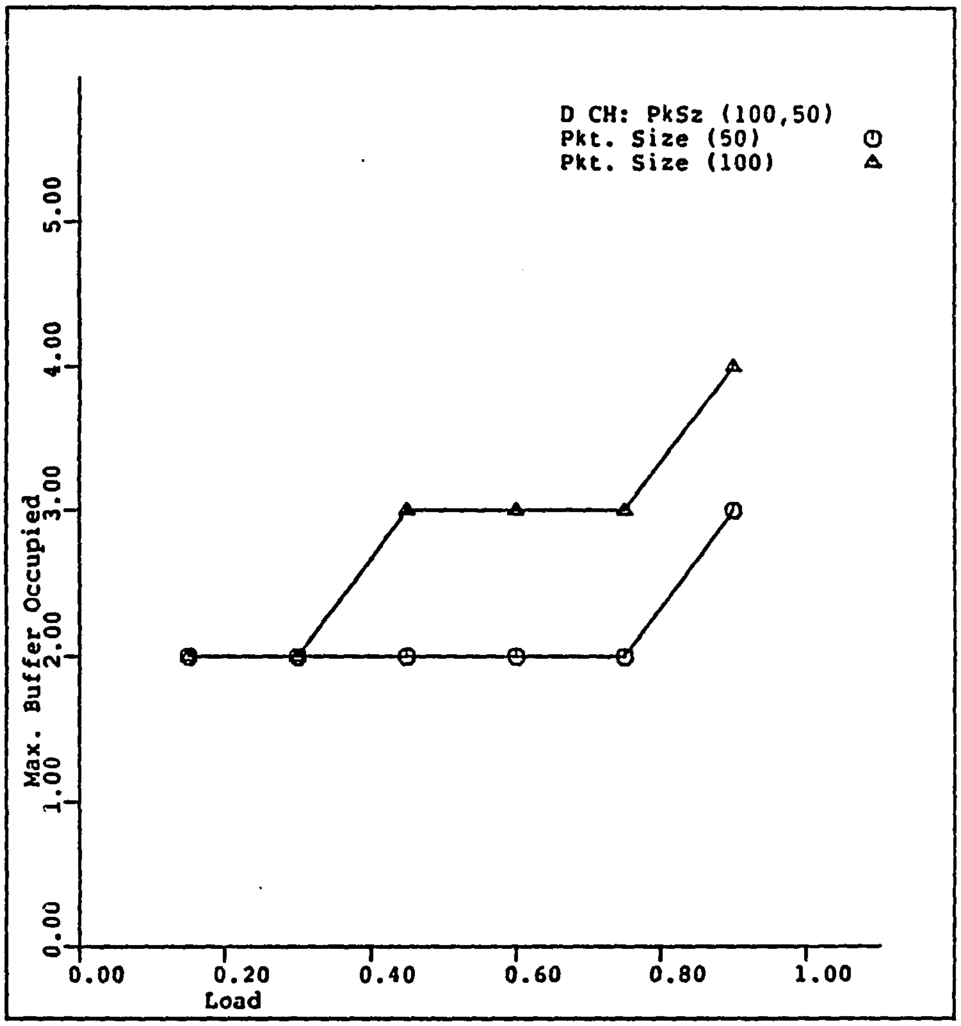


Figure 5.4: Buffer Occupancy of the D Channel Control Messages as a Function of Normalize Load

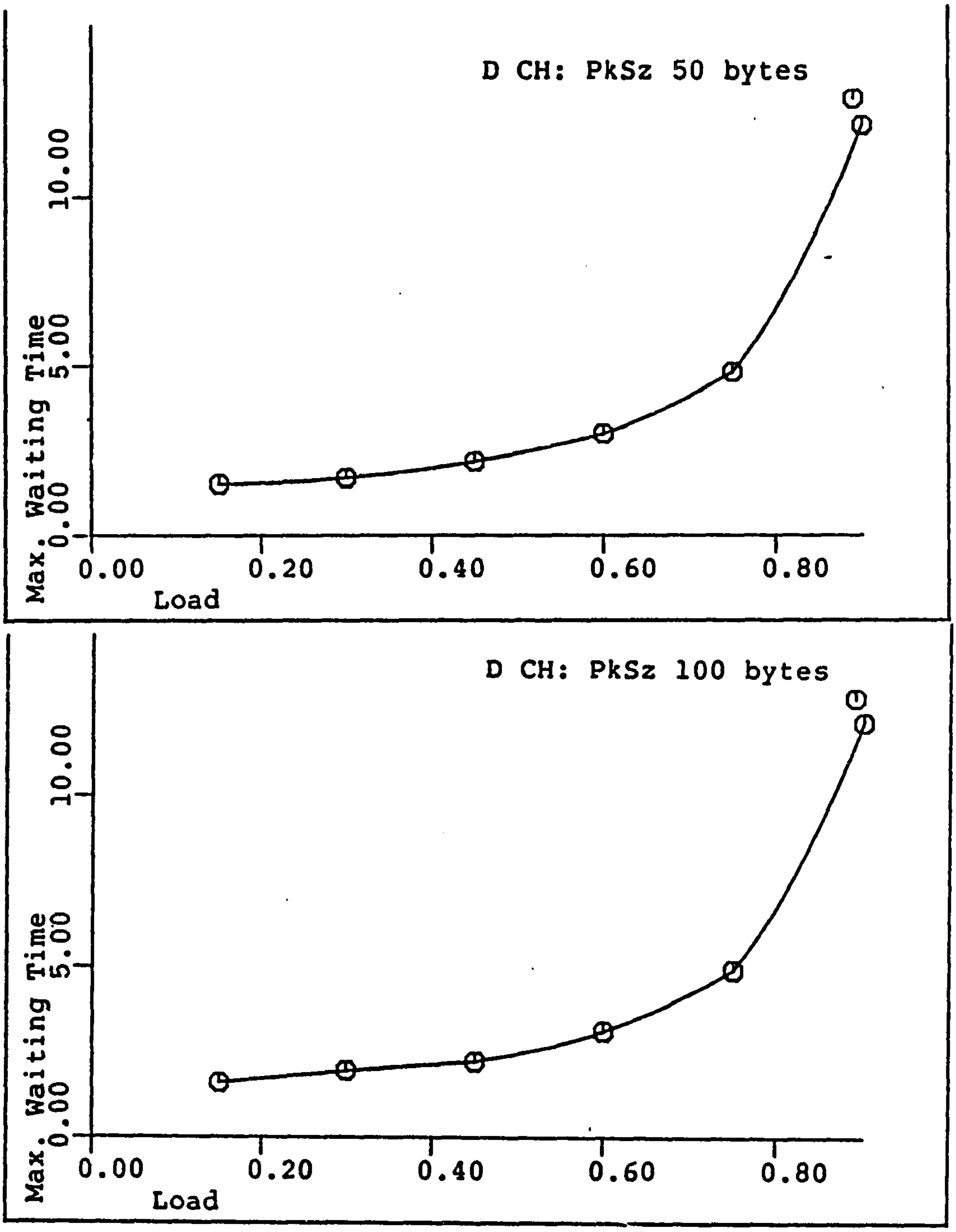


Figure 5.5: Expected Peak Waiting Time of the D Channel Control Messages as a Function of Normalize Load

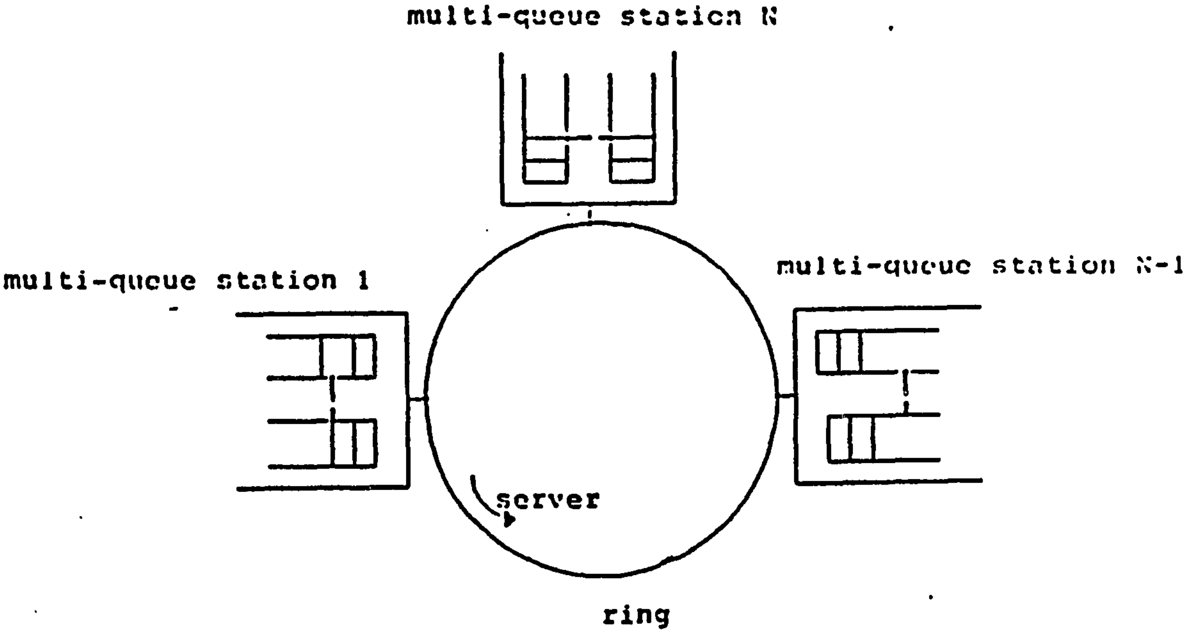


Figure 5.6: D Channel as a Cyclic Server (prioritized case)

5. RLACK: a release message from the called party
6. CONACK: a connect message from the called party

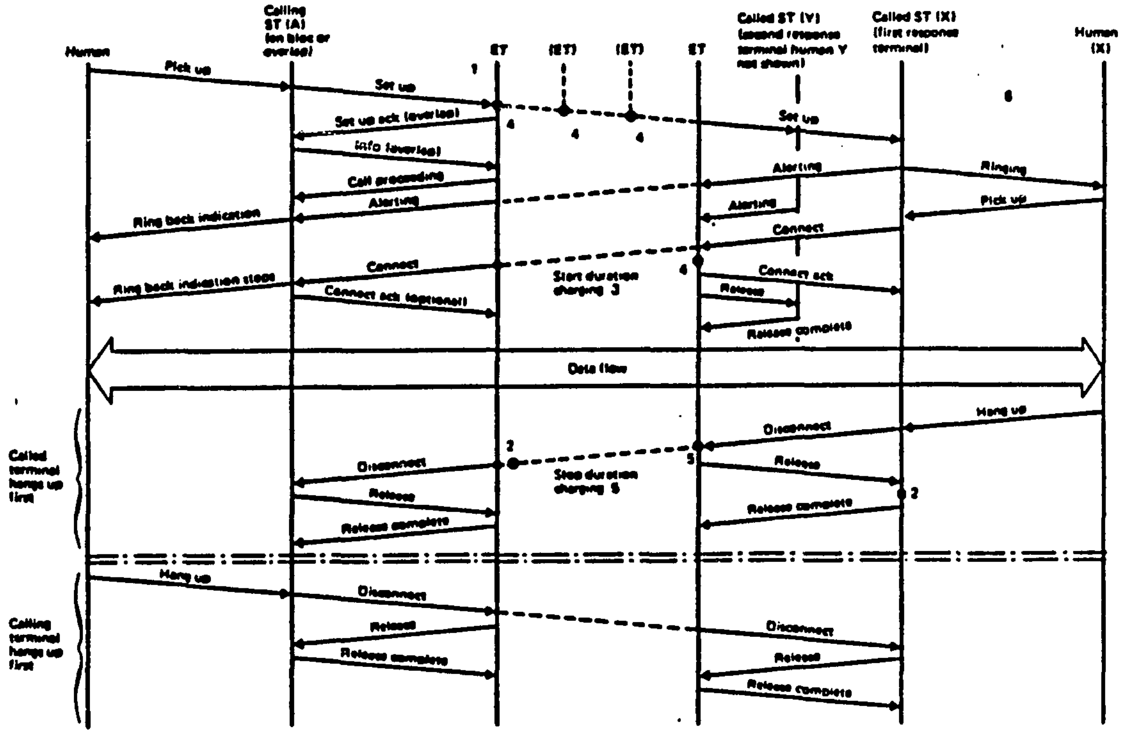
5.2.2.2 Control messages transfer rate According to a study conducted by the Bellcore [17], the number of calls originating from a premise is as follows:

- For residence, 3.9 calls per hour.
- For business, 10.6 calls per hour.
- For high usages,[13] 27.2 calls per hour.

We will analyze the D channel behavior for varying call originating rate.

---

[13] An example of high usage is a PBX.



Note 1 — The sequence for overlap sending is not represented in this diagram.

Note 2 — A terminal should not release the D-channel connection and power until after this point.

Note 3 — A proposal for further study (it may be a national matter).

Note 4 — Proposed switch-through points and the sequence in which they occur.

Note 5 — Proposed network release points and sequence.

Note 6 — The interactions between the human and the terminal are shown for illustration only.

Figure 5.7: Call Establishment and De-establishment Procedure

5.2.2.3 Control messages lengths

The control messages lengths are specified by the CCITT in its recommendations I.451 [7]. But these lengths do not include the overhead introduced by LAPD. To compute the pragmatic lengths of the control messages, shown in the Table 5.1, we assume the following:

1. The bit stuffing will increase the control message length by 3% [17].
2. For control message field, the modulo 8 transmission mode is supported.
3. Only 128 addresses, for TEs, are supported.
4. The setup message will not carry user information.

5.2.2.4 Assumptions

Since the call establishment and de-establishment procedure is complex, only the simulation model of the procedure is developed with the following assumptions:

1. The D channel is used only for signalling and control information transfer.
2. Only unacknowledge frame transfer mode of LAPD is allowed.
3. The call-traffic is symmetric.[14]
4. All calls, originated and received, are accepted.
5. The calls are terminated by the calling party, not by the called party.

---

[14] The number of calls originated and received at a station for a given period is same.

Table 5.1: Circuit Mode Connection Messages

Control Messages	Length (bytes)
Call Establishment Messages	
ALERT	22
CALL PROCeeding	12
CONNect	32
CONNect ACKnowledge	12
SETUP	56
SETUP ACKnowledge	21
Call Information Phase Messages	
RESume	12
RESUME ACKnowledge	6
RESUME REJect	6
SUSPend	6
SUSPend ACKnowledge	6
SUSPend REJect	9
USER INFOrmation	10
Call Dis-establishment Messages	
DETach	15
DETach ACKnowledge	12
DISConnect	15
RELease	15
RELease COMplete	15
Miscellaneous Messages	
CANCel	12
CANCel ACKnowledge	3
CANCel REJect	6
CONgestion CONtrol	10
FACility	16
FACility ACKnowledge	6
FACility REJect	9
INFOrmation	31
REGister	9
REGister ACKnowledge	6
REGister REJect	9
STATUS	10

6. The channel identification field is set in the SETUP message and is not modified either by the calling party or by the called party.
7. The Overlap information mode is not allowed.
8. The connections are not modified during the call[15].
9. The SETUP and RLACK message arrivals are independent and Poisson distributed.
10. The delay between DIS and RL control messages is zero. Similarly, the delay between ALRT and CONACK control messages is zero.
11. The service discipline of the queuing model is non-preemptive, exhaustive, and first come first serve.
12. A high priority queue in a station is served before a low priority queue service is initiated.

5.2.2.5 Message traffic

- The call arrival process is Poisson with an *upper mean limit of 45 calls per hour.*
- Calls last for an average duration of 60 seconds.

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[15] An example of connection modification is an addition of a third party after establishing a connection.

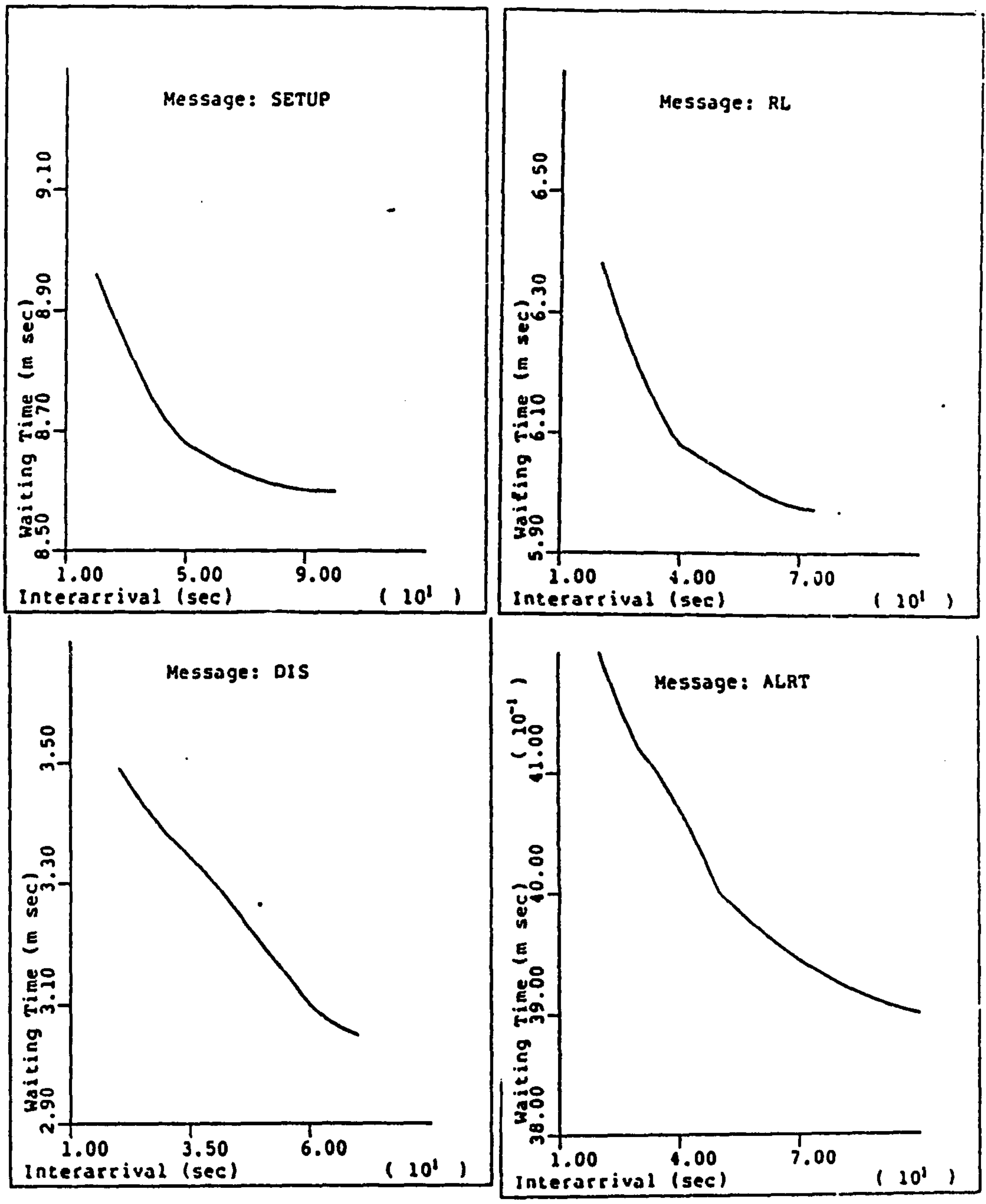

Figure 5.8: Expected Waiting Times of SETUP, RL, DIS, and ALRT Messages as a Function of Call Inter-arrival Time

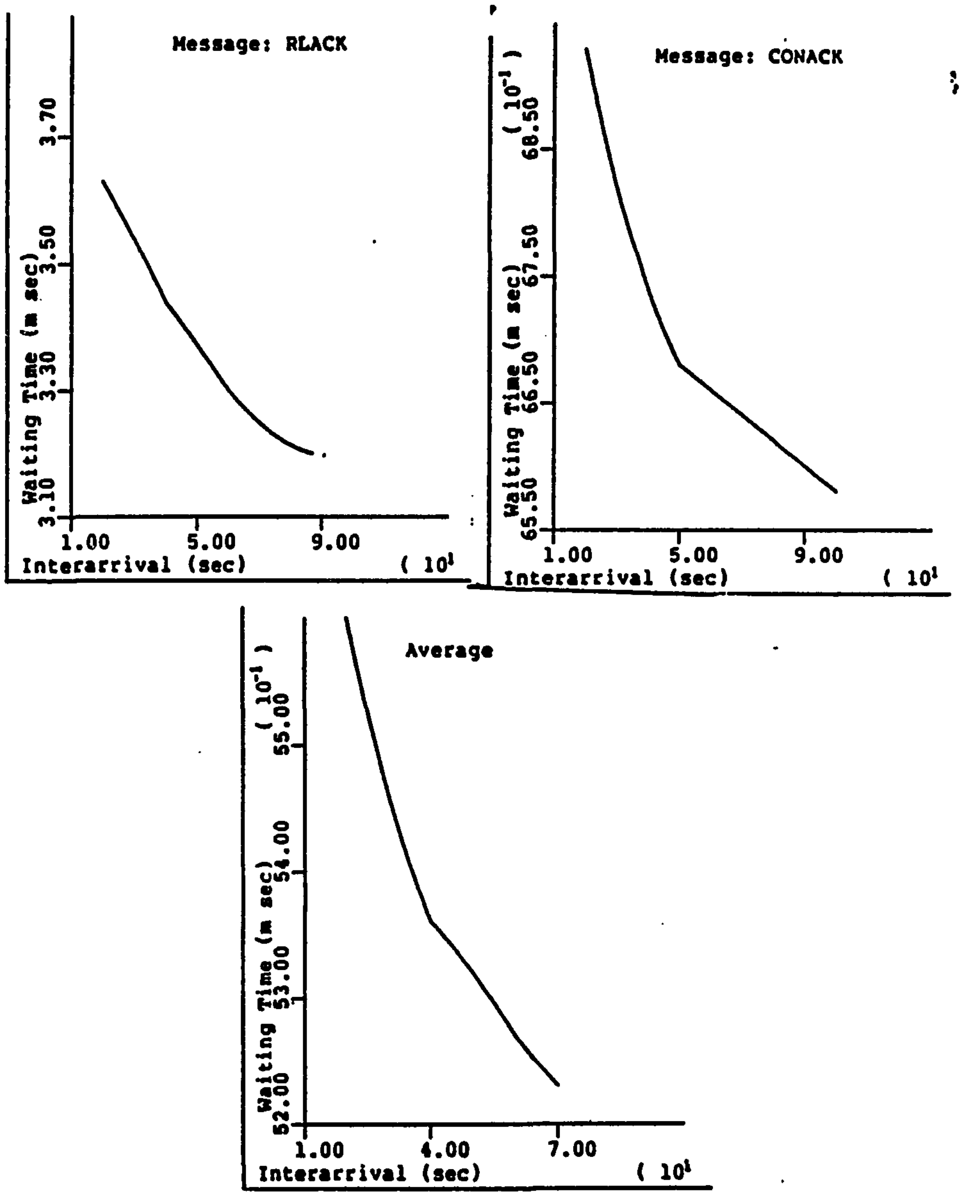

Figure 5.9: Expected Waiting Times of RLACK and CONACK as a Function of Call Inter-arrival Time

5.2.2.6 Results The simulation model results are shown in Figures 5.8 and 5.9. Since some of these parameters have practical significance, the waiting time of messages is computed in realtime units. The graphs indicate that at a call arrival rate of 45 calls per hour per station a call can be disconnected in about 3.450 msec, and the average wait time for a control message is about 3.50 msec.

5.3 Token Channel

5.3.1 Traffic categories

The token channel behavior is analyzed for the following categories of data traffic:

- *Homogenized data traffic*[16] without any TTRT.
- Homogenized data traffic with the static TTRT.
- *Non-homogenized data traffic*[17] with the static TTRT.
- Non-homogenized data traffic with the dynamic TTRT.

5.3.2 Traffic characteristics

- The arrival process is Poisson.
- All stations are symmetrical.

---

[16] The term homogenized data traffic is used to represent a data traffic with no timing or priority restrictions.

[17] The term non-homogenized data traffic is used to represent a data traffic with timing restriction.

- Arrival of a packet and the size of the packet are mutually independent.
- The length of the packet is exponentially distributed.

5.3.3 Token channel performance without the TTRT: homogenized traffic case

In this case, the token channel operation is similar to the non-prioritized, D channel operation.[18] Thus, the analytical model of the D channel is used to compute the expected waiting time and the expected queue length of the token channel.

5.3.3.1 Analytical and simulation model The expected waiting time and the expected queue length for this case can be represented with equations 5.3 and 5.5, respectively. But to compute the numerical values of the expected waiting time and the expected queue length the packet size must be converted into a discrete random variable. Since the packet length is exponentially distributed, we expect that most of the traffic generated by the stations will not lie on the token channel boundary. Thereby, the *number of token channels* required to transmit a packet may not be geometrically distributed, particularly when packet size is not very large as compared to the size of the token channel. Therefore, the simulation model was modified to compute the mean and variance of the number of token channels in a packet. These values are then used for computing the performance of the token channel under different loading conditions. For all other aspects, the simulation model of the token channel is similar to the D channel simulation model.

---

[18] The service discipline is non-preemptive, exhaustive, and FCFS.

5.3.3.2 Results The performance characteristics of the token channel for the packets of 1 Kbytes size are shown in Figure 5.10, Figure 5.11, Figure 5.12, and Figure 5.13. The simulation and analytical results indicate that, compare to the D channel, the expected waiting time and the expected queue length increase at a much higher rate at higher values of the normalized load. The prime reason of this poor performance of token channel is large number of fill characters which are transmitted to convert the packet size into an integral number of token channels.

5.3.4 Token channel performance with the static TTRT: homogenized traffic case

Since the state space of the analytical model of the token channel with the TTRT is very large, the analytical model is hard to develop. Consequently, only the simulation model was developed to analyze the behavior of the token channel.

5.3.4.1 Results The simulation model results indicate that:

- A large value, such as 100 * E[PkSz][19], of the TTRT will yield almost the same performance as of the token channel without any TTRT restriction.
- For high intensity data traffic, such as more than 50% of the token channel capacity, a low value of the TTRT, such as 3 * E[PkSz], will increase the variance and the expected value of waiting time.
- For low intensity data traffic, even a low value of the TTRT has no statistically significant effect on the token channel performance.

---

[19] E[PkSz] represents the expected value of the packet size.

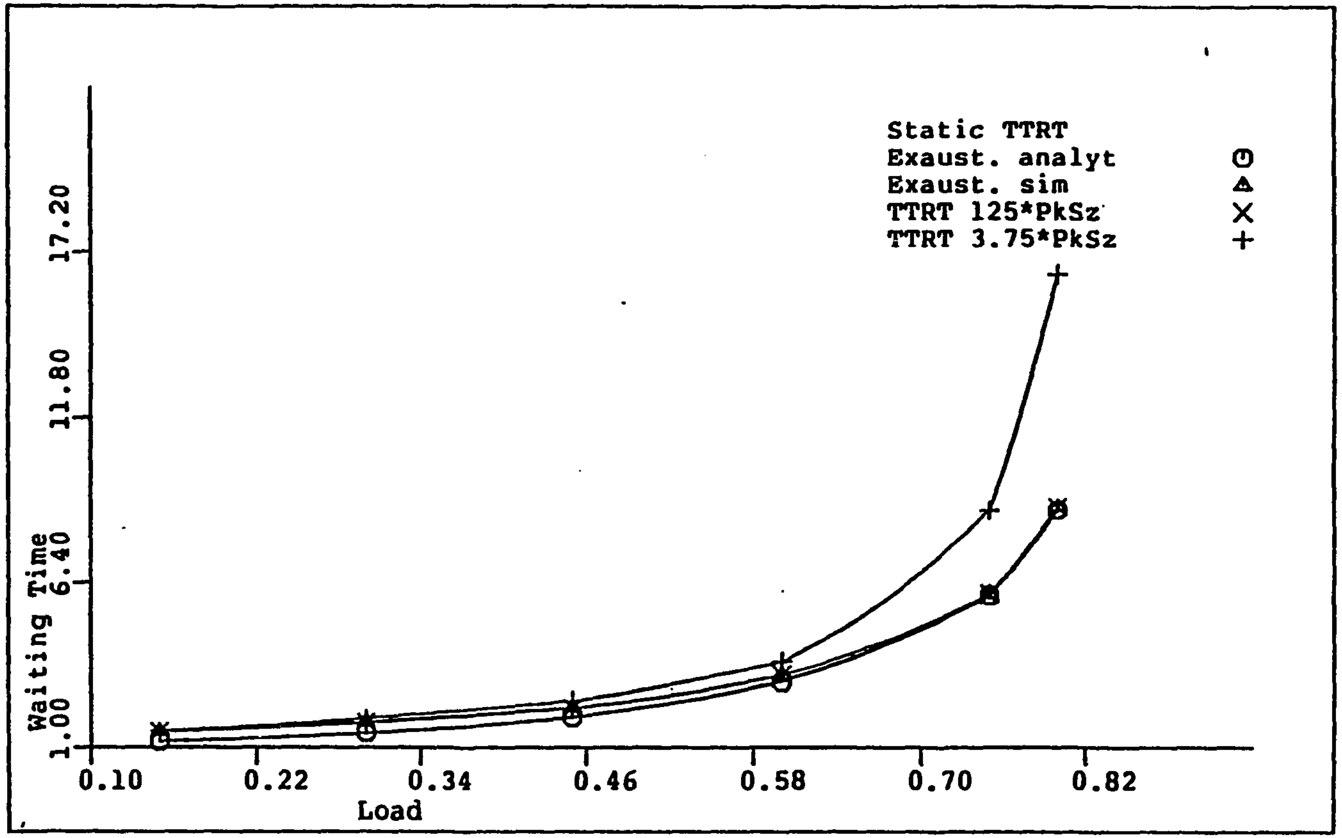

Figure 5.10: Expected Normalized Waiting Time of Homogenized Data Packets as a Function of Normalized Load

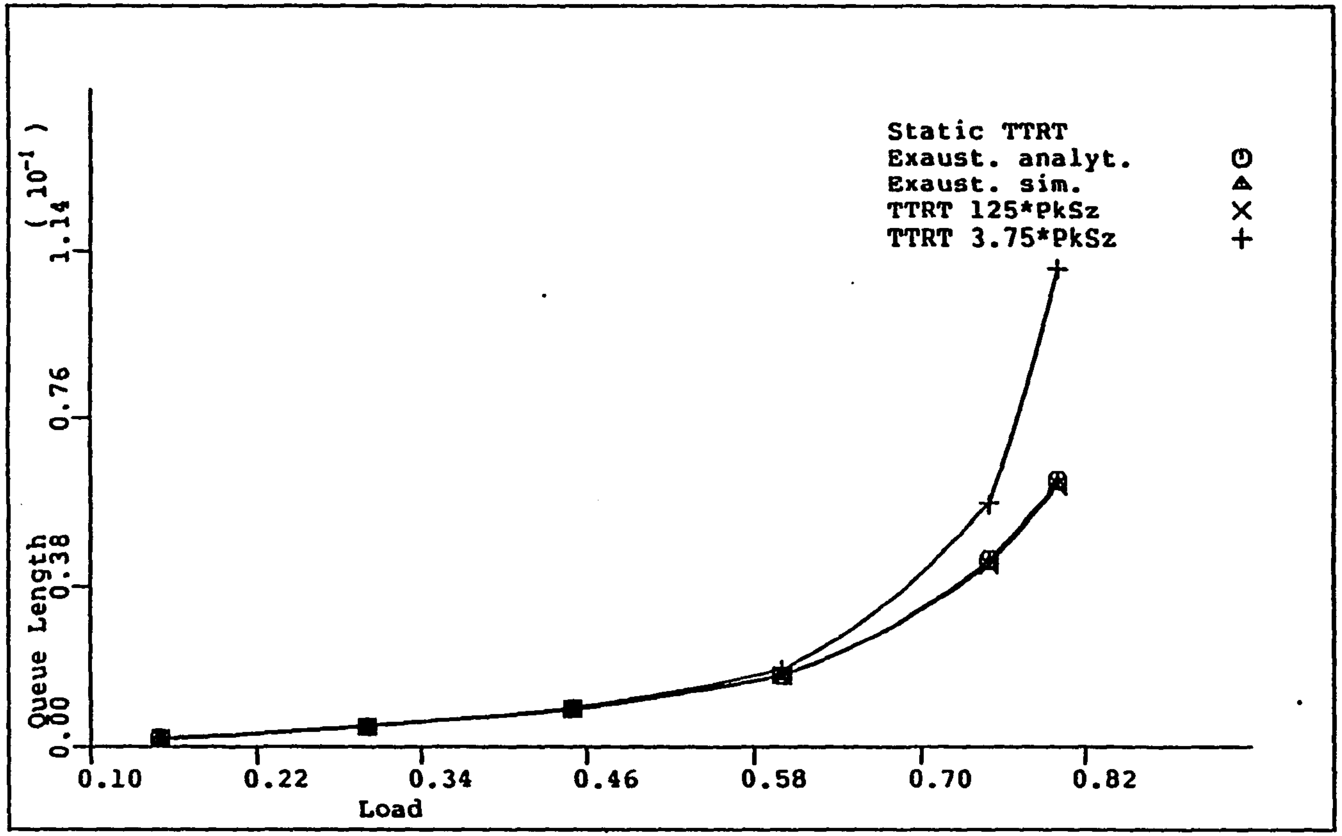

Figure 5.11: Expected Queue Length of Homogenized Data Packets as a Function of Normalized Load

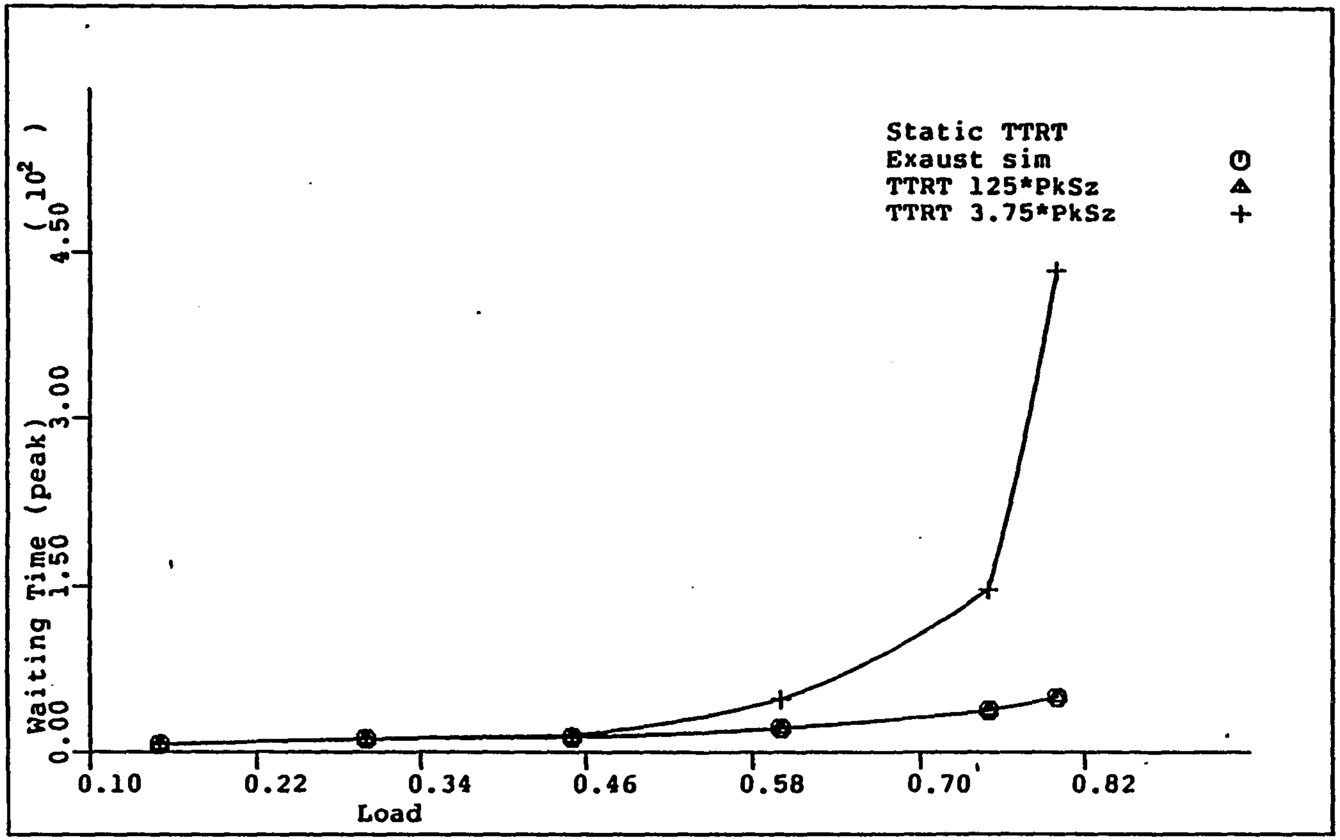

Figure 5.12: Maximum Waiting Time of Homogenized Data Packets as a Function of Normalized Load

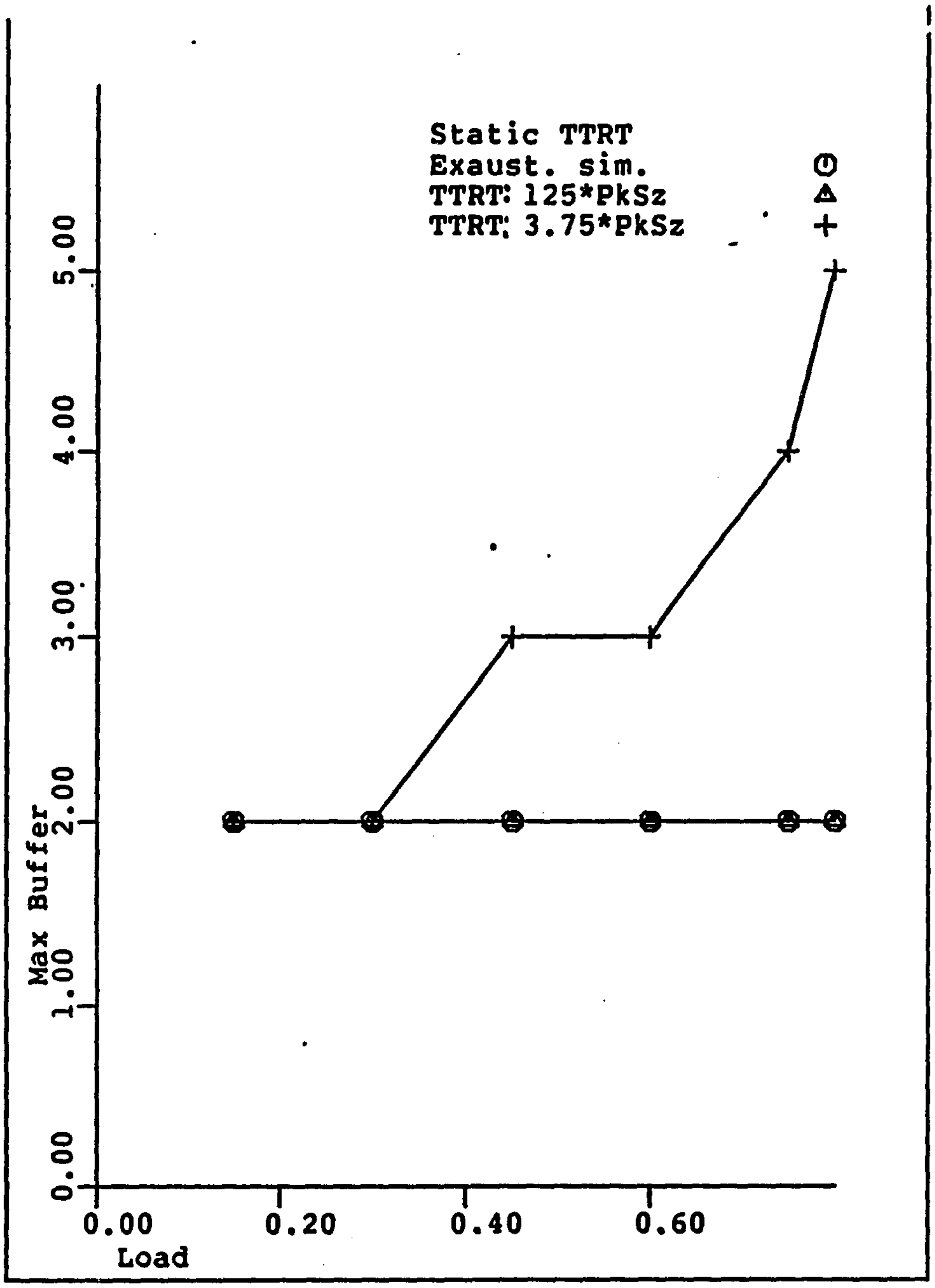

Figure 5.13: Maximum Buffer Occupancy of Homogenized Data Packets as a Function of Normalized Load

5.3.5 Token channel performance with the static TTRT: non-homogenized traffic case

For performance comparison, we divide the data traffic into two broad categories: synchronous and asynchronous. A synchronous data packet can be transmitted if the token is received within the TTRT and constitutes 10%[20] of the total traffic generated by the stations. An asynchronous data packet can only be transmitted if the token is received within the TTRT and the transmission of the pending asynchronous data packet will not exceed the bound set by the TTRT. Asynchronous data traffic constitutes 90% of total data traffic generated by the stations. Both, synchronous and asynchronous data traffic, have the same characteristics as stated in section 5.3.1.

5.3.5.1 Results The simulation model results indicate that:

- A lower value of the TTRT reduces the expected waiting time of the synchronous, data traffic but increases the expected waiting time of the asynchronous data traffic.
- The overall expected waiting time, variance, and number of buffers required for waiting PDUs are drastically increased for lower values of the TTRT.
- A higher value of the TTRT will reduce the expected waiting time of asynchronous data traffic but will increase the expected waiting time of synchronous data traffic.

---

[20] This value is selected for comparison purpose only, and it has no other significance.

5.3.6 Token channel performance with the dynamic TTRT: non-homogenized traffic case

In this case, the TTRT is dynamically changed. If a station has a pending synchronous data packet, it will request to reduce the TTRT. The station which is holding the token will do so when it will transmit the token into the ring. The previous value of the TTRT is restored when no station has a pending synchronous data packet.

5.3.6.1 Results The simulation model results indicate that:

- For synchronous data traffic, compare to the static TTRT approach, the dynamic TTRT approach yields lower expected waiting time, lower expected variance of waiting time.
- For asynchronous data traffic the dynamic TTRT approach is comparable to the static TTRT approach.
- In cases where synchronous traffic is required to be transmitted at lower values of the expected waiting time, the overall performance of the dynamic TTRT approach is better than the static TTRT approach in terms of expected waiting time, variance of expected waiting time, required buffers for pending PDUs, and peak waiting time.

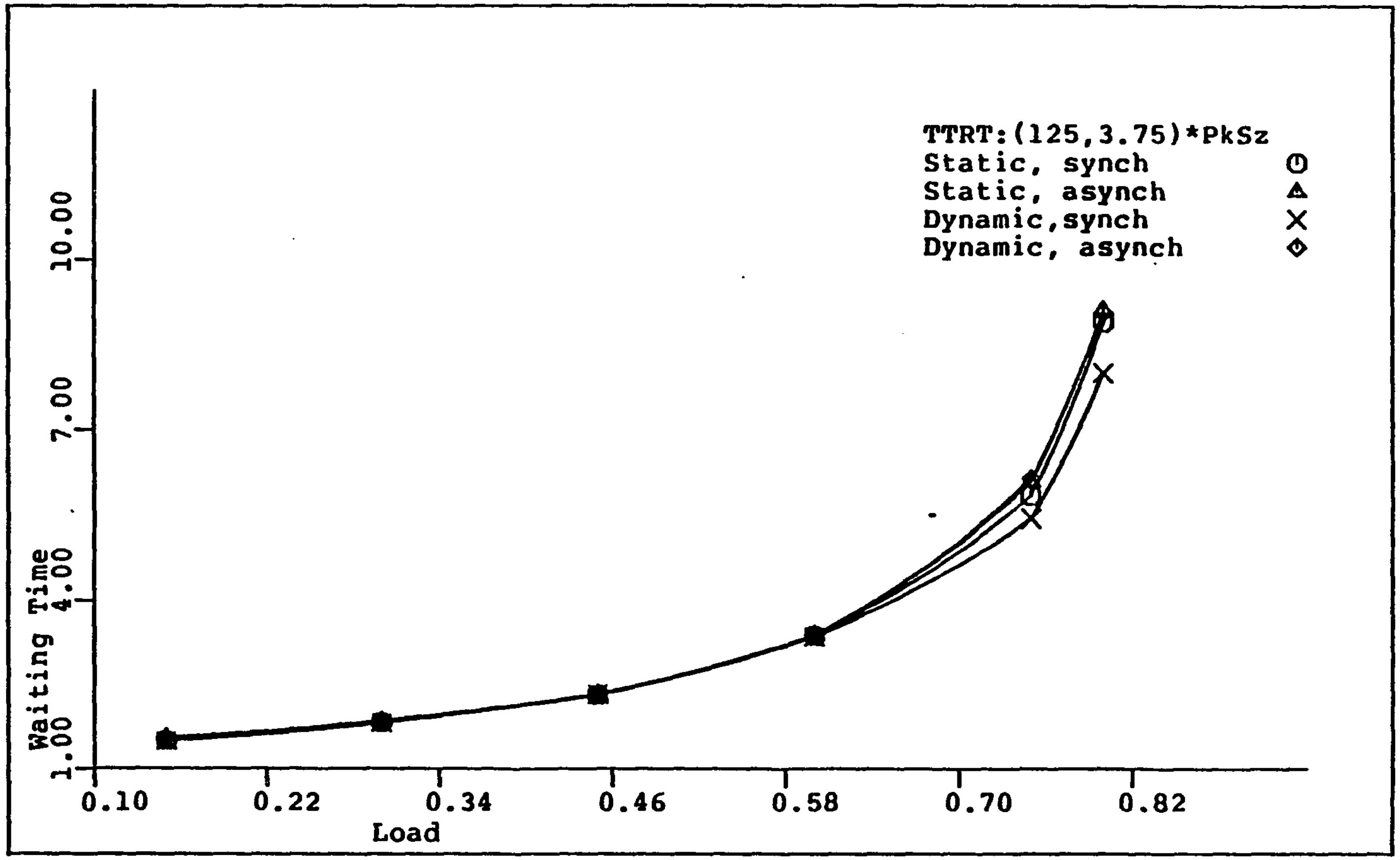

Figure 5.14: Expected Normalized Waiting Time of Non-homogenized Data Packets as a Function of Normalized Load

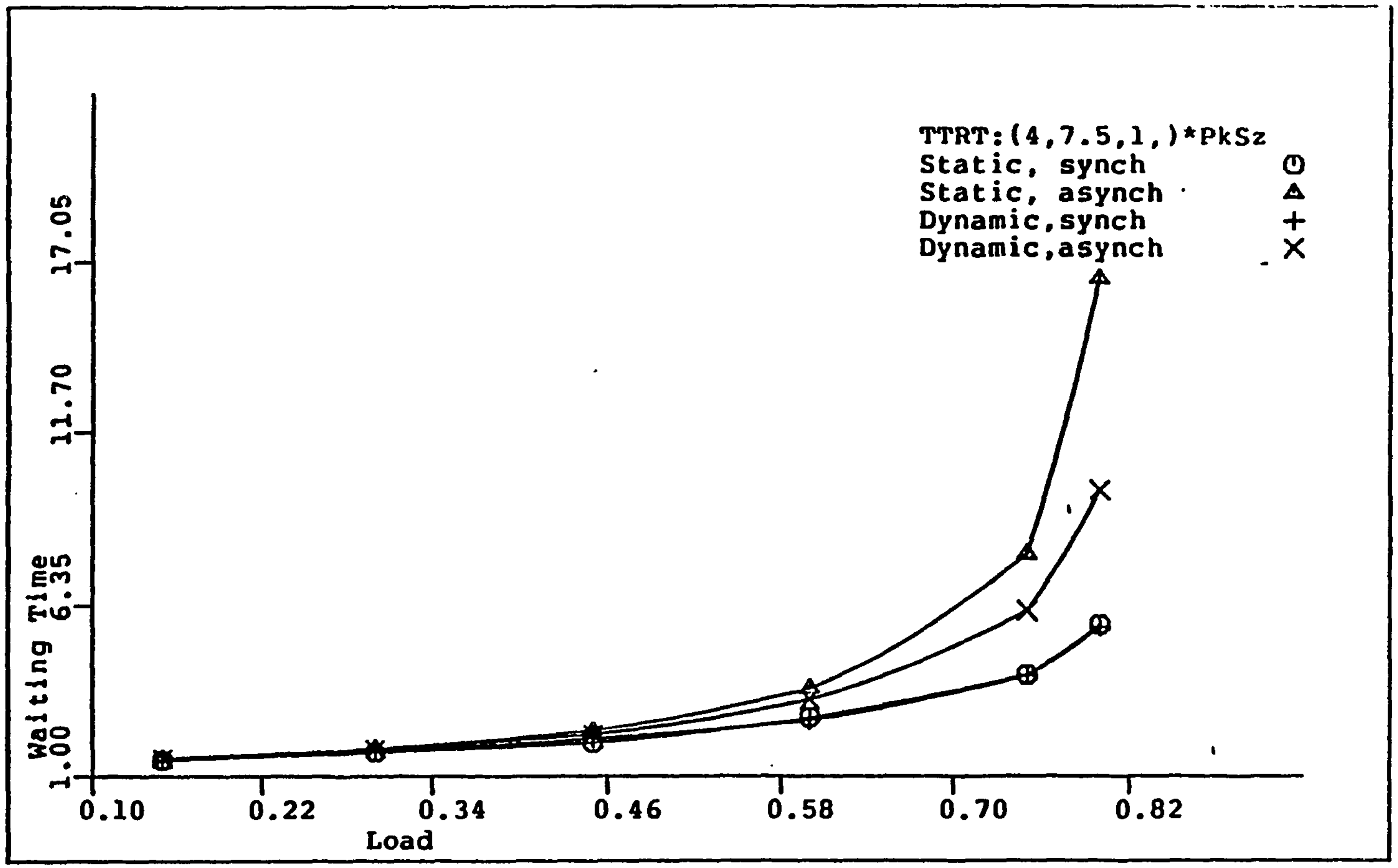

Figure 5.14 (continued)

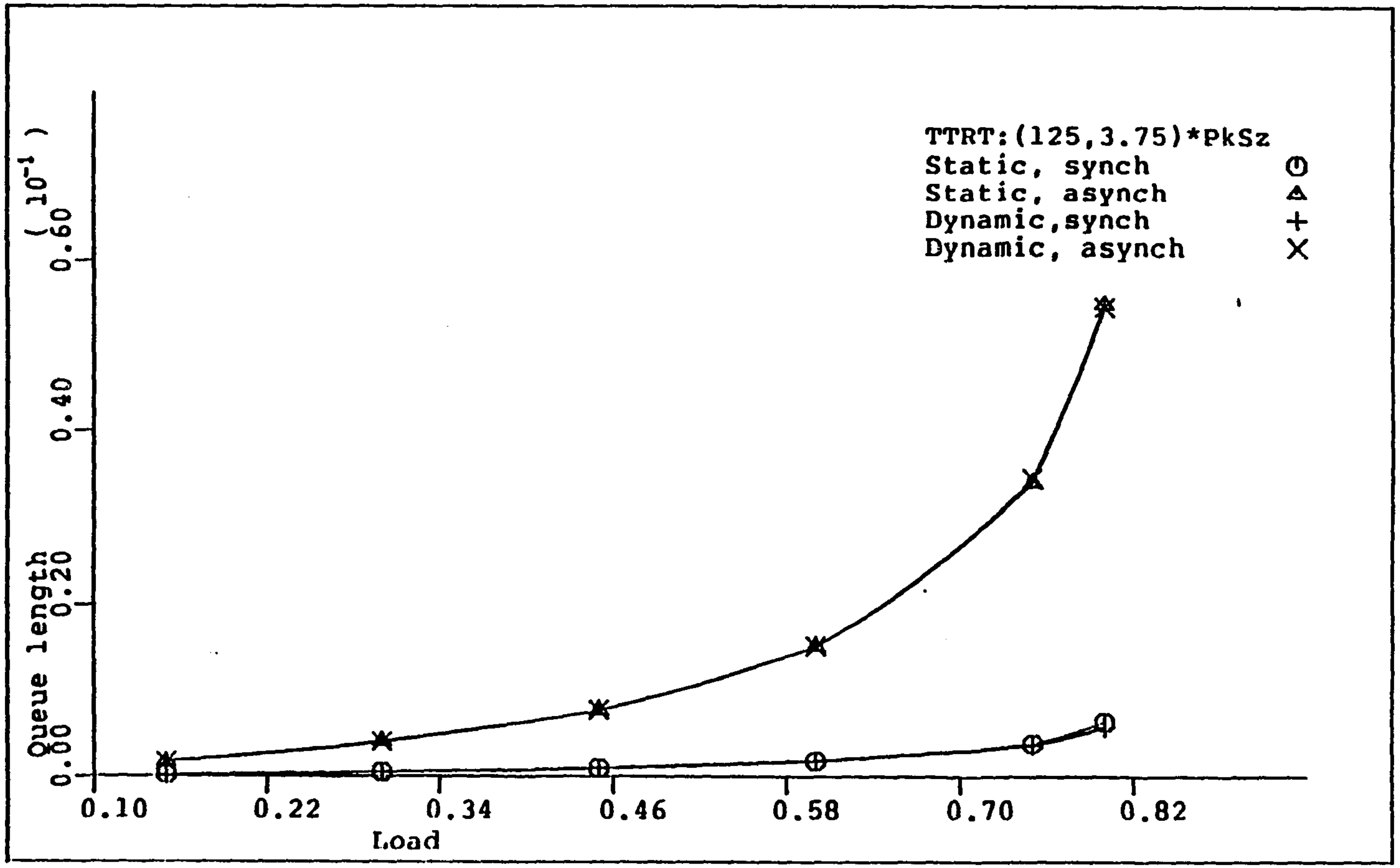

Figure 5.15: Expected Queue Length of Non-homogenized Data Packets as a Function of Normalized Load

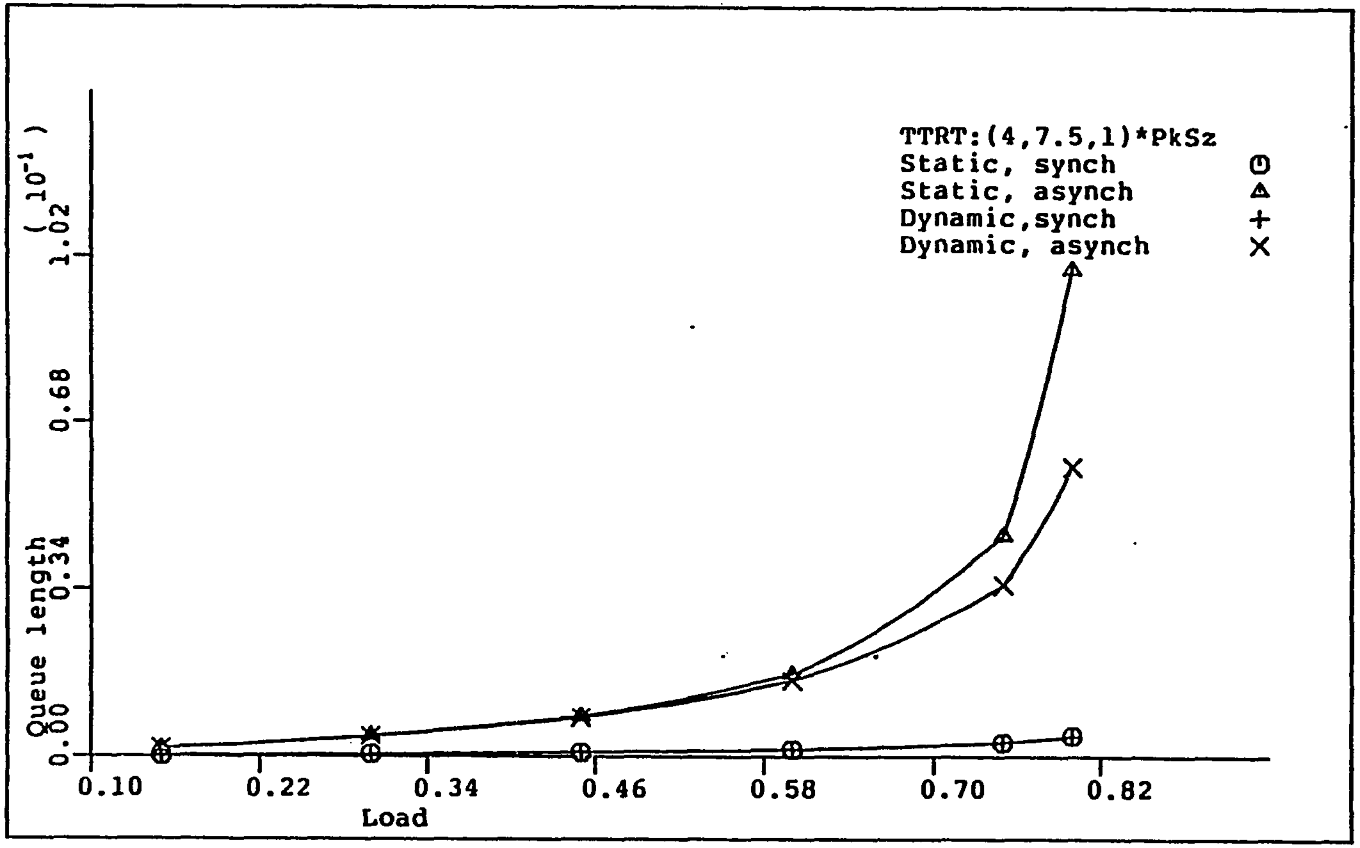

Figure 5.15 (continued)

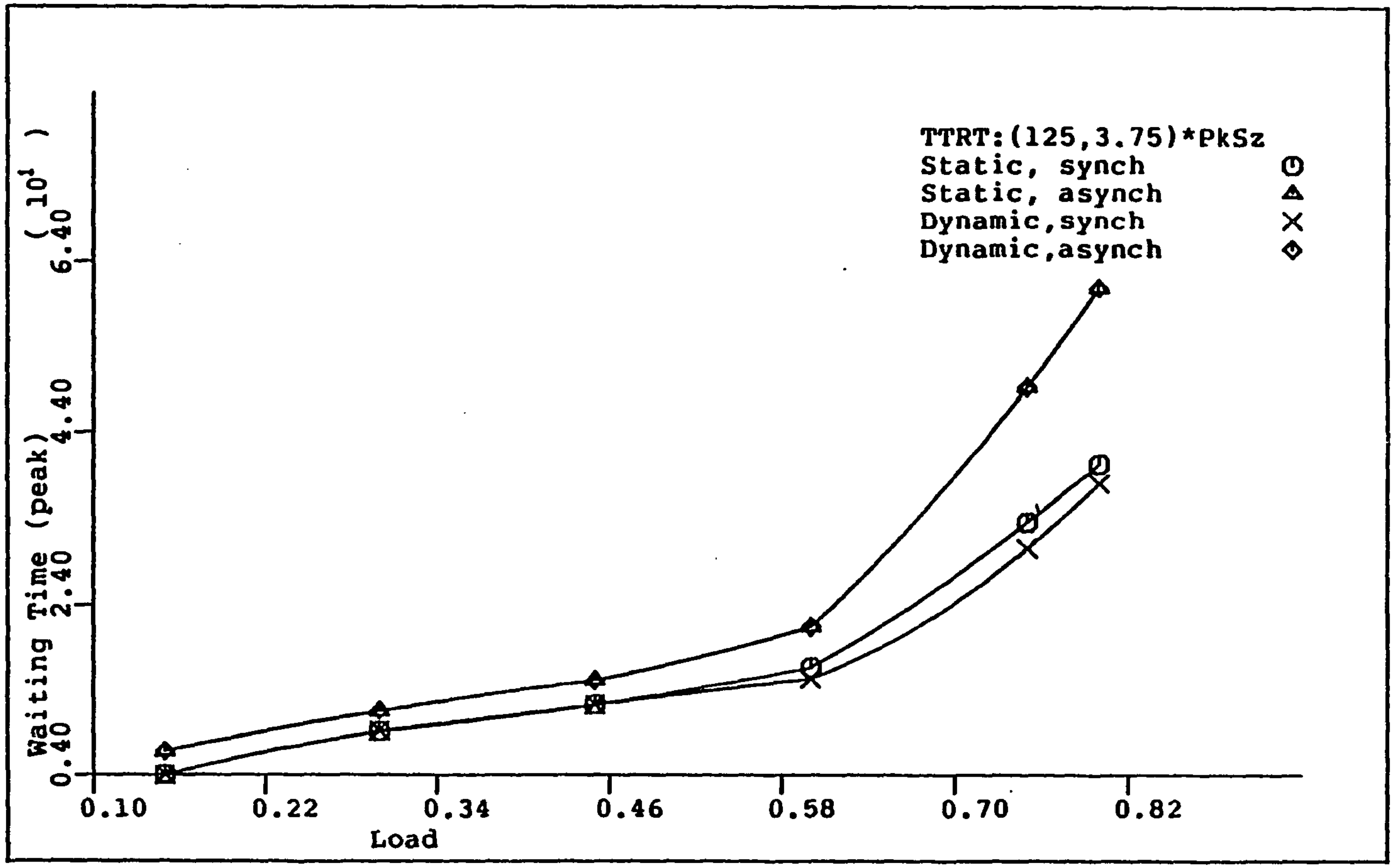

Figure 5.16: Maximum Waiting Time of Non-homogenized Data Packets as a Function of Normalized Load

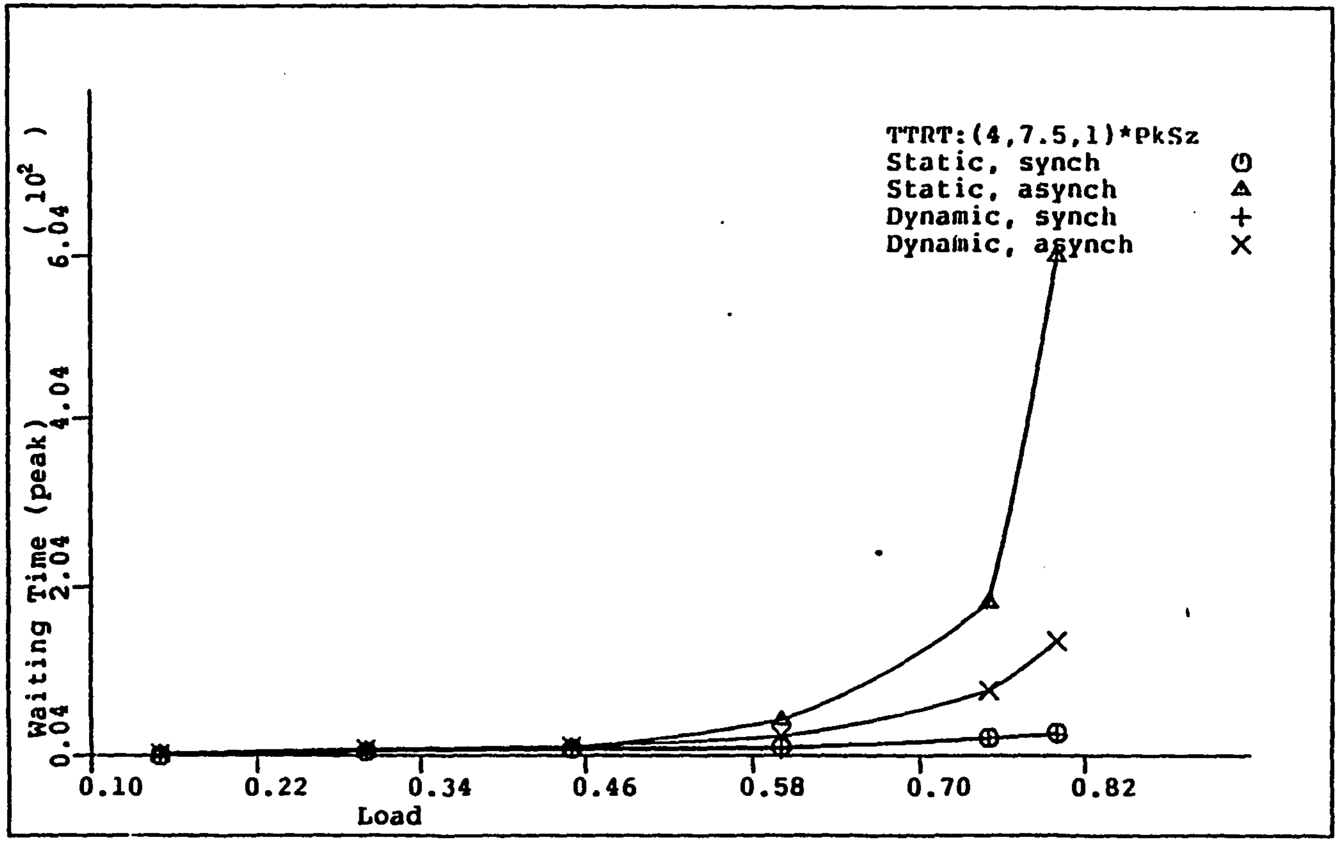

Figure 5.16 (continued)

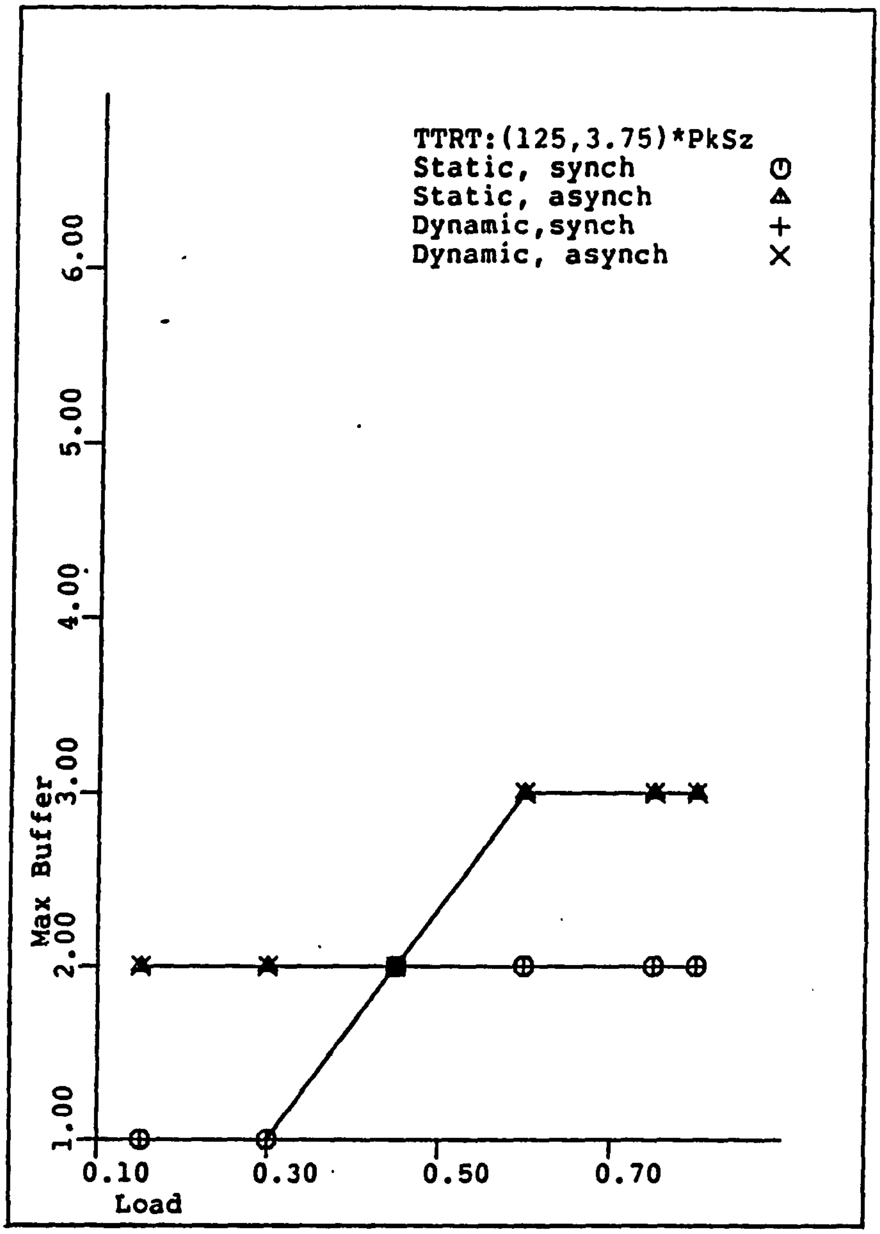

Figure 5.17: Maximum Buffer Occupancy of Non-homogenized Data Packets as a Function of Normalized Load

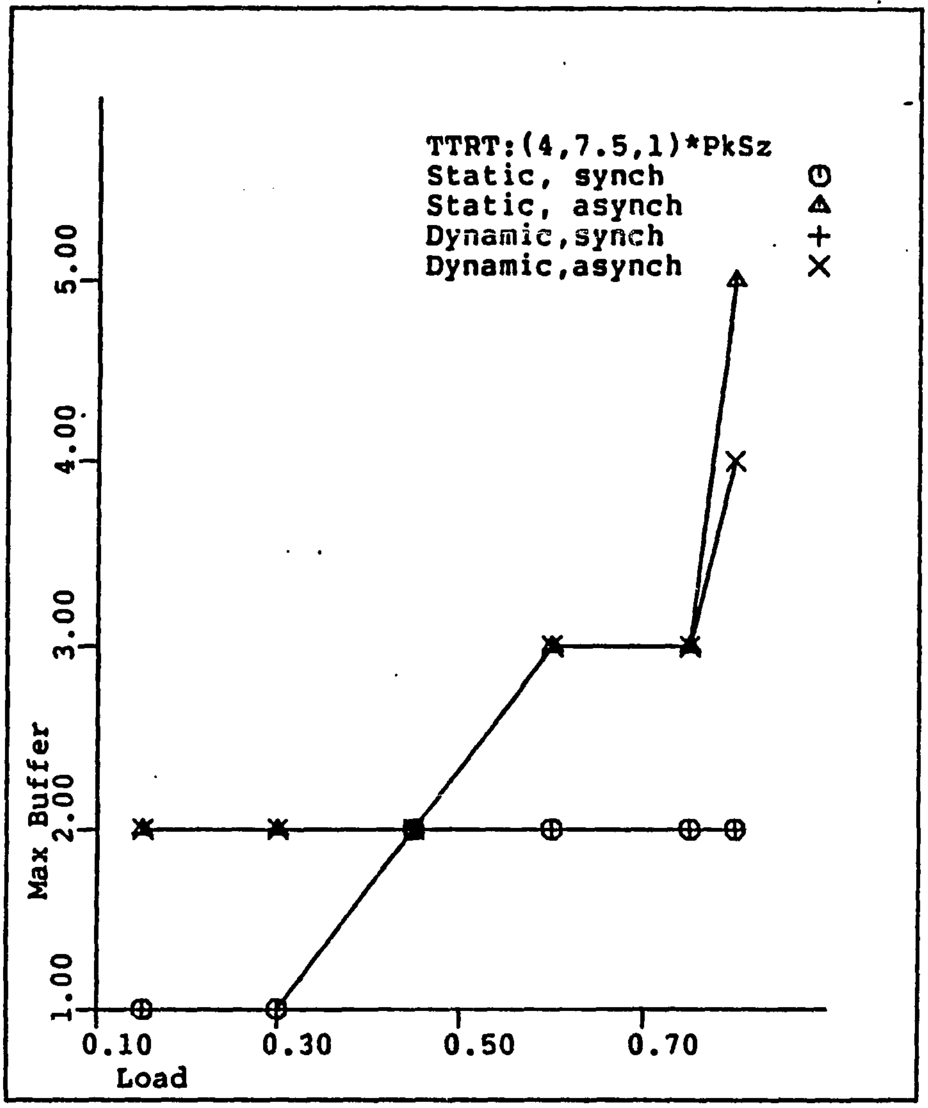

Figure 5.17 (continued)

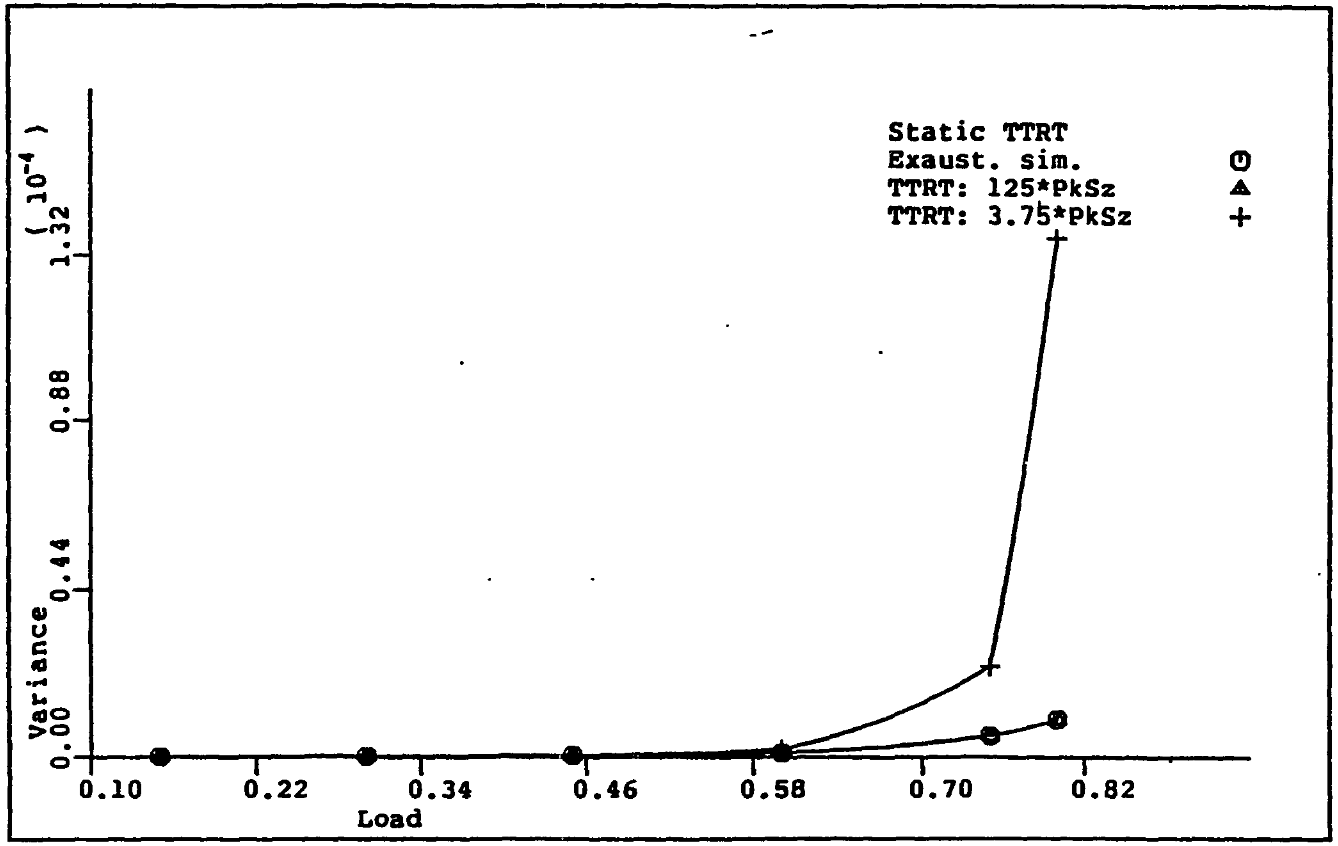

Figure 5.18: Variance of Waiting Time of Homogenized Data Packets as a Function of Normalized Load

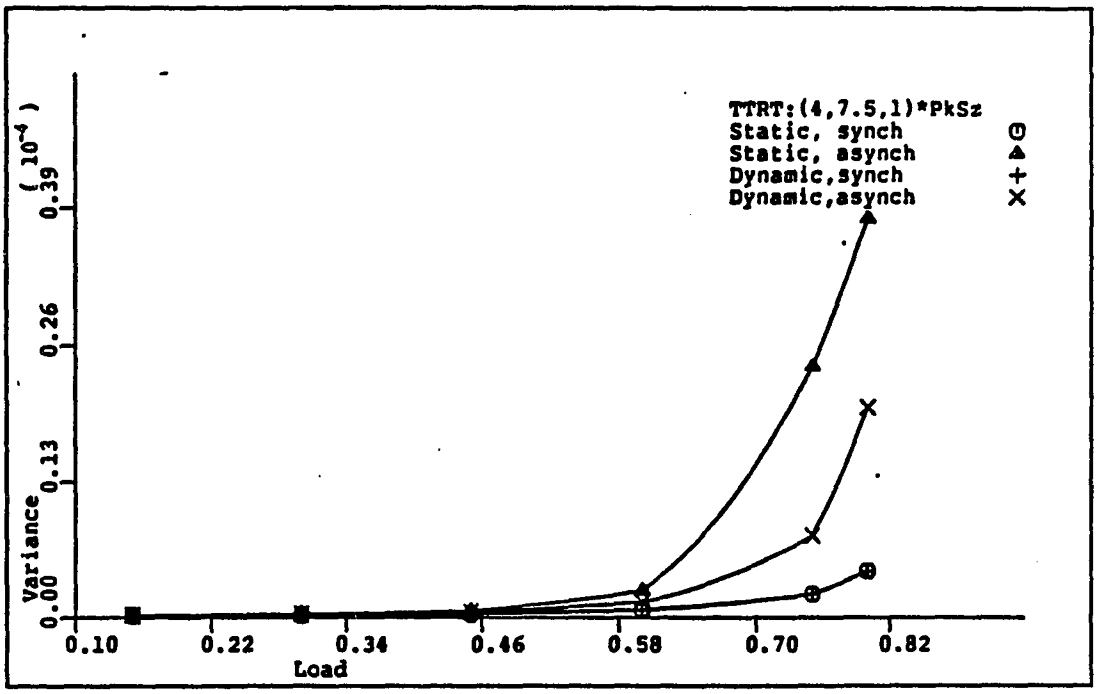

Figure 5.19: Variance of Waiting Time of Non-homogenized Data Packets as a Function of Normalized Load

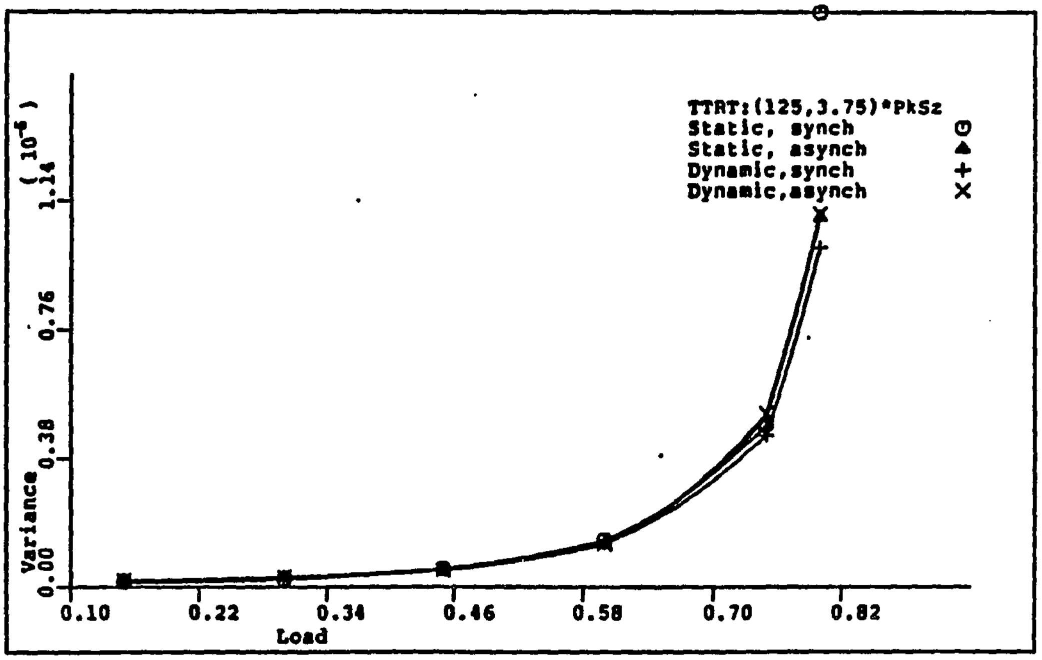

Figure 5.19 (continued)

6 CONCLUSION

The proposed MACS provides a dynamically controlled, circuit switched bandwidth—up to 1.544 Mbps—to the LAN users. The users data are transparently transmitted across the ISDN and incoming data is transparently shipped to the users by exploiting the ring topology and using a distributed access control technique.

The *semantic gap* between the ISDN and the proposed MACS is very nominal. Consequently, the ISDN/LAN interface does not require an extensive buffering or mapping. It eliminates queuing and processing delays—generally, encountered in gateways and bridges.

The proposed strategy allows rapid connection and disconnection of circuit switched calls a to a user and the expected delay of signalling information is nominal.

A contribution of this research effort is a comprehensive analysis of the TTRT and its extension to improve the LAN performance. It is concluded that a static TTRT, in general, reduces the throughput of the network, and increases the network-access-delay. The proposed strategy solves these problems by dynamically adjusting the TTRT.

6.1 Future Work

Several comparative studies are required to understand the full potential of the proposed MACS. Particularly, the following aspects of the proposed strategy need to be further investigated:

- Development of an analytical model of the token channel under TTRT restrictions.
- Comparison of the TTRT and the priority.
- Extension of the status channel to utilize the ISDN channels of the LAN for supporting a circuit switch facility on the token channel.

7 ACKNOWLEDGEMENT

I extend my sincere thanks to Dr. Douglas W. Jacobson for proposing this problem and extending highly experienced and pragmatic advice throughout my stay at Iowa State University, particularly, for providing the computing and financial resources whenever needed. My special thanks are for Dr. Arthur Pohm for his continuous support during this research effort.

Taking this opportunity, I would like to extend my thanks to Dr. Gercek Gokhan for assisting in developing the analytical model and providing support to further extend this research work.

Finally, I want to extend my special thanks to Dr. Smay, Dr. Oldehoeft, and Dr. Comstock for evaluating this effort and providing thoughtful critique.

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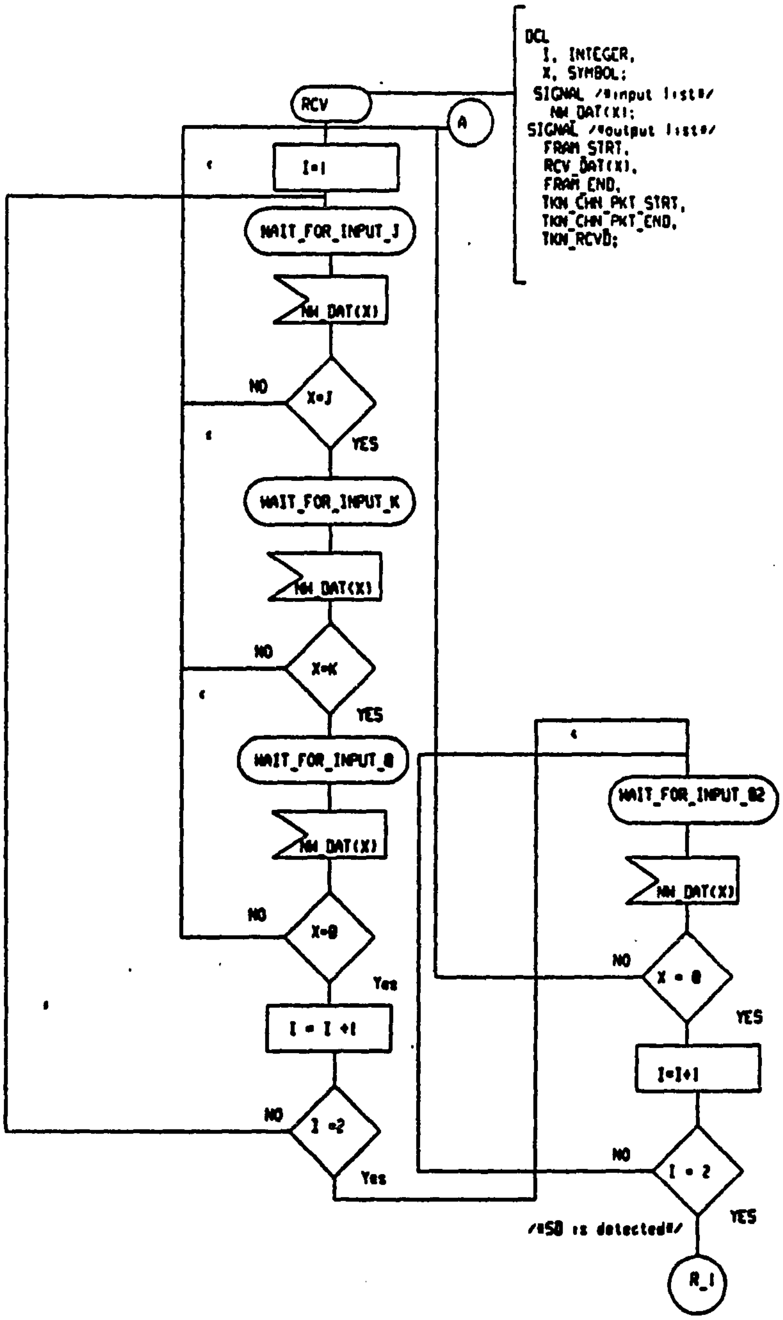
9 APPENDIX



```
DCL
  I, INTEGER,
  X, SYMBOL;
 SIGNAL /*input list*/
   NW_DAT(X);
SIGNAL /*output list*/
  FRAM_STRT,
  RCV_DAT(X),
  FRAM_END,
  TKN_CHN_PKT_STRT,
  TKN_CHN_PKT_END,
  TKN_RCVD;
```

Figure 9.1: Process Diagram of RCV

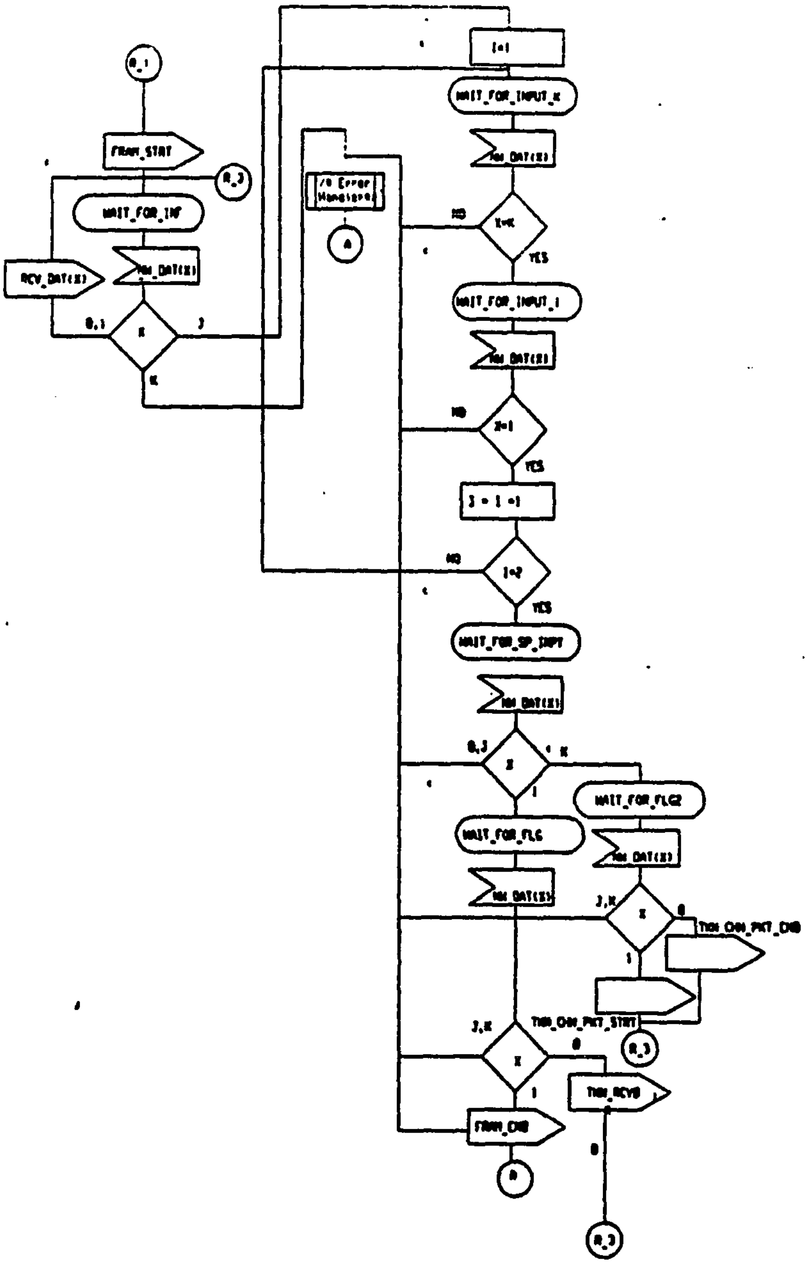


Figure 9.2: Process Diagram of RCV

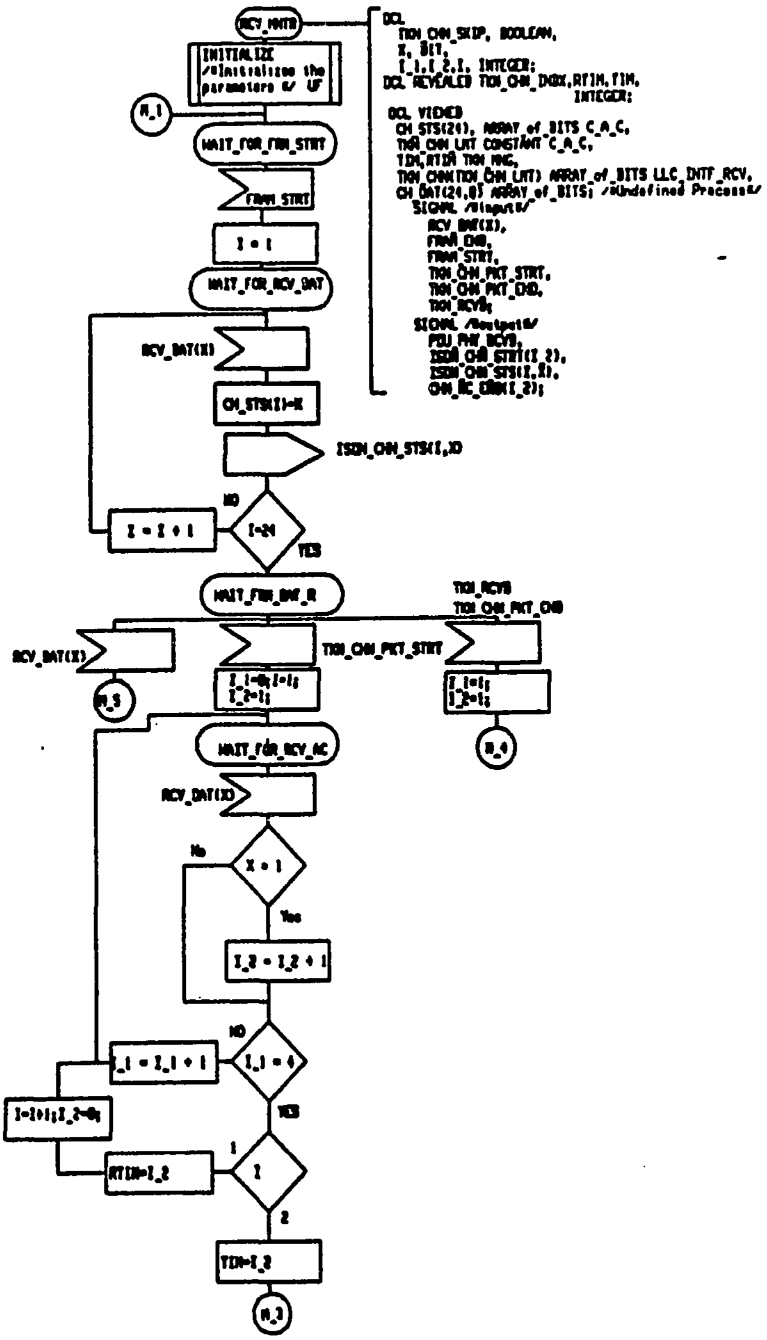


Figure 9.3: Process Diagram of *RCV_MNTR*

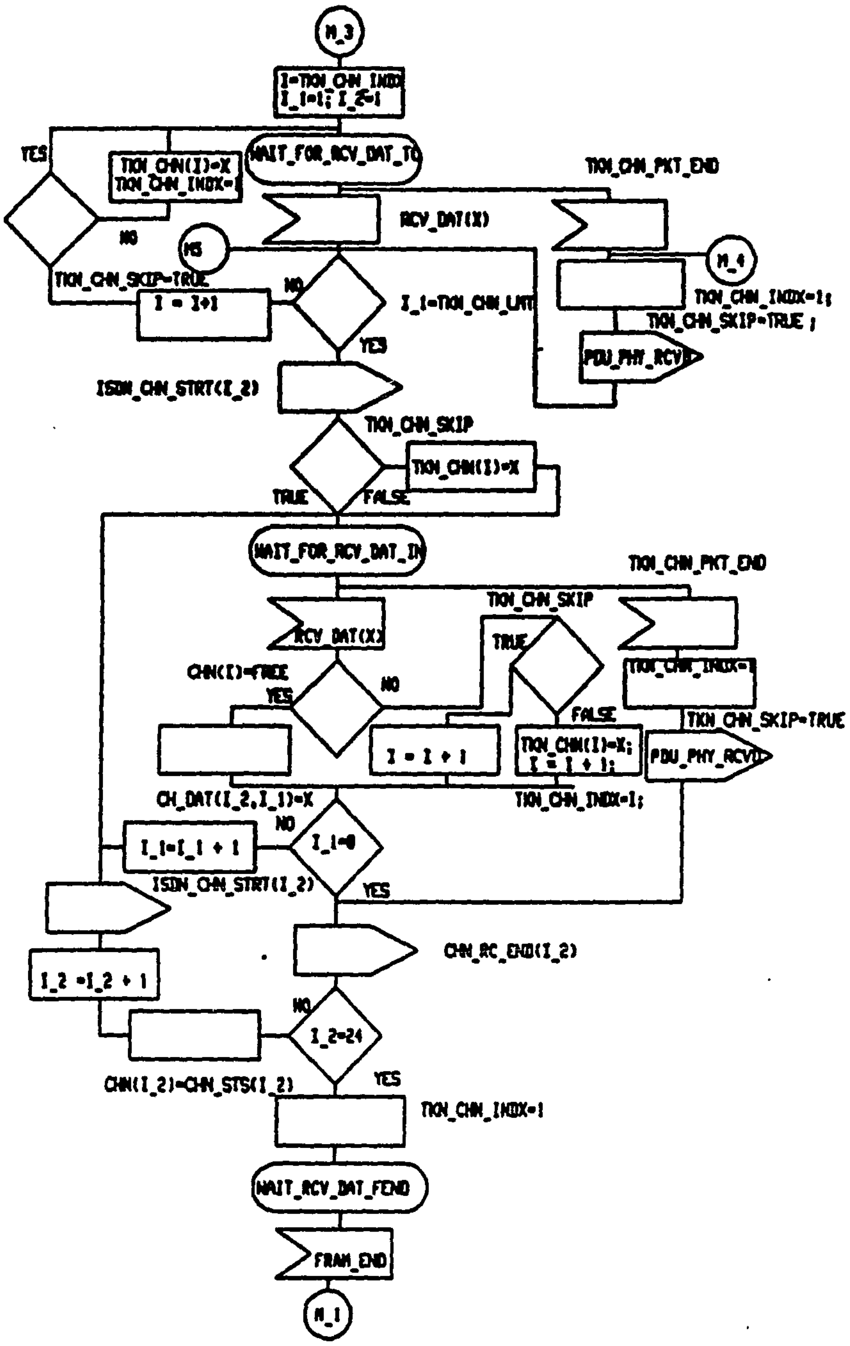


Figure 9.4: Process Diagram of *RCV_MNTR*

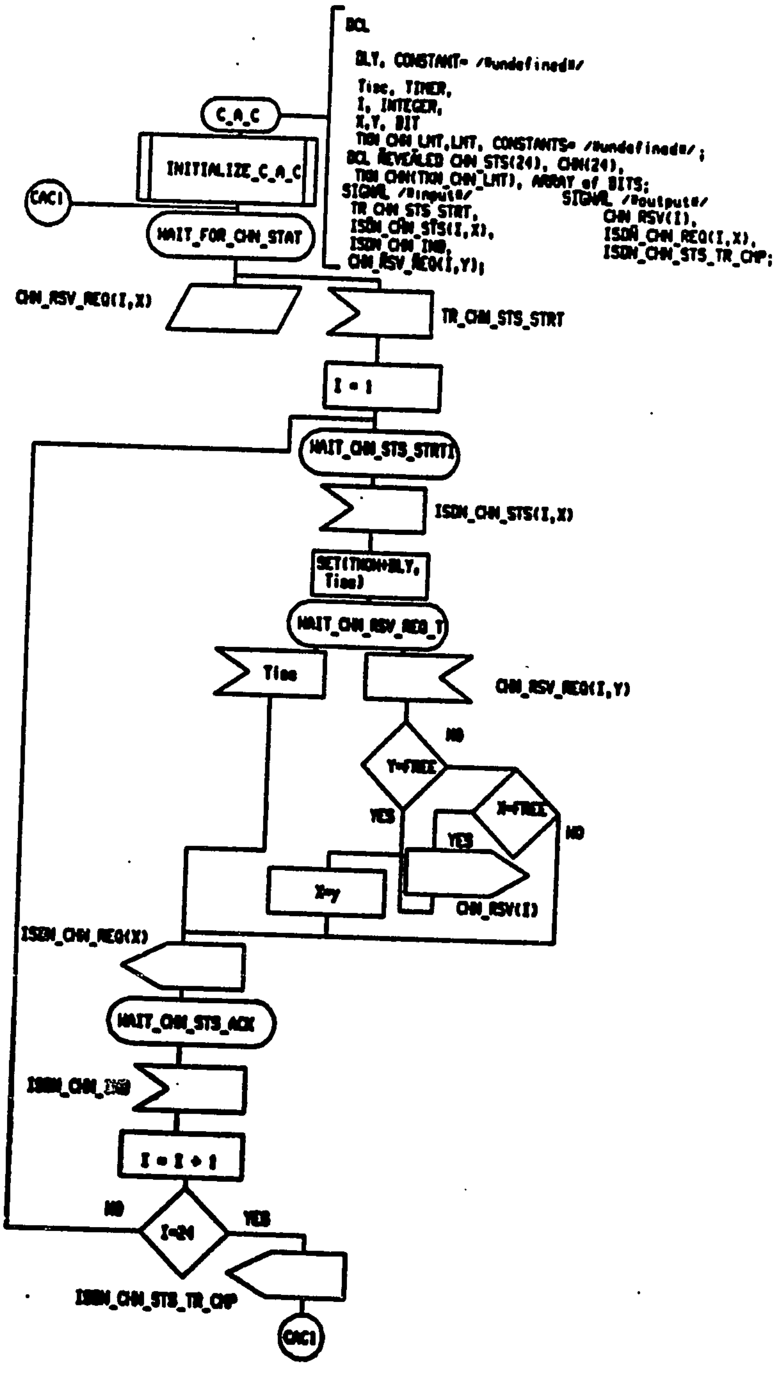


Figure 9.5: Process Diagram of *C_A_C*

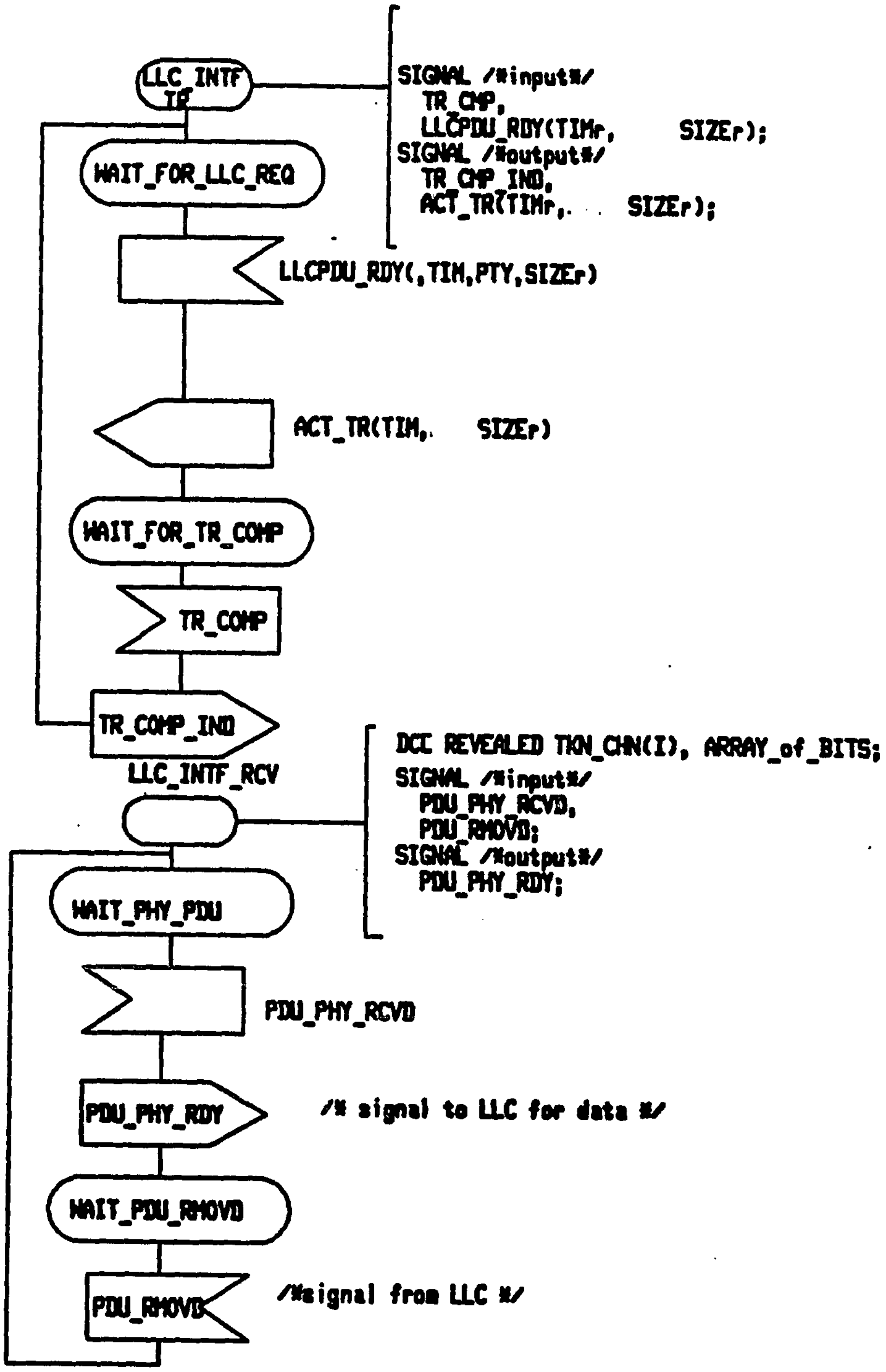


Figure 9.6: Process Diagram of *LLC_INTF_TR* and *LLC_INTF_RCV*

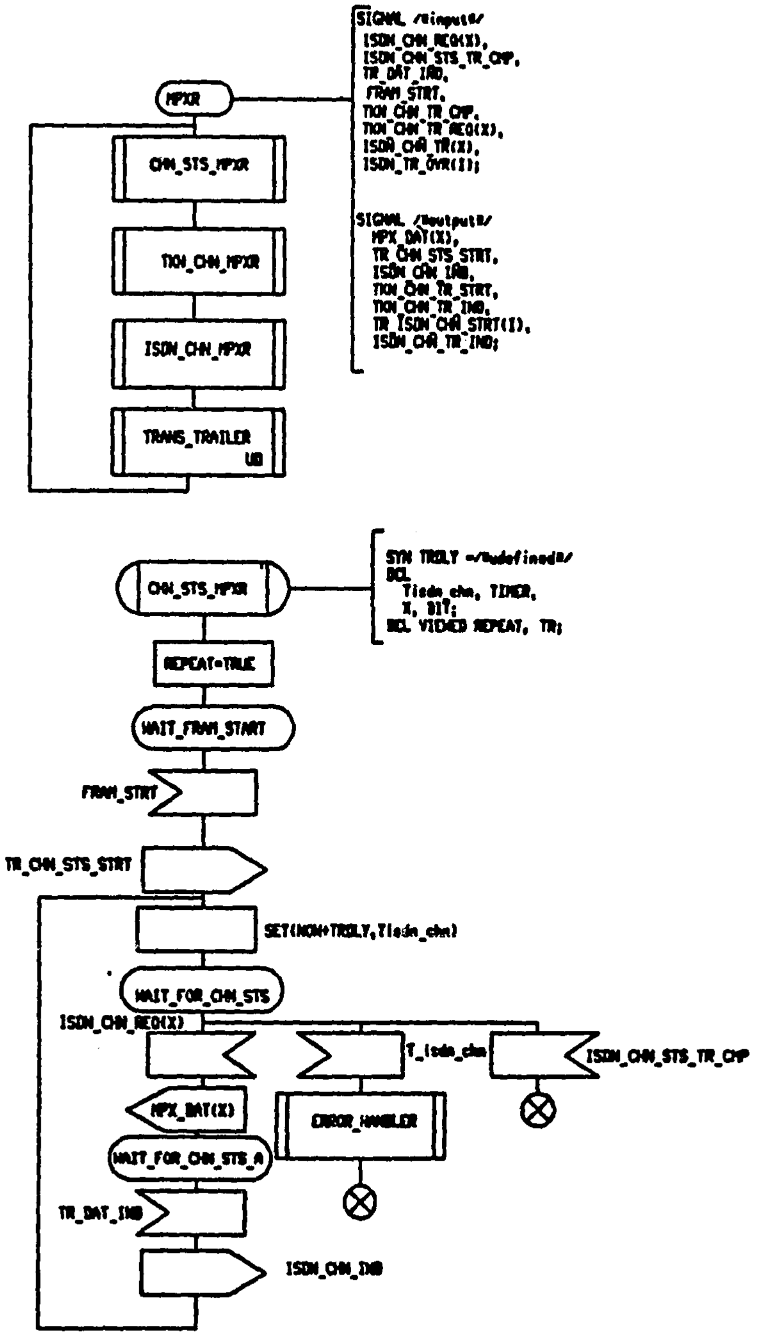


Figure 9.7: Process Diagram of MPXR

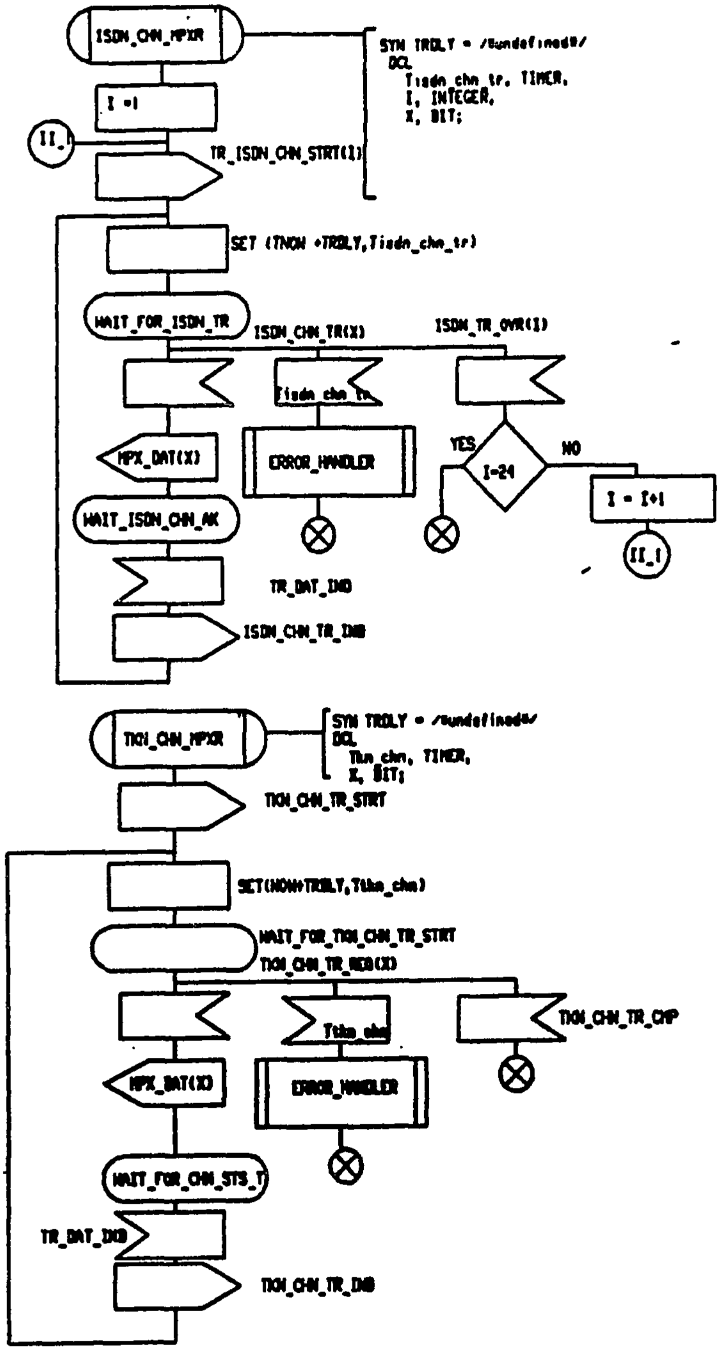


Figure 9.8: Process Diagram of MPXR

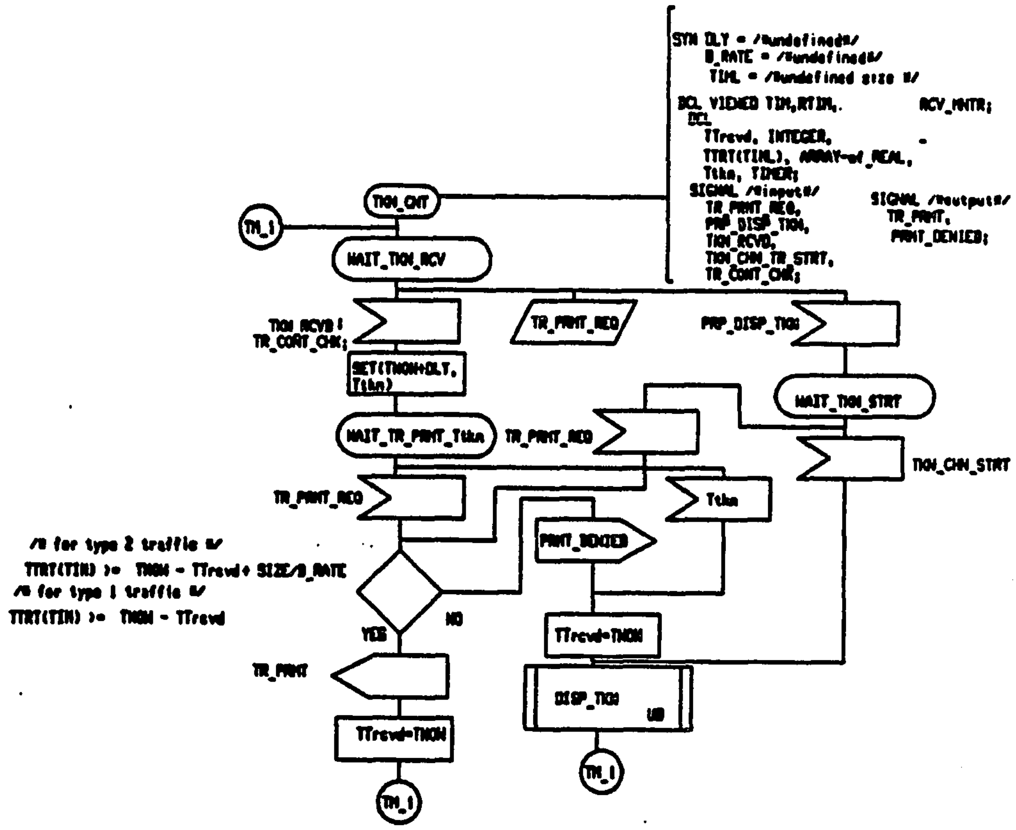
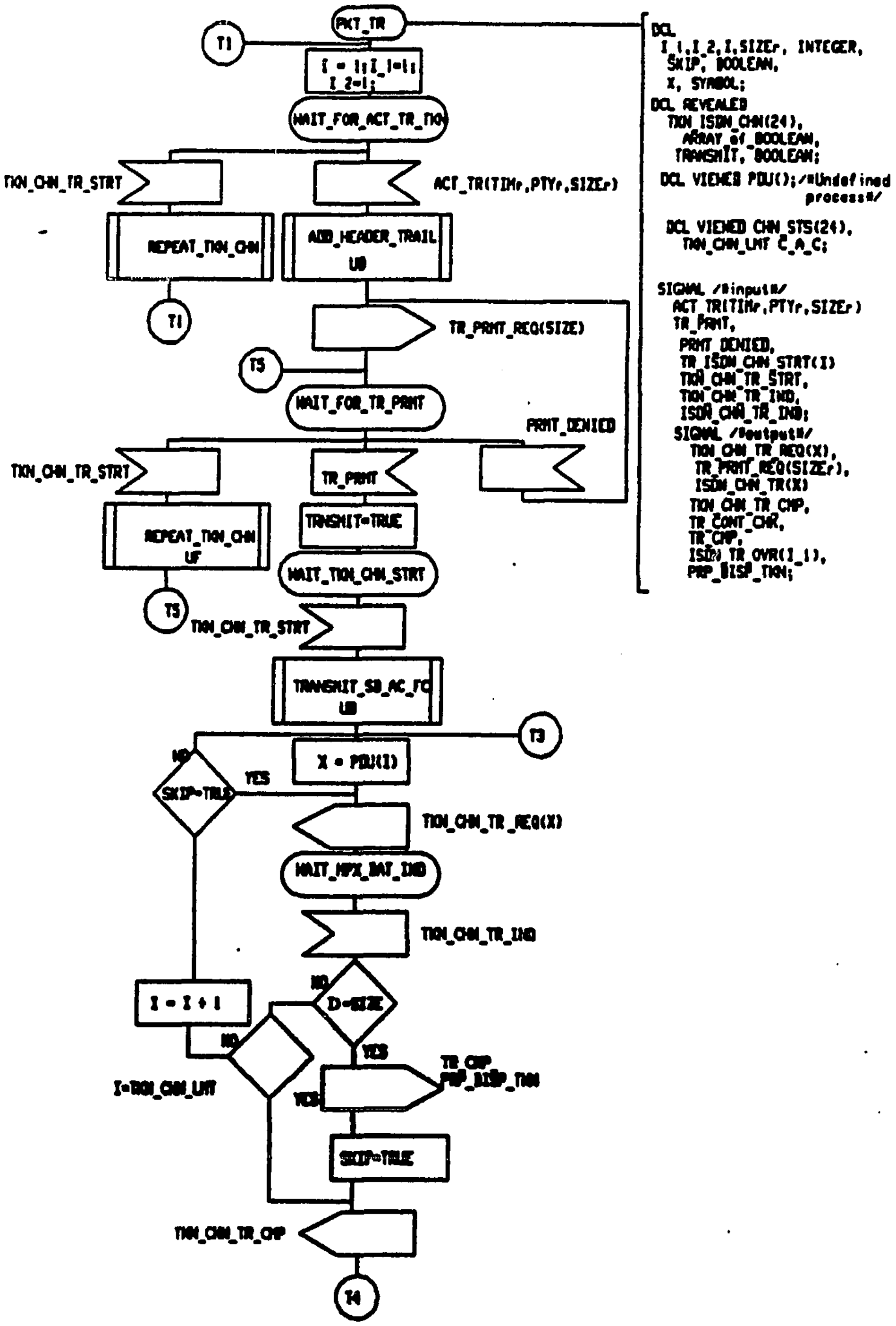


Figure 9.9: Process Diagram of *TKN_CNT*



```
DCL
 I_1,I_2,I,SIZEr, INTEGER,
  SKIP, BOOLEAN,
  X, SYMBOL;
DCL REVEALED
  TKN_ISDN_CHN(24),
    ARRAY of BOOLEAN,
   TRANSMIT, BOOLEAN;
 DCL VIEWED PDU();/*Undefined
                     process*/

 DCL VIEWED CHN_STS(24),
   TKN_CHN_LMT C_A_C;

SIGNAL /*input*/
  ACT_TR(TIMr,PTYr,SIZEr)
  TR_PRMT,
   PRMT_DENIED,
   TR_ISDN_CHN_STRT(I)
   TKN_CHN_TR_STRT,
   TKN_CHN_TR_IND,
   ISDN_CHN_TR_IND;
  SIGNAL /*output*/
    TKN_CHN_TR_REQ(X),
     TR_PRMT_REQ(SIZEr),
     ISDN_CHN_TR(X)
    TKN_CHN_TR_CMP,
    TR_CONT_CMR,
    TR_CMP,
    ISDN_TR_OVR(I_1),
    PRP_DISP_TKN;
```

Figure 9.10: Process Diagram of *PKT_TR*

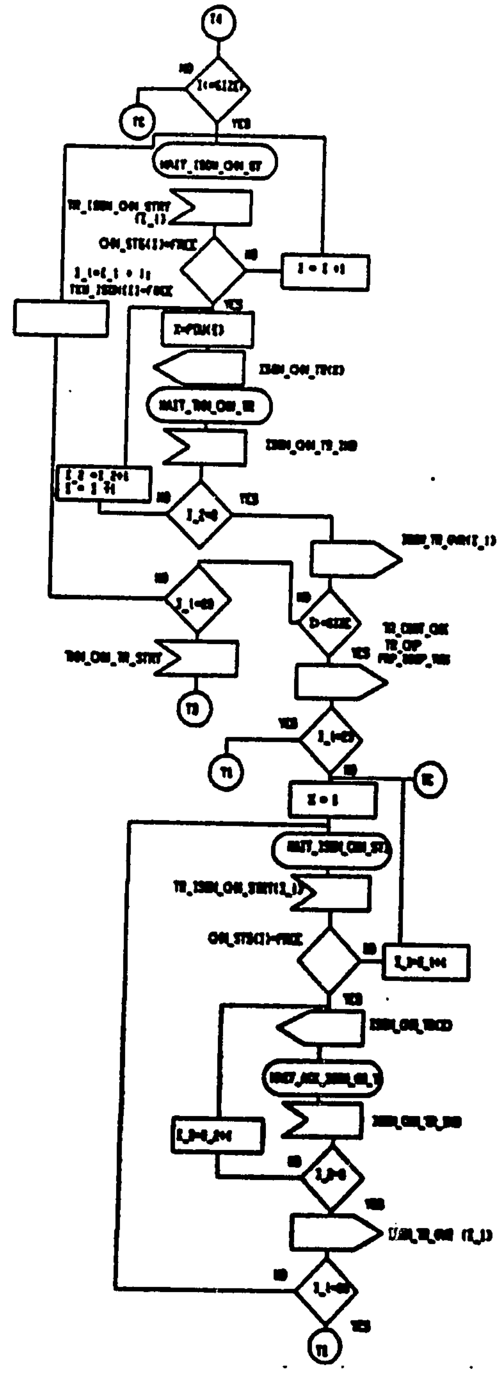
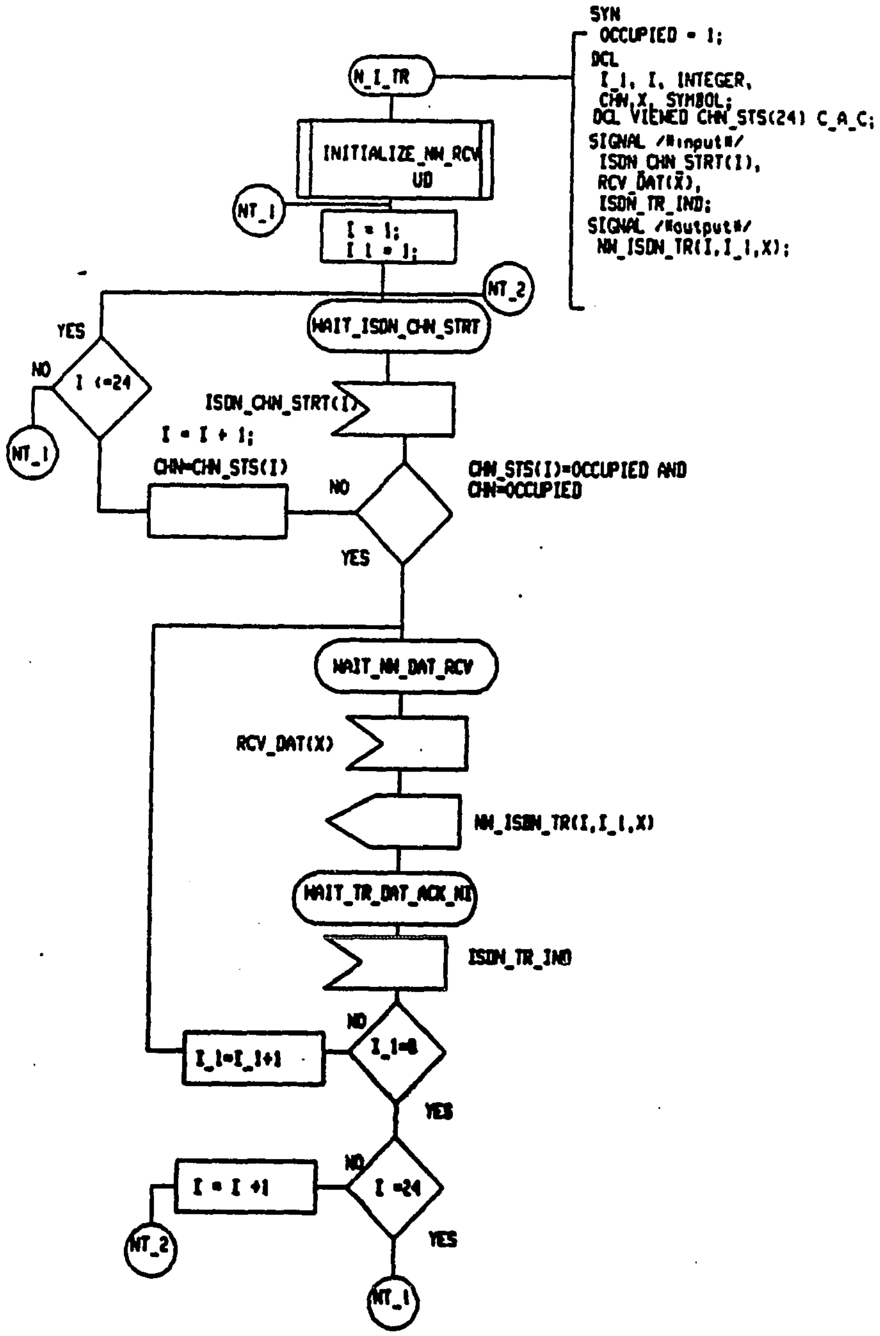


Figure 9.11: Process Diagram of *PKT_TR*



```
SYN
 OCCUPIED = 1;
DCL
 I_1, I, INTEGER,
 CHN,X, SYMBOL;
DCL VIEWED CHN_STS(24) C_A_C;
SIGNAL /*input*/
 ISDN_CHN_STRT(I),
 RCV_DAT(X),
 ISDN_TR_IND;
SIGNAL /*output*/
 NN_ISDN_TR(I,I_1,X);
```

Figure 9.12: Process Diagram of *N_I_TR*

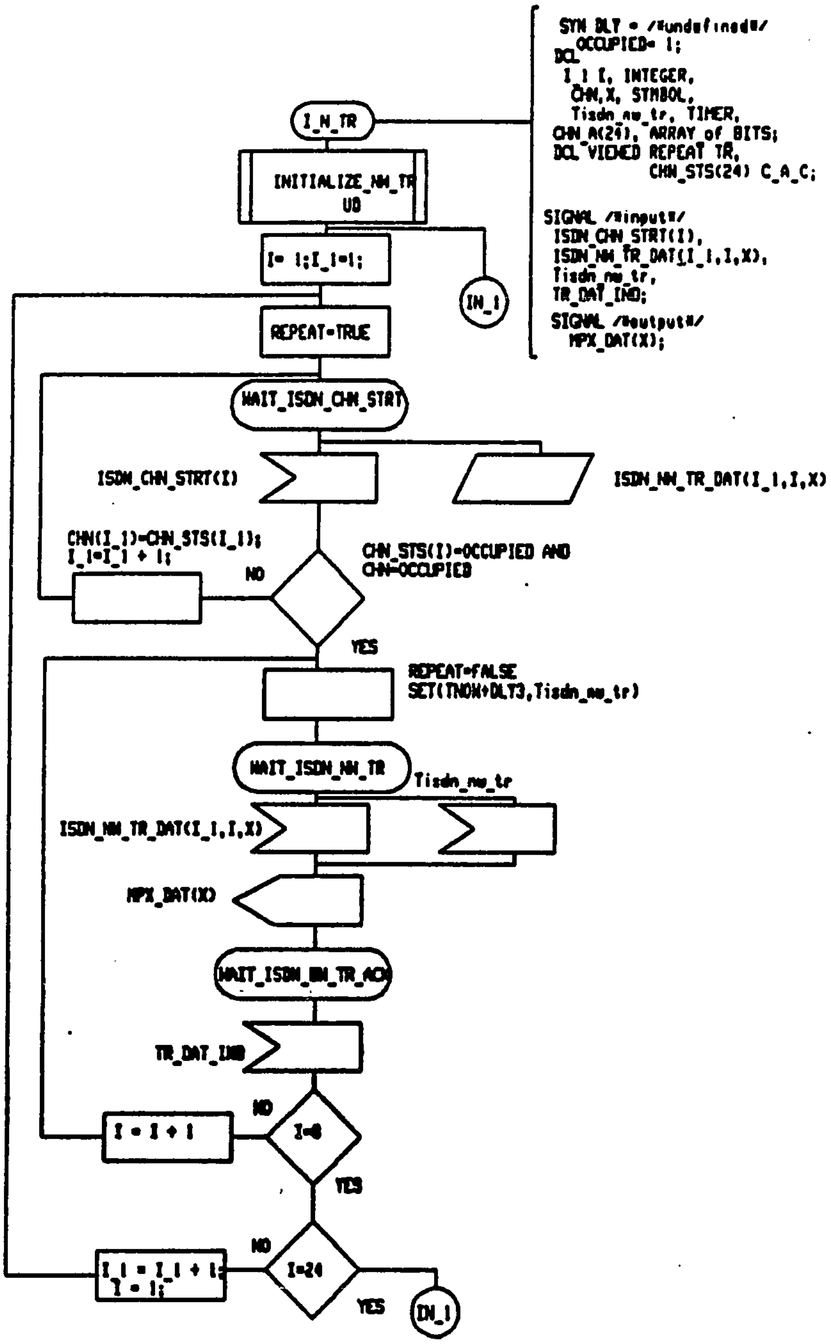
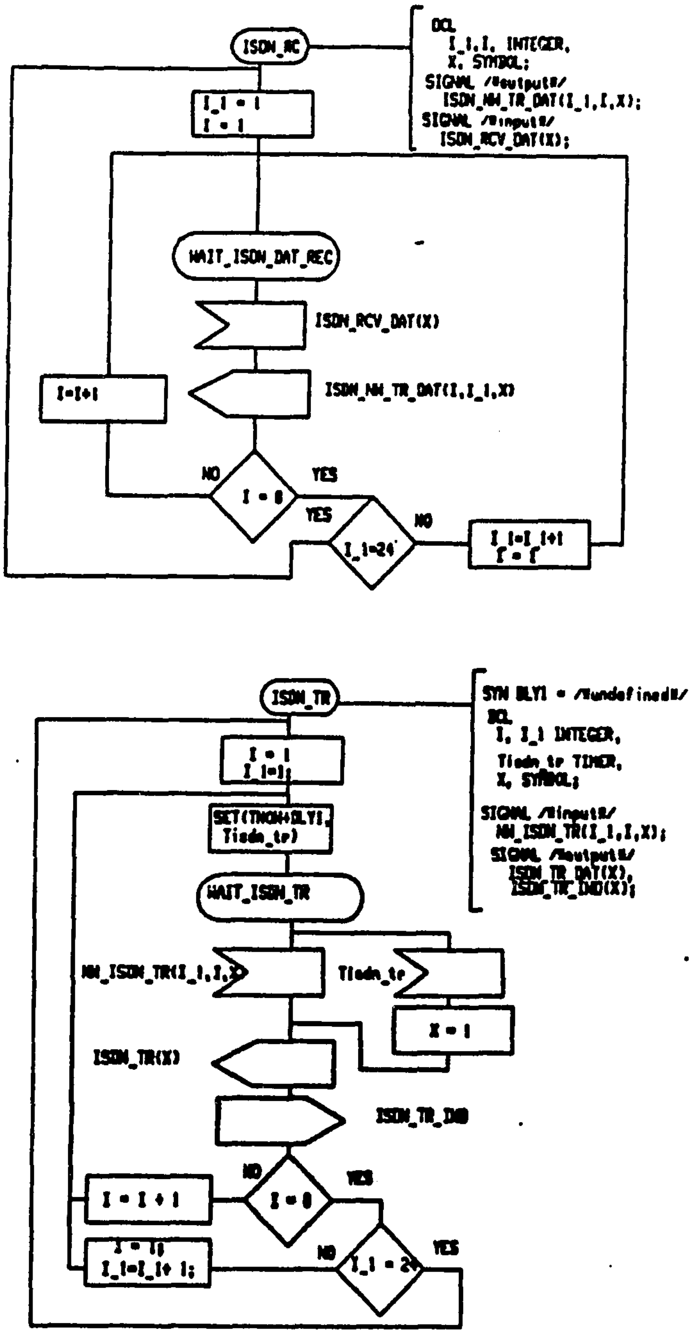


Figure 9.13: Process Diagram of *I_N_TR*



```
DCL
  I_1,I, INTEGER,
  X, SYMBOL;
SIGNAL /*output*/
  ISDN_NW_TR_DAT(I_1,I,X);
SIGNAL /*input*/
  ISDN_RCV_DAT(X);
```

```
SYN DLY1 = /*undefined*/
DCL
  I, I_1 INTEGER,
  Tisdn_tr TIMER,
  X, SYMBOL;
SIGNAL /*input*/
  NW_ISDN_TR(I_1,I,X);
 SIGNAL /*output*/
   ISDN_TR_DAT(X),
   ISDN_TR_IND(X);
```

Figure 9.14: Process Diagram of *ISDN_RC* and *ISDN_TR*