Evaluation of the Performance of the Message Transfer Part in Signaling System No. 7

By

Samir Adil Naoum

Supervisor

Dr. Souheil F. Odeh

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University of Jordan

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This thesis was successfully defended and approved on 4/5/1997 .

Examination Committee	**Signature**
Dr. Souheil F. Odeh	Souheil Odeh
Dr. Ahmad M. Mustafa	A. Mustafa
Dr. Jamal S. Rahhal	
Dr. Omar M. Hassan	

To My Father, Mother, and Sister

To My Wonderful Aunts, Maysoon & Rihab Abdullah

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Abstract

Evaluation of the Performance of the Message Transfer Part

in Signaling System No. 7

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Samir Adil Naoum

Supervisor

Dr. Souheil F. Odeh

Signaling System No. 7 is a specification developed by the International Telegraph and Telephone Consultative Committee. In this research a comprehensive study of the Signaling System is made. The purpose of this study is to get familiar with the structure of this system, its main parts, the signals being used, and the format of these signals. Next, a mathematical description is used to represent the efficiency of the system.Following that, two different network structures are developed.

The effect of three different factors on the efficiency is studied. These factors are: the probability of error (P_e), the initial threshold value upon which a decision is made at each signaling point whether to forward or not the arriving signal units, and a factor we introduced called the Link Loading Effect Factor (LLEF).

A software simulation, using MATLAB, is used and the system efficiency, η_{system}, for different value settings of P_e, initial threshold value (V_{thi}) and LLEF is calculated. The results are compared to find the effect of each of these factors.

الملخص

تقييم اداء الجزء الناقل للبيانات في نظام الاشارات رقم ٧

اعداد

سامر عادل نعوم

المشرف

د. سهيل عودة

نظام الاشارات رقم ٧ هو نظام رقمي تم تطويره من قبل الهيئة الدولية الاستشارية للتلفون والتلغراف. يشمل هذا البحث دراسة شاملة لهذا النظام من اجل التعرف على الاجزاء الرئيسية فيه, الاشارات المستخدمة وتركيبها. يلي ذلك ايجاد المعادلة الرياضية من اجل تمثيل كفاءة النظام.

سوف يتم دراسة تاثير ثلاثة عوامل على كفاءة النظام هذه العوامل هي: احتمالية الخطأ, قيمة العتبة التي على اساسها يتم تمرير الاشارة الواصلة الى نقطة في النظام بالاضافة الى عامل ثالث هو معامل تاثير تحميل المستعمل وهو معامل تم استنباطه في البحث.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 What is Signaling System No. 7.

Signaling system No. 7(SS7) is a specification developed by the International Telegraph and Telephone Consultative Committee (CCITT). Signaling system No. 7 network is a digital network used for call setup and control. What makes SS7 advantageous over most of the remaining signaling systems is that it utilizes a common channel signaling system. This means that one channel (either analog or digital) is only used for sending the signaling information whether the system has one bearer channel or multiple bearer channels.

Common Channel Signaling, compared with in-band signaling in which voice and signaling information are carried over the same channel, has the following advantages:

a) Faster call setup times.

b) More efficient use of voice circuits.

c) Support for services which require signaling during a call.

Part of the previous studies included the study of the effect of the loading of MSUs on the Mean Total Queueing Delay and on the Standard Deviation of the Queueing Delay of each channel of traffic. The study considered both types of error correction, the basic correction method and the preventive cyclic retransmission error correction method. Such study can be found in the CCITT recommendations Q721-Q725.

Also,Valdimaisson (1994) presented an extension of the classical methods used to evaluate blocking probability. In his work , he presented analytical methods and compared them with the simulation results. Extensive simulation has been performed focusing on ways to reduce blocking to acceptable levels. From his study he found that the major factors that affect blocking are; swithcing element size, speed advantage of the switch fabric, routing algorithms and connection bandwidth.

Takine, Snugpta, and Hasegawa (1994) showed in their work that the delay distribution depends highly on the correlations.

In this research the effect of the probability of error, the initial threshold value upon which a decision is made at each signaling point, and an introduced factor called the Link Load Effect Factor (LLEF) on the throughput of the system is made clear.

1.2 Structure of Signaling System No. 7

SS7 network is composed mainly from signaling points interconnected by links. Each signaling point is uniquely identified by a numeric point code. Point codes are carried in signaling messages exchanged between signaling points to identify the source and destination of each message. The signaling point uses a routing table to select the appropriate signaling path for each message.

There are three kinds of signaling points in the SS7 network:

i) Service Switching Points (SSPs): Function as switches that originate, terminate, or tandem calls.

ii) Signal Transfer Points (STPs): Send call setup messages to other SSPs. It also routes each incoming message to an outgoing signaling link based on routing information contained in the SS7 message. It may also send a query message to a centralized database to determine how to route a call.

iii) Service Control Points (SCPs): Sends a response to the originating SSP containing the routing number(s) associated with the dialed number.

The hardware and software functions of the SS7 protocol are divided into 4 functional levels. These levels are somewhat analogous to the Open Systems Interconnect (OSI) 7-layer model defined by the International Standards Organization (ISO).

The first three levels form together what is known as the Message Transfer Part (MTP). The MTP is responsible for the transfer of all the signaling messages as required by the users connected to the system, and performing all the subsidiary functions such as error control and signaling security. The functions provided by each of the first three levels are:

1- Signaling data link functions (level 1).

2- Signaling link functions (level 2).

3- Signaling network functions (level 3).

In talking about levels, the functions provided by the user parts are considered as level 4. Fig. 1.1 shows the functional levels of SS7.

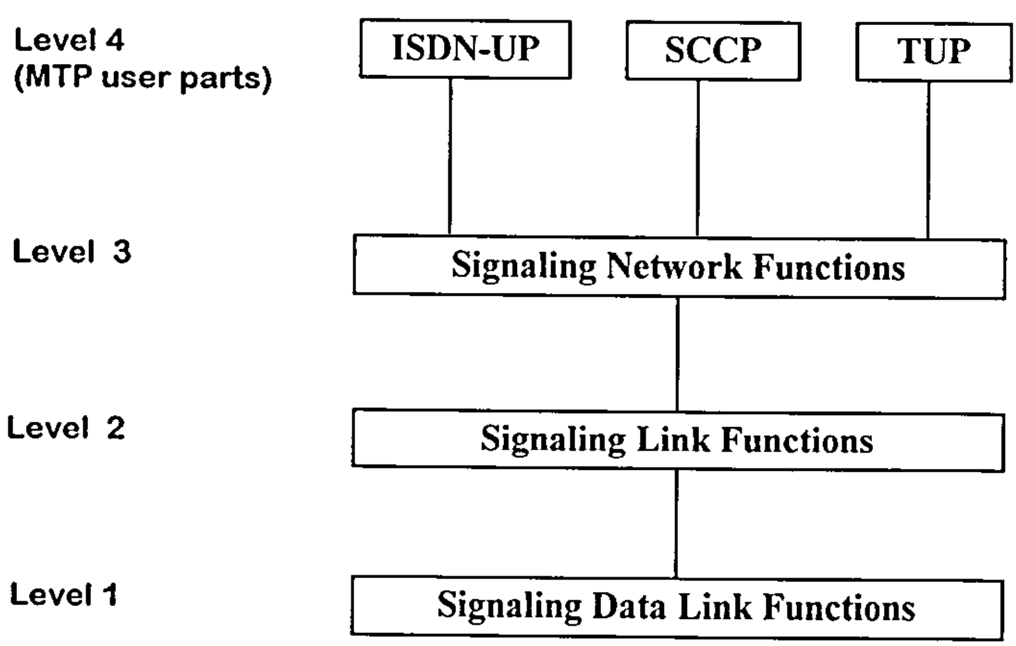


Fig. 1.1 Functional levels of SS7.

1.2.1 Signaling Data Link Functions (Level 1).

These functions define the physical, electrical, and functional characteristics of a signaling data link and the means to access it.

1.2.2 Signaling Link Functions (Level 2).

These functions define the functions and procedures for relating to the transfer of signaling messages over one individual signaling data link. Level 2 functions together with level 1 as a bearer which provides a signaling link for reliable transfer of signaling messages between two points.

The signaling link functions include:

- Signal unit delimitation and alignment,
- Error detection,
- Error correction,
- Signaling link error monitoring,
- Link state control functions, and
- Flow control.

1.2.2.1 Signal unit delimitation and alignment.

At the beginning and end of each signal unit there is a unique 8-bit code pattern, called the flag. This flag has the sequence 01111110. In order to ensure that the code is not imitated by any other part of the signal unit, the transmitting signaling link terminal inserts a "0" after every sequence of five consecutive 1's before the flags are attached and the signal unit is transmitted. At the receiving signaling link terminal, and after flag detection and removal, each "0" which directly follows a sequence of five consecutive 1's is deleted.

Loss of alignment occurs when a bit pattern disallowed by the delimitation procedure (more than five consecutive 1's) is received, or when a certain maximum length of signal unit is exceeded.

1.2.2.2 Error Detection.

The error detection function is performed by means of 16 check bits provided at the end of each signal unit. The check bits are generated by the transmitting signaling link terminal. They are the one's complement of the sum (modulo 2) of the following:

i) The remainder of $x^k(x^{15} + x^{14} + x^{13} + \ldots + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, where k is the number of bits in the signal unit existing between, but not including, the final bit of the opening flag and the first bit of the check bits, excluding bits inserted for transparency, and;

ii) The remainder after multiplication by x^{16} and then division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$ of the content of the signal unit described in (i).

1.2.2.3 Error correction.

There are two forms of error correction:

- The basic method which applies for signaling links using non-intercontinental terrestrial transmission means and for intercontinental signaling links where the one-way propagation delay is less than 15 ms.

This method is non-compelled, positive / negative acknowledgment, retransmission error correction system. A signal unit which has been transmitted is retained at the transmitting signaling link terminal until a positive acknowledgment for that signal unit is received. If a negative acknowledgment is received, then the transmission of new signal units is interrupted and those signal units which have been transmitted but not yet positively acknowledged starting with that indicated by the negative acknowledgment will be retransmitted once, in the order which they were first transmitted.

- The preventive cyclic retransmission method which applies for intercontinental signaling links where the one-way propagation delay is greater than or equal to 15 ms and for all signaling links established via satellite.

The preventive cyclic retransmission method is a non-compelled, positive acknowledgment, cyclic retransmission, forward error correction system. A signal unit which has been transmitted is retained at the transmitting signaling terminal until a positive acknowledgment for that signal unit is received. During the period when there are no new signal units to be transmitted, all the signal units which have not been positively acknowledged, are retransmitted cyclically.

1.2.2.4 Signaling link error monitoring.

Two signaling link error rate monitor functions are available:

- Signal unit error rate monitor: which provides the criteria for taking the link out of service and is applied whilst the link is in service.
- Alignment error rate monitor: applied whilst the link is in the proving state of the initial alignment procedure.

1.2.2.5 Link state control functions.

Link state control is a function of the signaling link which provides directives to the other signaling link functions.

1.2.2.6 Flow control.

Flow control is initiated when congestion is detected at the receiving end of the signaling link. The congested receiving end of the link notifies the remote transmitting end of the condition by means of an appropriate link status signal unit and withholds acknowledgments of all incoming message signal units. While congestion exists, the remote transmitting end is periodically notified of this condition. The remote transmitting end will indicate the link as failed if the congestion continues for too long.

1.2.3 Signaling Network Functions (Level 3).

The functions provided by this level can be divided into two major categories:

1.2.3.1 Signaling Message Handling Functions.

The purpose of the signaling message handling functions is to ensure that the signaling message originated by a particular user part at a signaling point (originating point) is delivered to the same user part at the destination point indicated by the sending user part.

The signaling message handling functions are divided into:

- The message routing function, used at each signaling point to determine the outgoing signaling link on which a message has to be sent towards its destination point.

- The message discrimination function, used at a signaling point to determine whether or not a received message is destined to the point itself. If the message is not destined to that signaling point, it is transferred to the message routing function.

- The message distribution function, used at each signaling point to deliver the received message (destined to the point itself) to the appropriate user part.

1.2.3.2 Signaling Network Management.

The purpose of the signaling network management functions is to provide reconfiguration of the signaling network in the case of failures and to control traffic in case of congestion. Such a reconfiguration is affected by the use of appropriate procedures to change the routing of signaling traffic in order to bypass the faulty link or signaling points.

2- Signaling link management.

The signaling link management function is used to restore failed links, activate idle (not yet aligned) links, and to deactivate aligned signaling links. The following procedures are implemented:

- Signaling link activation, deactivation and restoration,
- Link set activation, and
- Automatic allocation of signaling terminals and signaling data links.

3- Signaling route management.

The signaling route management is used to distribute information about the signaling network status in order to block or unblock signaling routes. The following functions are implemented:

- Transfer-controlled procedure,
- Transfer-prohibited procedure,
- Transfer-allowed procedure,
- Transfer-restricted procedure,
- Signaling-route-set-test procedure, and
- Signaling-route-set-congestion test procedure.

Fig. 1.2 shows the detailed structure of the signaling system.

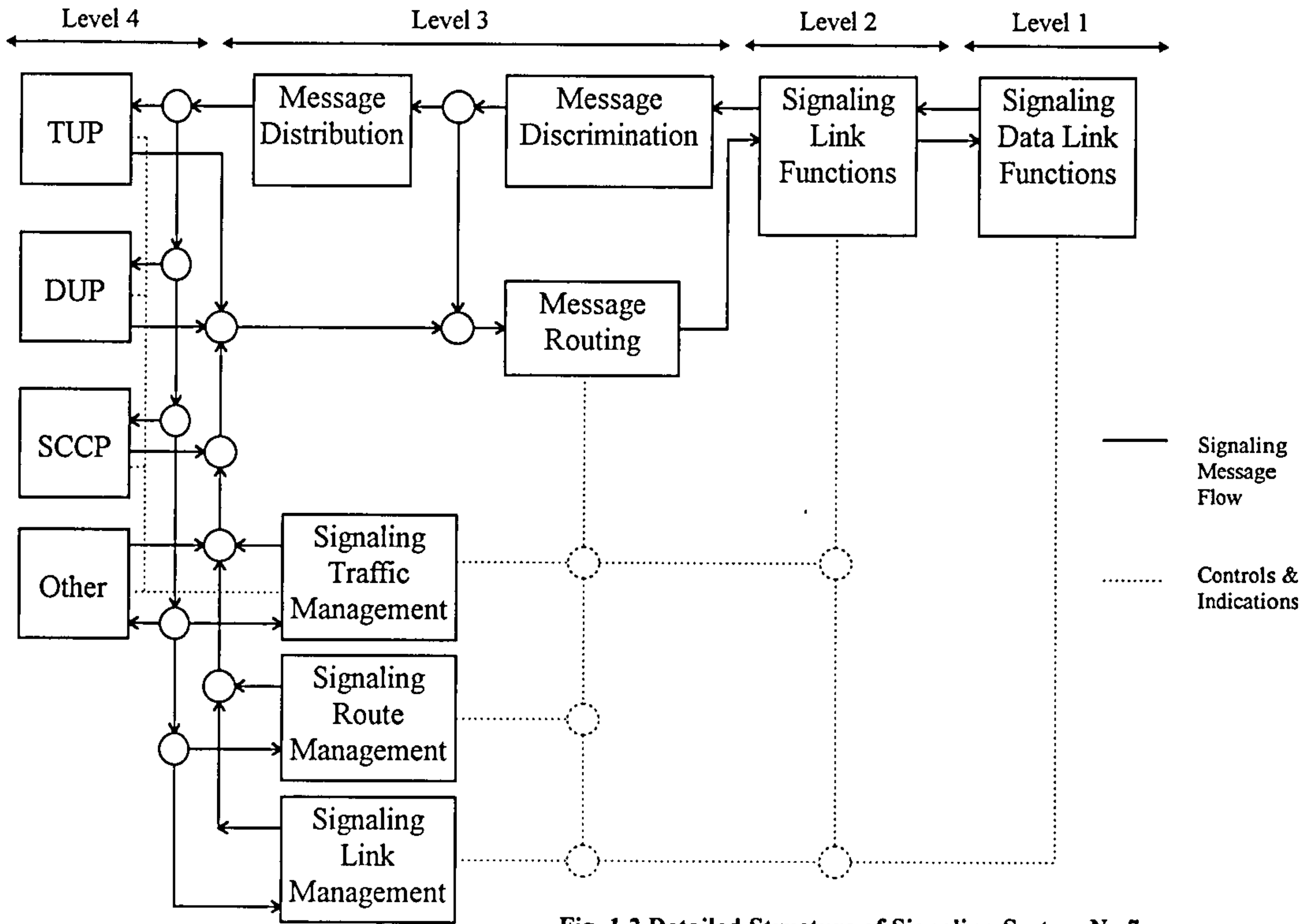


Fig. 1.2 Detailed Structure of Signaling System No.7
(CCITT Recommendation Q.700)

1.3 Basic Signal Unit Format.

Information and signaling from one originating point to the other is carried through what is called a signaling unit. A signal unit could have either only fixed length fields in the case of Fill-In Signal Units (FISU) and Link Status Signal Unit (LSSU) or fixed length fields and a varible length field in the case of a Message Signal Unit. The variable length field is called the signaling information field and is used to convey the user part generated information. The fixed length fields, on the other hand, are used to carry message control.

1.3.1 Signal Unit Format.

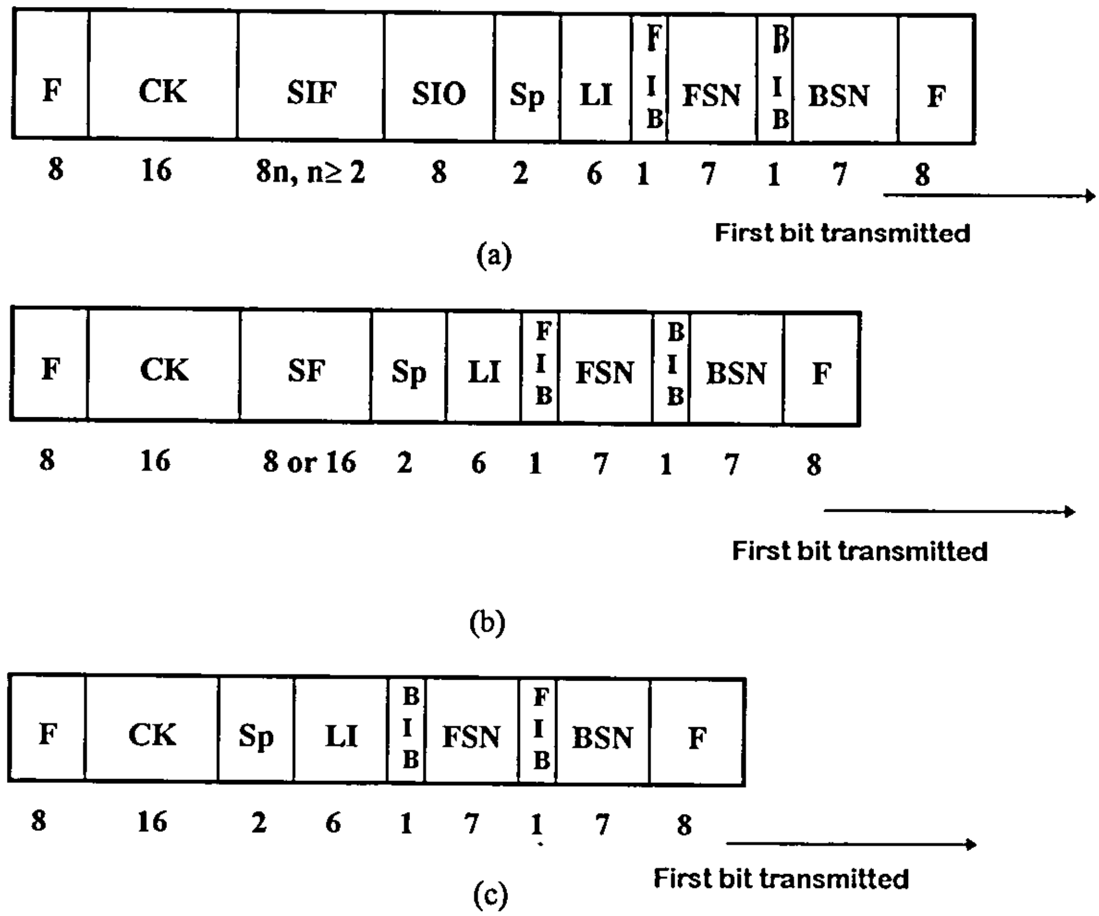
There are three types of signal units, and the length indicator contained in these signals is used to differentiate between them. These three types are:

1- Message Signal Unit (MSU).

2- Link Status Signal Unit (LSSU).

3- Fill-In Signal Unit (FISU).

Fig. 1.3 shows the format of these signal units.



(a) Basic format of Message Signal Unit.
(b) Basic format of Link Status Signal Unit.
(c) Basic format of a Fill-In Signal Unit.

BIB	Backward indicator bit	F	Flag
BSN	Backward sequence number	SF	Status field
SIF	Signaling information octet	CK	Check bits
SIO	Service information octet	LI	Length indicator
FSN	Forward sequence number	FIB	Forward indicator bit
N	Number of octets in the SIF	Sp	Spare

Fig. 1.3 Format of MSU, LSSU, and FISU.

1.3.1.1 The Message Signal Unit (MSU).

A signal unit which carries the useful information generated by the different user parts. It is the signal unit which is being retransmitted if erroneously received.

1.3.1.2 The Link Status Signal Unit (LSSU).

A signal unit which contains information about the signaling link in which it is transmitted.

1.3.1.3 The Fill-In Signal Unit (FISU).

A signal unit containing only error control and delimitation information, which is transmitted when there are no message signal units or link status signal units to be transmitted.

1.3.2 Fields of the signal unit.

The fields which the signal unit could be composed of are:

1.3.2.1 Flag.

Which indicates both the start and end of the message signal unit. The opening flag for one signal is normally the closing flag for the other. The bit pattern for the flag is 0 1 1 1 1 1 1 0.

1.3.2.2 Length indicator.

The length indicator is a 6-bit field used to indicate the number of octets following the length indicator and preceding the check bits, and is a number in binary code ranging from 0-63. The length indicator for the message signal unit is set to have a value larger than 2 since the 0 and 1 values for the length indicator are reserved for both the fill-in signal unit and the link status signal unit respectively.

1.3.2.3 Service information octet.

The service information octet is an 8-bit field composed of two parts, the service indicator and the subservice field.

The service information octet, which is a 4-bit field, is used by the signaling message handling functions to perform message distribution and in some special applications to perform message routing. Table 1.1 shows the service indicator codes for the international signaling network.

Table 1.1 Service indicator codes for the international signaling network.

Bits				
D	C	B	A	
0	0	0	0	Signaling network management messages
0	0	0	1	Signaling network testing and maintenance messages
0	0	1	0	Spare
0	0	1	1	SCCP
0	1	0	0	Telephone User Part
0	1	0	1	ISDN User Part
0	1	1	0	Data User Part
0	1	1	1	Data User Part
1	0	0	0	Reserved for MTP testing part
1	0	0	1	Spare
to				
1	1	1	1	

The 4-bit sub-service field, contains the network indicator which is used by the signaling message handling functions to determine the type of network (national or international) to which the user part belongs. Bits A & B of this field are kept as spare while bits C & D (network indicator) are those which are in use. Table 1.2 shows the codes for the network indicator.

Table 1.2 The codes for the network indicator.

Bits		
D	C	
0	0	International network
0	1	Spare
1	0	National network
1	1	Reserved for national use

1.3.2.4 Forward and backward sequence numbers.

The forward sequence number is the sequence number of the signal unit in which it is carried. The backward sequence number is the sequence number of a signal unit being acknowledged.

Both the forward and backward sequence numbers are in binary code ranging from 0-127.

1.3.2.5 Forward and backward indicator bits.

The forward and backward indicator bits are used along with the forward and backward sequence numbers and are used in signal unit sequence control acknowledgment.

1.3.2.6 Check bits.

This is a 16-bit field, generated according to a certain algorithm and used for error detection.

1.3.2.7 The signaling information field.

It is used to carry the information generated by the user parts. It consists of an integral number of octets, not less than 2 and not more than 272. If the length of the signaling information field is equal to 272 then there will be 268 information octet while the remaining 4 octets are reserved for routing. The formats and codes of the signaling information field varies from one user part to another depending on which user part is in use.

1.3.2.8 Spare fields

Those are coded "0" unless indicated otherwise.

1.3.2.9 Status field.

This field appears only in the link status signal unit. The length of this field depends on the value of the length indicator whether it is 1 or 2. If its value is equal to 1 then the status field consists only of one octet and it consists of two octets if the value of the length indicator is equal to 2. A status field which is one octet in length will look like that in Fig. 1.4.

	C B A
Spare	Status indication
5	3

→ First bit transmitted

Fig 1.4 Status field format

Table 1.3 shows the indication that bits A, B, and C have.

Table 1.3 Indication of bits A, B, and C.

Bits			Status indication
C	B	A	
0	0	0	Out of alignment
0	0	1	Normal
0	1	0	Emergency
0	1	1	Out of Service
1	0	0	Processor Outage
1	0	1	Busy
1	1	0	Spare
1	1	1	Spare

Chapter two will consider the Telephone User Part of signaling system No. 7. A descripition of this user part is made based on the signals and messages used and the format of each.

Chapter Two

TELEPHONE USER PART

2.1 Telephone User Part of Signaling System No. 7

The telephone user part of signaling system No. 7 provides the necessary functions to use signaling system No. 7 for international telephone call control signaling. As is the case with each of the user parts, the telephone user part has its own signaling messages, known as telephone signaling messages.

These messages are responsible for path set-up, type of call selection(national or international), charging information, language being used, type of the link between the two users (terrestrial or via satellite) and notification of failure(hardware or software).

2.2 Telephone Signaling Messages

In our work we will be dealing with some of these signals, but before going into them let us consider a field which is common to all of these signals, this field is the label.

2.2.1 Label

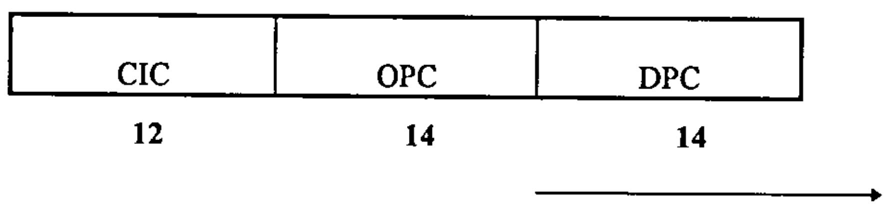
A 40-bit field common to all telephone signaling messages, used for message routing and identification of the concerned telephone circuit. This field is divided into three subfields which are:

2.2.1.1 Destination point code: A 14-bit field identifying the signaling point to which the message is routed.

2.2.1.2 Originating point code: A 14-bit field identifying the signaling point from which the message has originated.

2.2.1.3 Circuit identification code: A 12-bit field identifying the telephone circuit among those interconnecting the destination point and originating point.

Fig. 2.1 shows the structure of the standard telephone label.



CIC: Circuit identification code
OPC: Originating point code
DPC: Destination point code

Fig. 2.1 Standard telephone label structure.

2.2.2 Telephone Signaling Messages and their formats.

The telephone signaling messages that we are going to encounter in our work are:

2.2.2.1 Initial Address Message(IAM).

This message is being sent in the forward direction in the first stage of call set-up, it contains the necessary address information needed for specifying the path. Fig. 2.2 shows the format of this signal along with the indication of each of its fields.

		LKJIHGFEDCBA		FEDCBA	0001	0001	
Address Signals	Number of address signals	Message indicators	Sp	Calling Party Category	Heading Code H1	Heading Code H0	label
n x 8	4	12	2	6	4	4	40

Sp:spare

First bit transmitted →

Fig. 2.2 Initial Address Message (IAM) format.

1- Label: As in 2.2.1 above.

2- Heading code H0 is coded 0 0 0 1.

3- Heading code H1 is coded 0 0 0 1.

4- Number of address signals: A 4-bit binary code representing the number of address signals contained in the initial address message.

5- Address signals: Table 2.1 shows the binary code representation of each of the dialed numbers.

Table 2.1 Binary code representation of each of the dialed numbers.

0000	digit 0	0100	digit 4	1000	digit 8	1100	code 12
0001	digit 1	0101	digit 5	1001	digit 9	1101	spare
0010	digit 2	0110	digit 6	1010	spare	1110	spare
0011	digit 3	0111	digit 7	1011	code 11	1111	ST

6- Message indicators: Table 2.2 shows the indication of each of the possible codes in the message indicator field.

Table 2.2 Possible codes in the message indicator field.

Bits		
B	**A**	**Nature of address indicator**
0	0	Subscriber number
0	1	Spare, reserved for national use
1	0	National (significant) number
1	1	International number

Bits		
D	**C**	**Nature of circuit indicator**
0	0	No satellite circuit in connection
0	1	One satellite circuit in connection
1	0	Spare
1	1	Spare

Bits		
F	**E**	**Continuity check indicator**
0	0	Continuity check not required
0	1	Continuity check required
1	0	Continuity check previously performed
1	1	Spare

Bit	
G	**Echo suppresser indicator**
0	Outgoing half suppresser not included
1	Outgoing half suppresser included

Bit	
H	**Incoming international call indicator**
0	Call other than international incoming
1	Incoming international call

Bit	
I	**Redirected call indicator**
0	Not a redirected call
1	Redirected call

Bit	
J	**All digital path required**
0	Ordinary call
1	Digital path required

Bit	
K	**Signaling path indicator**
0	Any path
1	All signaling system No. 7

Bit	
L	Spare

7- Calling party category: Table 2.3 shows the indication of each of the possible codes in the calling party category field.

Table 2.3 possible codes in the calling party category field.

Bits						
F	E	D	C	B	A	
0	0	0	0	0	0	Unknown source
0	0	0	0	0	1	Operator, language French
0	0	0	0	1	0	Operator, language English
0	0	0	0	1	1	Operator, language German
0	0	0	1	0	0	Operator, language Russian
0	0	0	1	0	1	Operator, language Spanish
0	0	0	1	1	0	Administration use
0	0	0	1	1	1	
0	0	1	0	0	0	
0	0	1	0	0	1	Reserved
0	0	1	0	1	0	Ordinary calling subscriber
0	0	1	0	1	1	Calling subscriber with priority
0	0	1	1	0	0	Data call
0	0	1	1	0	1	Test call
0	0	1	1	1	0	Spare
0	0	1	1	1	1	Payphone
0	1	0	0	0	0	Spare
to						
1	1	1	1	1	1	

8- Filler: In case of an odd number of address signals, the code 0000 is inserted after the last address signal. This ensures that the variable length field that contains the address signals consists of an integral number of octets.

2.2.2.2 Subsequent Address Message (SAM).

This message is sent in the forward direction prior to the initial address message. It contains further information needed for specifying the path. Fig. 2.3 shows the format of this message along with the indication of each of its fields.

		0000	0011	0001	
Address signals	No. of address signals	Filler	Heading code H1	Heading code H0	Label
n x 8	**4**	**4**	**4**	**4**	**40**

First bit transmitted →

Fig. 2.3 Subsequent Address Message (SAM) format.

1- Label: As in 2.2.1 above.

2- Heading code H0 is coded 0 0 0 1.

3- Heading code H1 is coded 0 0 1 1.

4- Address signals are code as in Table 2.1 above.

5- Number of address signals: a 4-bit binary code representing the number of address signals contained in the subsequent address message.

2.2.2.3 Continuity Check Message (COT).

This message is sent in the forward direction and is used to verify that an acceptable path (for transmission of data, speech, etc.) exists. Fig. 2.4 shows the format of this message along with the indication of its fields.

	0010	
Heading code H1	Heading code H0	Label
4	4	40

First bit transmitted →

Fig. 2.4 Continuity Check Message (COT) format.

1- Label: As in 2.2.1 above.

2- Heading code H0 is coded 0 0 1 0.

3- Heading code H1 is coded according to the signal to be sent, that is, H1 is coded

0 0 1 0 if continuity-signal.

0 1 0 0 if continuity-failure signal.

2.2.2.4 Address Complete Message (ACM).

This signal is sent in the backward direction to indicate that all the address signals needed for routing the call to the called party have been received. It also specifies whether the call is to be charged or not, or if the called number is a payphone station.

Fig. 2.5 shows the format of this message along with the indication of each of its fields.

HGFEDCBA	0001	0100	
Message indicators	Heading code H1	Heading code H0	Label
8	4	4	40

→ First bit transmitted

Fig. 2.5 Address Complete Message (ACM) format.

1- Label as in 2.2.1 above.

2- Heading code H0 is coded 0 1 0 0.

3- Heading code H1 is coded 0 0 0 1.

4- Message indicators. Table 2.4 shows the indication of each of the possible codes in the message indicator field.

Table 2.4 Indication of each of the possible codes in the message indicator field.

Bits		
B	A	**Type of address complete signal indicators**
0	0	Address complete signal
0	1	Address complete signal, charge
1	0	Address complete signal, no charge
1	1	Address complete signal, payphone

Bit	
C	**Subscriber free indicator**
0	No indication
1	Subscriber free

Bit	
D	**Incoming echo supressor indicator**
0	No incoming half echo suppressor included
1	Incoming half echo suppressor included

Bit	
E	**Call forwarding indicator**
0	Call not forwarded
1	Call forwarded

Bit	
F	**Signaling path indicator**
0	Any path
1	All signaling system No. 7

Bit	
G	Spare
H	Spare

2.2.2.5 Call Supervision Message.

A number of signals are included under the call supervision message group, some of these signals which will appear in our work are, answer signal, clear-back signal and clear forward signal along with others. It is the code in the heading code H1 field that makes one signal differ from the other. The answer signal is a signal being sent in the backward direction to indicate that the call is answered and in the same time to indicate whether the call is subject to charge, no charge or unqualified (Which is for national use only and indicate that the call is answered).

The clear-back signal is a signal being sent in the backward direction to indicate that the called party has cleared. The clear forward signal is a signal being sent in the forward direction to terminate the call or call attempt and release the circuit concerned. This signal is normally sent when the calling party clears. Fig. 2.6 shows the format of the call supervision message along with the code used for each kind of the signals available within this message.

	0110	
Heading code H1	Heading code H0	Label
4	**4**	**40**

First bit transmitted →

Fig. 2.6 Call Supervision Message format.

1- Label as in 2.2.1 above.

2- Heading code H0 is coded 0 1 1 0.

3- Heading code H1 is coded as in Table 2.5.

Table 2.5 Possible codes for H1.

H1				
0	0	0	0	Answer signal, unqualified
0	0	0	1	Answer signal, charge
0	0	1	0	Answer signal, no charge
0	0	1	1	Clear back signal
0	1	0	0	Clear forward signal
0	1	0	1	Re-answer signal
0	1	1	0	Forward transfer signal
0	1	1	1	Calling party clear signal
1	0	0	0	Spare
to				
1	1	1	1	

2.2.2.6 Circuit Supervision Message.

A number of signals are included under the circuit supervision message, those signals are to release, reset, block, unblock, block acknowledge, unblock acknowledge or continuity check request the circuit depending on a certain conditions.

Fig. 2.7 shows the format of this message along with the code for each of the signals mentioned above.

	0111	
Heading code H1	Heading code H0	Label
4	**4**	**40**

First bit transmitted →

Fig. 2.7 Circuit Supervision Message format.

1- Label as in 2.2.1 above.

2- Heading code H0 is coded 0 1 1 1.

3- Heading code H1 is coded as in Table 2.6.

Table 2.6 Possible codes for H1.

H1				
0	0	0	0	Spare
0	0	0	1	Release guard signal
0	0	1	0	Blocking signal
0	0	1	1	Blocking acknowledgment signal
0	1	0	0	Unblocking signal
0	1	0	1	Unblocking acknowledgment signal
0	1	1	0	Continuity check request signal
0	1	1	1	Reset circuit signal
1	0	0	0	
to				Spare
1	1	1	1	

CHAPTER THREE

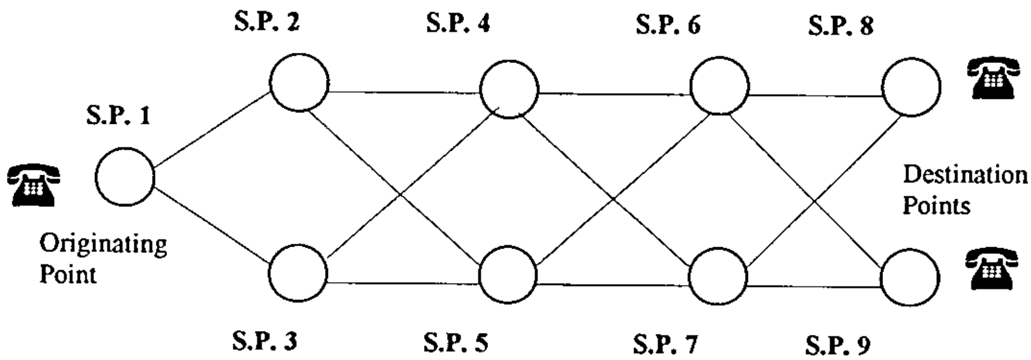
SOFTWARE AND SIMULATION

3.1 Introduction

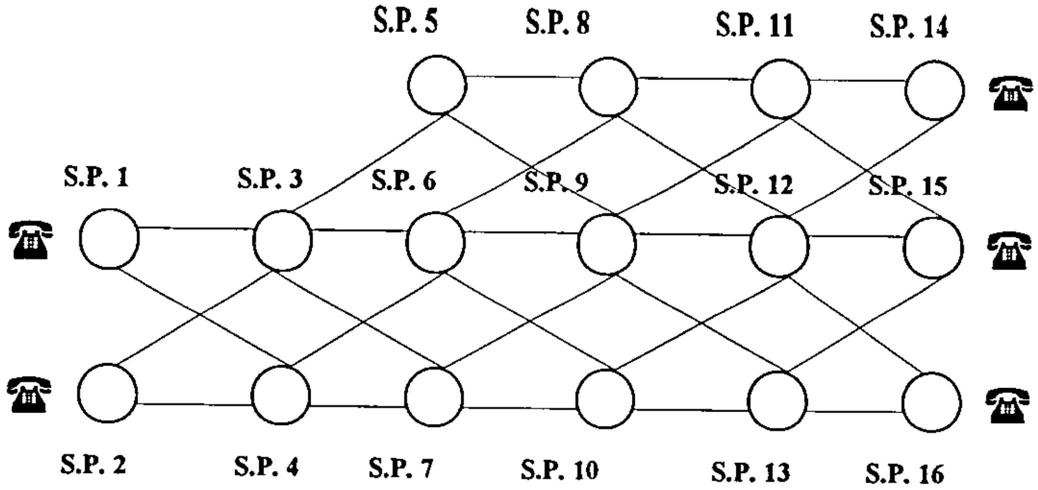
In this chapter the main parts of the signaling system are programmed using simulation in order to study the effect of the Probability of Error (P_e), the Link Loading Effect Factor (LLEF), and the Initial Threshold Value (V_{thi}) on the system efficiency. There will be certain assumptions along with the simulation as is the case in any simulation in order to limit the factors to be studied, and therefore, focus on those factors that might have dominating effect.

3.2 The software simulation

Two different models were developed to be used in the software simulation. Fig. 3.1 shows the used network structures for both of these models. Fig. 3(a) shows the first model while Fig. 3(b) shows the second.



(a) The first model



(b)

S.P.:Signaling Point

(b) The second model

Fig 3.1 Network structure. (a) The first model (b) The second model.

3.2.1 The first model.

3.2.1.1 Description of the first model.

The first model consists of 9 signaling points. Signaling point "1" is considered as the point where the signaling messages originate. Signaling points "8" and "9" are considered as the points where the signaling messages will arrive. The links that connect the signaling points are assumed to be full-duplex, that is, data and signaling information are conveyed on both directions at the same time.

The path that connects the originating and destination points depends on the number dialed at the originating point. Table 3.1 shows the part of the dialed number associated with each signaling point. For example, if the dialed number is 1122447788 then the path connecting the originating and destination points will be starting from signaling point "1", passing through signaling points "2", "4", "7", and ending at signaling point "8".

Table 3.1 Dialed number allocation for each signaling point.

Signaling point	Associated number
1	11
2	22
3	33
4	44
5	55
6	66
7	77
8	88
9	99

3.2.1.2 First model assumptions.

In order to study the efficiency, the following assumptions are made:

1- Each signaling point has a certain probability density function (pdf) which is used to decide on a given signaling point base whether the signal unit arriving at that point would be directly forwarded or delayed by a certain time factor. The assumed pdf is a Uniform density function. The base upon which the decision whether directly forward or delay the arriving signal unit is a threshold value. If the randomly generated uniform number, generated at that signaling point each time a signal unit arrives at it is larger than the threshold value then the signal unit would be directly forwarded otherwise it will be delayed by a certain time factor.

2- Each signaling point is given a factor, called the link loading effect factor. This factor is used to illustrate the effect a single link (connecting the originating and destination signaling points) has among the other links.

This factor is represented by the amount of shifting of the threshold value to the right, and therefore, decreasing the probability of direct forwarding the arriving signal unit.

3- We can basically time divide the steps for establishing a connection between the originating point and the dialed destination point into three steps. The first step includes sending the necessary signals for establishing a link, the second includes the transfer of data, and the third includes sending the necessary signals for disconnecting the link.

The first and third steps are assumed to be error-free steps, that is, the signal units are not submitted to any kind of error while being transferred between the originating and destination points.

The second step includes the transfer of two types of signal units, message signal units and fill-in signal units. The first type, the message signal unit, is assumed to be transmitted with a probability of error set at the beginning of running the program. Upon receiving the message signal unit, a check is carried out to see if any transmission errors have occurred. If there is any, a negative acknowledgment is sent back to the originating point so that the signal unit is retransmitted. A positive acknowledgment is sent if the check reveales that there are no transmission errors.

4- Since there are two types of signal units being transferred during the second step, and since each of these signals has a meaning different from the other, then we can be talking about the probability of the transmitted signal unit being a message signal unit or a fill-in signal unit. It is assumed that in going from the originating point towards the destination point the probability of sending a message signal unit is 50% while the probability of sending a fill-in signal unit is 50% . In the opposite direction, that is, in going from the destination point towards the originating point, the probability of sending a message signal unit is 50% while 50% is kept for sending a fill-in signal unit.

The base upon which the above probability assumptions are made is that the two persons having a conversation over a telephone line can not keep talking without listening to each other, that is, they should be having some moments of silence during their talk and the durations of these moments differ from one to another.

5- In order to make the simulation close to reality, each user at the originating point side of the network has to face a probability of about 18% in finding the line busy and therefore has to delay his/her call by a certain time duration.

6- The operator language is assumed to be English. According to this the code for the calling party category in the Initial Address Message (IAM) is 0 0 0 0 1 0.

7- The dialed number is assumed to be international with no satellite circuit in the connection. In addition an all digital signaling system No. 7 path is required. This makes the code for the message indicator in the IAM equal to 1 1 1 1 1 0 0 0 1 1 0.

8-The Subsequent Address Message is assumed to carry two additional dialed numbers.

3.2.2 The second model.

3.2.2.1 Description of the second model.

As is shown in Fig. 3.1b, the second model consists of 16 signaling point. Signaling points "1" and "2" are considered as the points where the signal units originate from. Any of the Signaling points "8" to "16" can be considered as the destination point. This depends on the dialed number. The same assumptions that were made to the first model are applied to the second. Table 3.2 shows the part of the dialed number associated with each signaling point for the second model.

Table 3.2 Part of the dialed number associated with each signaling point for the second model.

Signaling point	associated number	Signaling point	associated number
1	11	9	42
2	12	10	43
3	21	11	51
4	22	12	52
5	31	13	53
6	32	14	61
7	33	15	62
8	41	16	63

3.2.3 Call-setup procedure

Fig. 3.2 shows the call-setup procedure along with the time sequence for the transfer of the Signal Units.

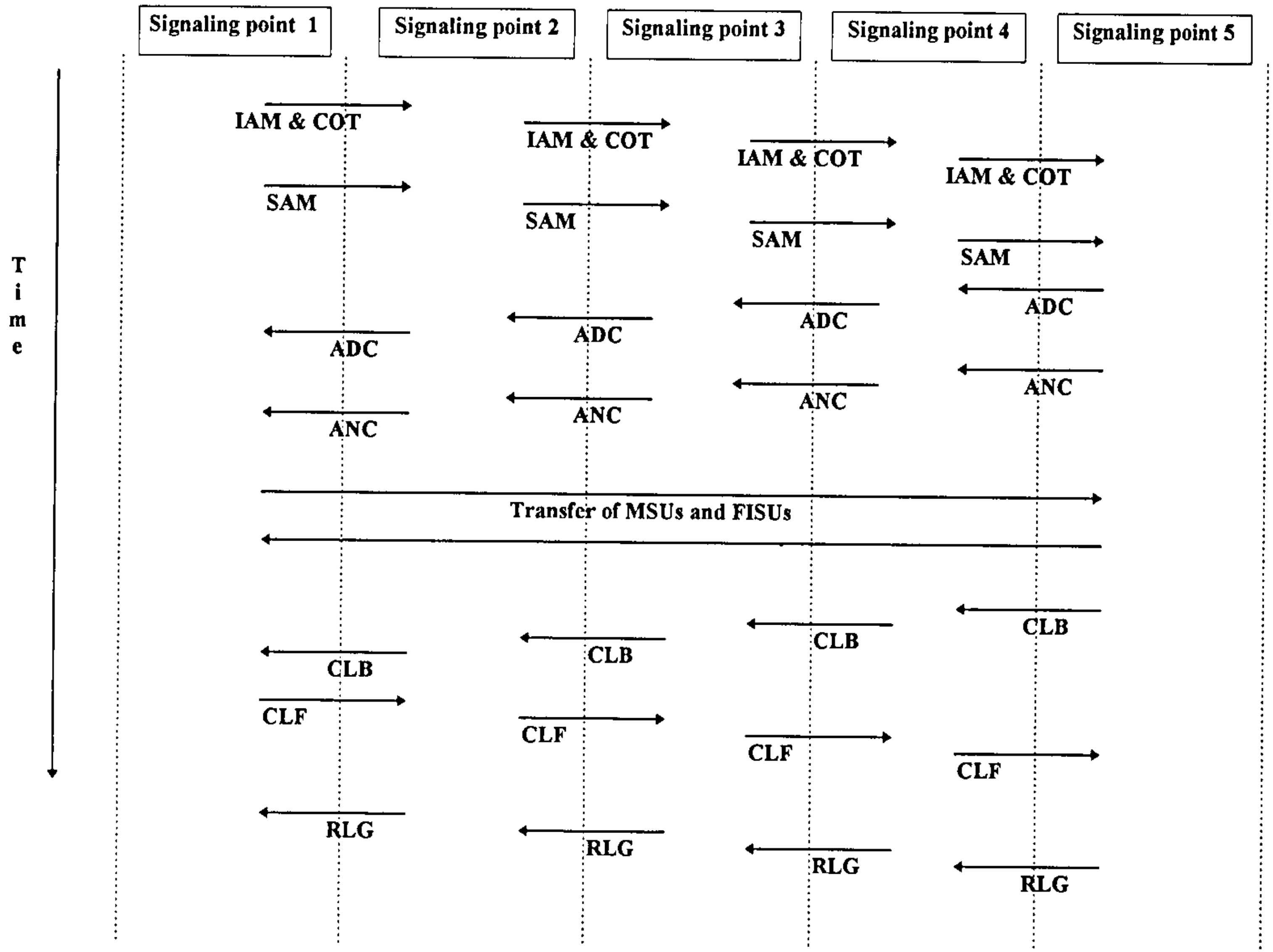
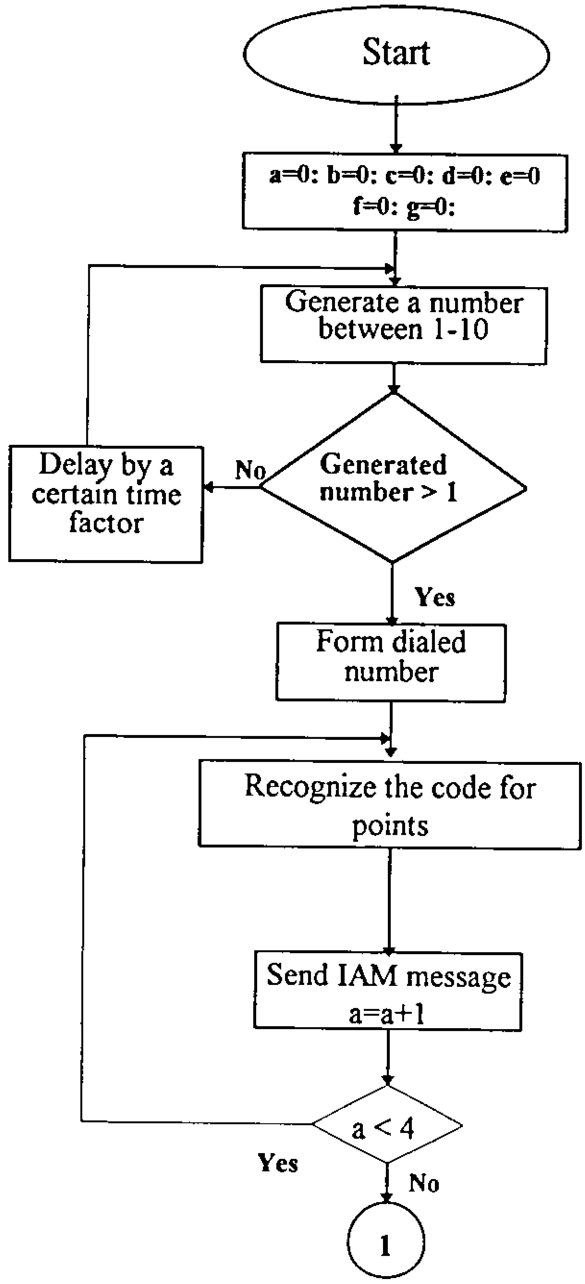
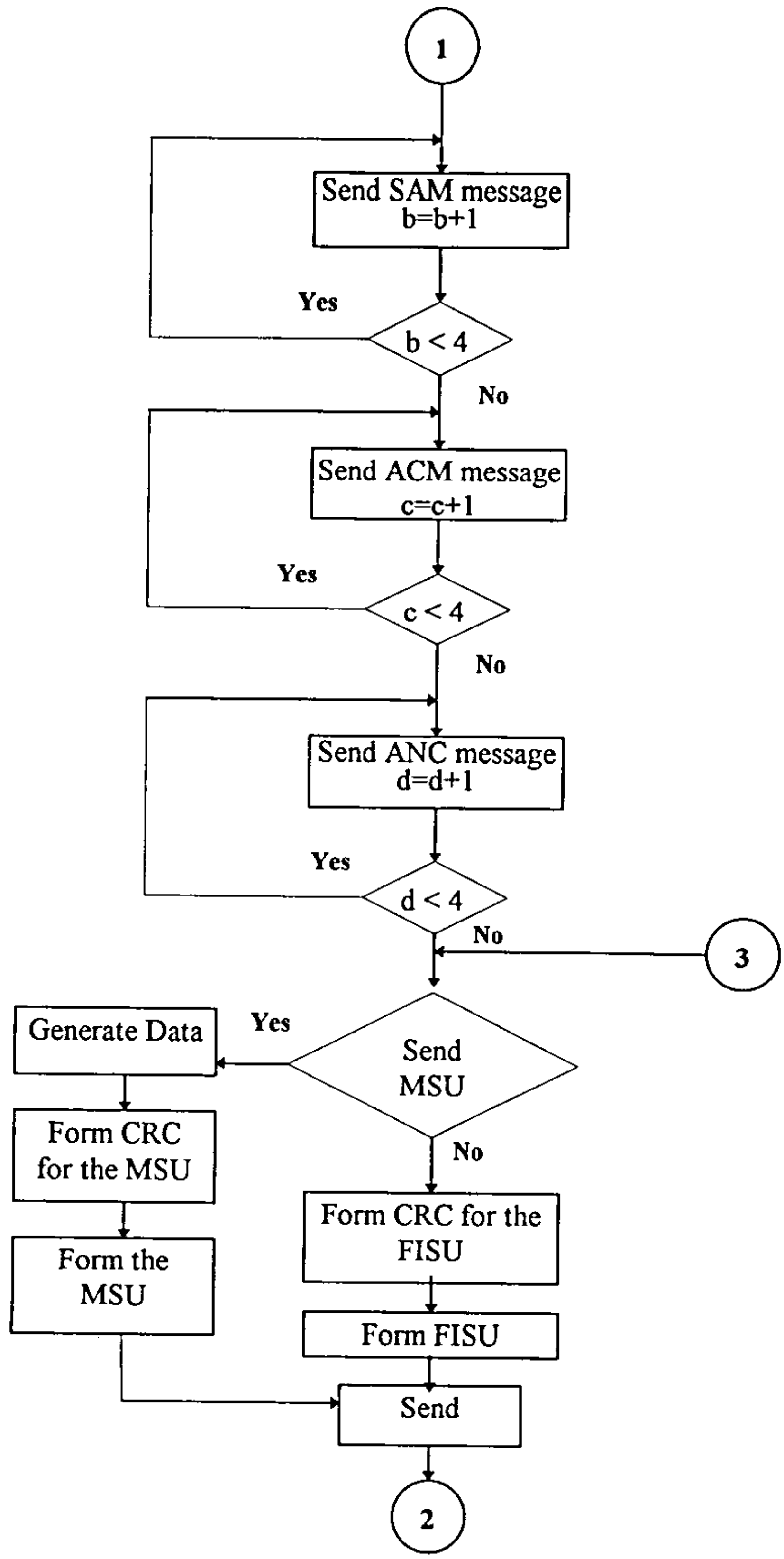


Fig. 3.2 Timing diagram for Signal Unit flow

3.2.4 Flowchart of the simulation program.

Fig. 3.3 shows the flowchart for the steps followed by the program simulation. The steps shown are for one single link but apply for all.




1
Send SAM message
b=b+1
Yes
b < 4
No
Send ACM message
c=c+1
Yes
c < 4
No
Send ANC message
d=d+1
Yes
d < 4
No
3
Generate Data
Yes
Send
MSU
Form CRC
for the MSU
No
Form CRC for the
FISU
Form the
MSU
Form FISU
Send
2

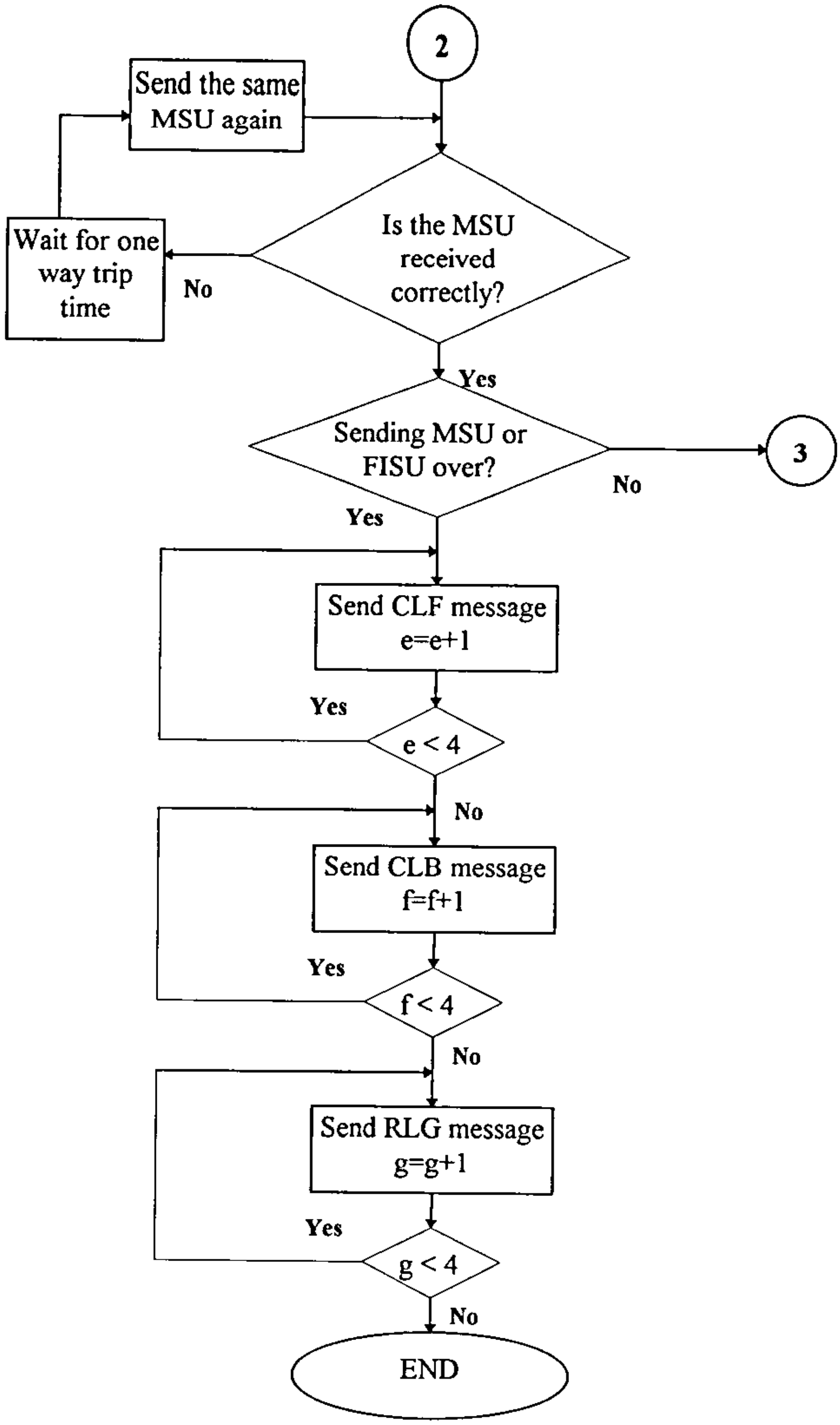


Fig. 3.3 Flowchart for a single link

3.2.5 Number of bits transmitted.

Establishing a link between the originating and destination points is time divided into three steps; step 1 and step 3 carries the necessary signaling information for establishing the link and then disconnecting it. Step 2, on the other hand, includes the transmission of MSUs and FISUs.

Table 3.3 below shows the number of bits for each of the telephone signaling message being transferred during the first and third steps. It also shows the number of transmissions for each of these signals and the total number of bits being transmitted.

Table 3.3 Number of bits transmitted.

Telephone signaling message	No. of bits	No. of transmissions	Overall No. of bits
Initial Address Message (IAM)	112	4	448
Continuity Signal (COT)	48	4	192
Subsequent Address Message (SAM)	72	4	288
Address Complete Signal (ADC)	56	4	224
Answer Signal (ANC)	48	4	192
Clear Forward Signal (CLF)	48	4	192
Clear Back Signal (CBK)	48	4	192
Release Guard Signal (RLG)	48	4	192
		Total	1920

3.3 Mathematical representation

In this section, a mathematical description is presented in order to help describe the efficiency of the system, η.

Let us first consider the LLEF that was previously introduced in our work to give an indication of the effect a single link has among the others. The LLEF is represented by the amount of shifting the threshold value to the right. The equation that gives the value of η as a function of LLEF is given by:

$$f_1(x_1) = 0.97677 * \left(a_1 + b_1 x_1^{c_1}\right) \qquad (3.1)$$

where x_1 is the given LLEF value; and

a_1= 0.9911: b_1= -0.9911: c_1= 1.7586

Fig. 3.5 shows η as a function of LLEF.

The second factor to be considered is the probability of error. Eq.3.2 gives the value of η as a function of the probability of error, P_e.

$$f_2(x_2) = 0.97677 * \left(a_2 + b_2 \exp\left(\frac{-x_2}{c_2}\right)\right) \qquad (3.2)$$

where x_2 is the given P_e value; and

a_2= -3.62: b_2= 4.61637: c_2= 4.1129

Fig. 3.6 shows η as a function of P_e.

The third factor is the initial threshold value (V_{thi}). Eq. 3.3 gives the value of η as a function of V_{thi}.

$$f_3(x_3) = 0.97677 * \left(a_3 + b_3 x_3^{c_3}\right) \tag{3.3}$$

where x_3 is the given V_{thi} value; and

a_3= 0.975: b_3= -0.975: c_3= 4.2763

Fig. 3.7 shows η as a function of V_{thi}.

Since f_1, f_2, and f_3 can be considered as being independent then η_{system} can be written as:

$$\eta_{system} = \alpha \cdot f_1 \cdot f_2 \cdot f_3 \tag{3.4}$$

$$\eta_{system} = \alpha \cdot \left(a_1 + b_1 x_1^{c_1}\right) \cdot \left(a_2 + b_2 \exp\left(\frac{-x_2}{c_2}\right)\right) \cdot \left(a_3 + b_3 x_3^{c_3}\right)$$

where α=1.01351

Fig. 3.7 shows η_{system} as a function of LLEF, P_e with V_{thi}=0.2.

Fig. 3.8 shows η_{system} as a function of LLEF, V_{thi} with P_e=0.01.

Fig. 3.9 shows η_{system} as a function of P_e, V_{thi} with LLEF=0.06.

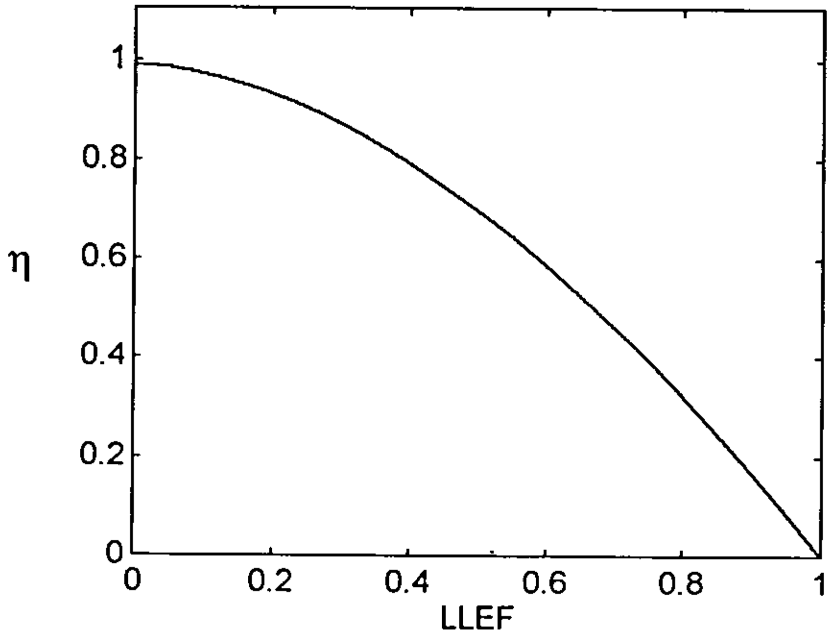


Fig. 3.4 η as a function of LLEF.

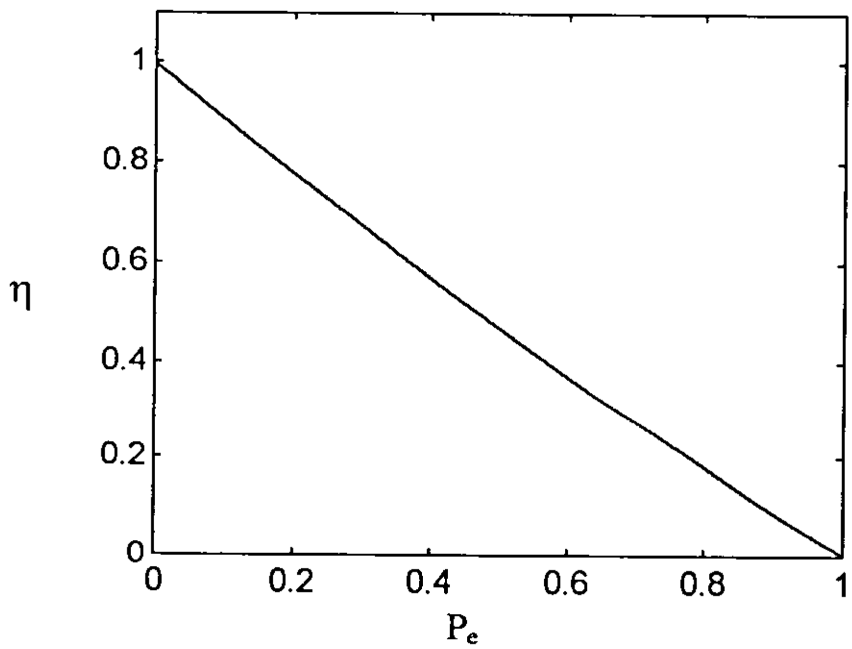


Fig. 3.5 η as a function of P_e.

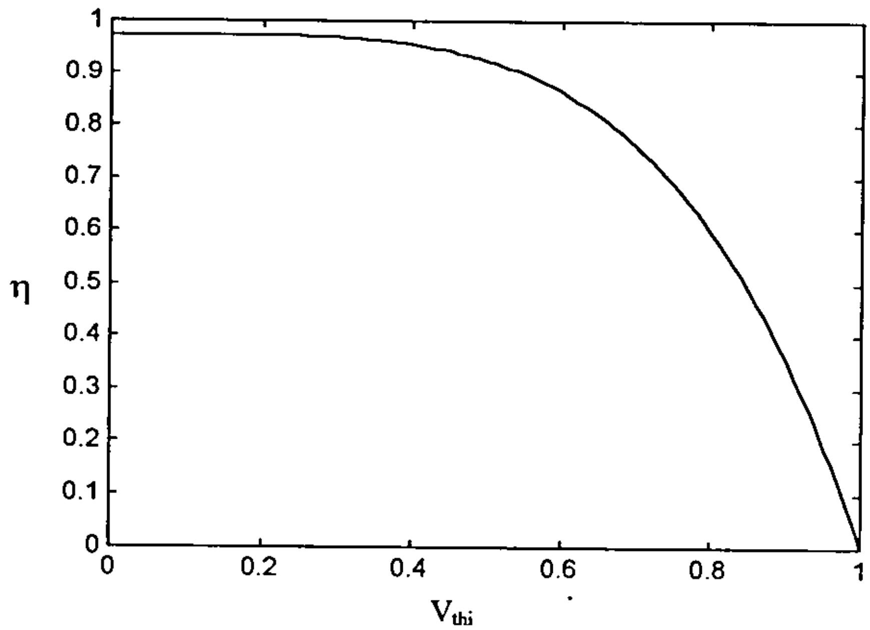


Fig. 3.6 η as a function of V_{thi}.

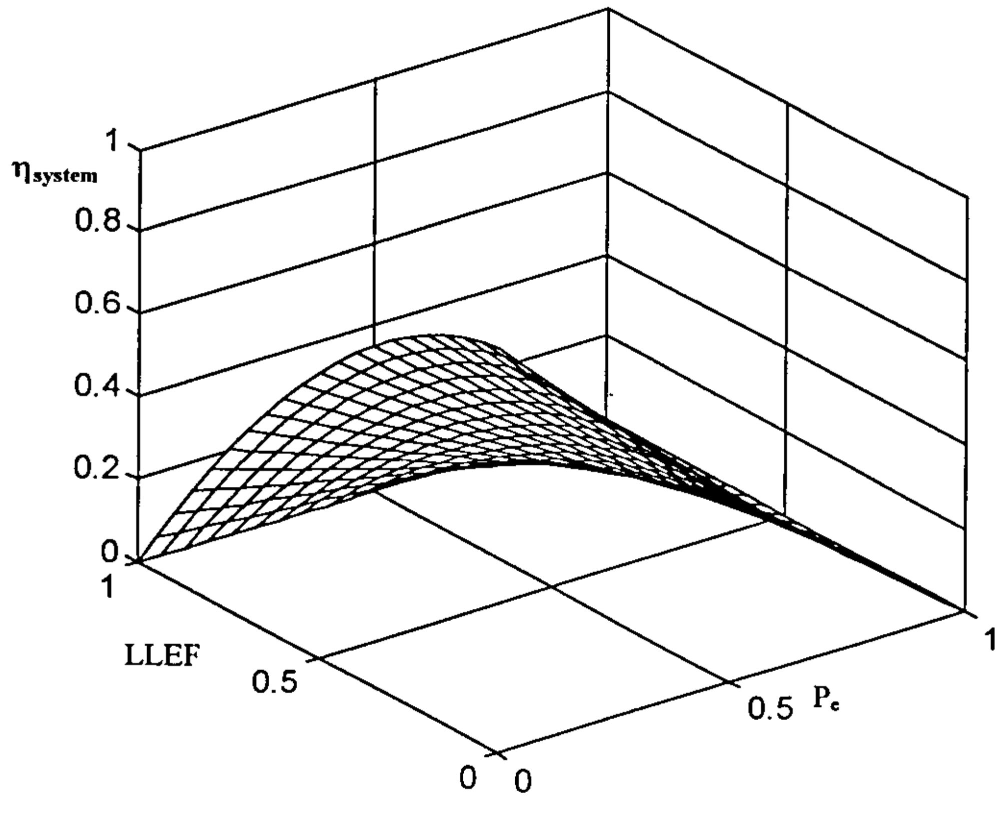


Fig. 3.7 η_{system} as a function of P_e, LLEF with V_{thi}=0.2.

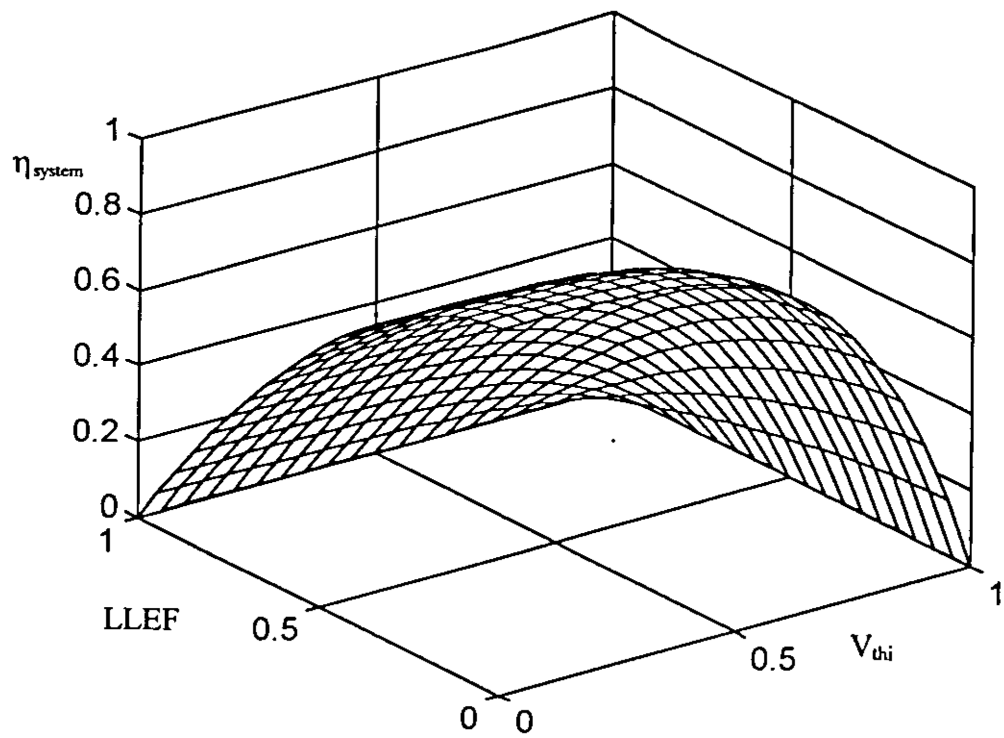


Fig. 3.8 η_{system} as a function of LLEF, V_{thi} with P_e=0.01.

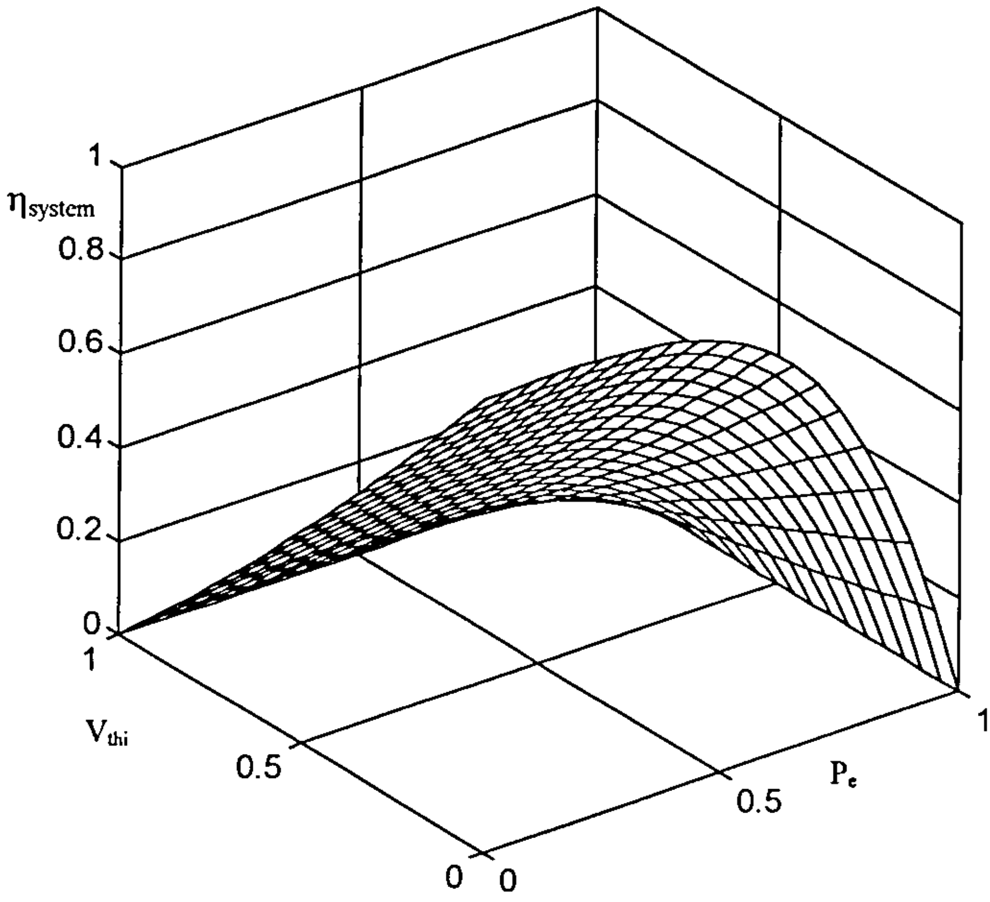


Fig. 3.9 η_{system} as a function of P_e, V_{thi} with LLEF=0.06.

3.4 Simualtion results.

The effect of three factors is studied in the simulation. These factors are:

1- Probability of error (P_e).

2- Link Loading Effect Factor (LLEF).

3- The Initial Threshold Value (V_{thi}).

As was mentioned earlier, the LLEF is modeled by the amount of shift in the threshold value to the right. Table 3.4 shows the value of η_{system} for different values of P_e and for values for LLEF and V_{thi} of (0.01, 0.1), (0.02, 0.2), and (0.06, 0.05).

Table 3.4 Value of η_{system} for different values of P_e and for values for LLEF and V_{thi} of (0.01, 0.1), (0.04, 0.2), and (0.06, 0.05).

LLEF=0.01 V_{thi}=0.1		LLEF=0.04 V_{thi}=0.2		LLEF=0.06 V_{thi}=0.05	
P_e	η_{system}	P_e	η_{system}	P_e	η_{system}
0	0.9755	0	0.9714	0	0.9689
0.2	0.7610	0.2	0.7578	0.2	0.7558
0.4	0.5566	0.4	0.5543	0.4	0.5529
0.6	0.3620	0.6	0.3605	0.6	0.3595
0.8	0.1766	0.8	0.1759	0.8	0.1754
1	0	1	0	1	0

Table 3.5 shows the value of η_{system} for different values of LLEF and for values for P_e and V_{thi} of (0.15, 0.2), (0.01, 0.05), and (0.05, 0.45).

Table 3.5 Value of η_{system} for different values of LLEF and for values for P_e and V_{thi} of (0.15, 0.2), (0.01, 0.05), and (0.05, 0.45).

P_e=0.15 V_{thi}=0.2		P_e=0.01 V_{thi}=0.05		P_e=0.05 V_{thi}=0.45	
LLEF	η_{system}	LLEF	η_{system}	LLEF	η_{system}
0	0.8835	0	0.9648	0	0.9681
0.2	0.8314	0.2	0.9079	0.2	0.9110
0.4	0.7072	0.4	0.7723	0.4	0.7749
0.6	0.5237	0.6	0.5719	0.6	0.5739
0.8	0.2868	0.8	0.3132	0.8	0.3142
1	0	1	0	1	0

Table 3.6 shows the value of η_{system} for different values of V_{thi} and for values for P_e and LLEF of (0.25, 0.16), (0.09, 0.12), and (0.01, 0.06).

Table 3.6 Value of η_{system} for different values of V_{thi} and for values for P_e and LLEF of (0.25, 0.16), (0.09, 0.12), and (0.01, 0.06).

P_e=0.25 LLEF=0.16		P_e=0.09 LLEF=.12		P_e=0.01 LLEF=0.06	
V_{thi}	η_{system}	V_{thi}	η_{system}	V_{thi}	η_{system}
0	0.74	0	.9058	0	0.9580
0.2	0.7392	0.2	.9049	0.2	0.9570
0.4	0.7252	0.4	.8878	0.4	0.9390
0.6	0.6567	0.6	.8039	0.6	0.8502
0.8	0.4550	0.8	.5570	0.8	0.5891
1	0	1	0	1	0

CHAPTER FOUR

ANALYSIS OF RESULTS

This chapter is concerned with the discussion of the results obtained in chapter 3. Several factors that can have an effect on the system effeciency η_{system} are taken into consideration. The effect of each is studied separately from the others.

From Table 3.4 it can be concluded that the probablity of transmission error P_e has a clear influence on η_{system}, that is, the lower P_e is the higher η_{system} will be.To show this, let us consider any of the columns in Table 3.4. It is very clear that for any values for LLEF and V_{thi}, η_{system} will be decreasing with an increaase in P_e. An explanation of this is based on the way of defining η_{system} as the ratio between the usueful and actual number of bits passing through a cross section of the network during a certain time duration. The usuful number of bits is the number of bits transmitted when transmitting Initial Address Messages, Continuity Signals, Subsequent Address Messages, Address Complete Signals, Answer Signals, Clear forward Signals, Clear Back Signals, Release Guard, Message Signal Units, Fill-In Signal Units ,and those included in the positive acknowledgments. The actual number of bits includes all of the above in addition to the bits inculded in the negative acknowledgments and the retransmissions of MSUs.

An increase in the probability of error leads to an increase in the number of retransmissions. Since the defintion of η_{system} takes into consideration the transmission of useful MSUs or FISUs and not their retransmissions, then increasing the number of retransmissions only means spending some extra time in transferring signal units that should have been delivered correctly from the first time. Therefore, η_{system} decreases with increasing P_e.

From Table 3.5 it can be concluded that the effect of the LLEF is very obvious. For example, let us consider any of the columns in Table3.5. It is very clear that for any values for P_e and V_{thi}, η_{system} will be decreasing with an increaase in the value of LLEF.

An explanation of this can be made from the fact that the LLEF gives an indication of the effect that a single link has among the other links. A value of 0.1 for the LLEF indicates that the link contributes by 10% of the load being put on the signaling point. This would lead to a decrease in the probability of direct forwarding a MSU or a FISU carried on one of the links passing through that signaling point. In other words, a delay is taking place at that signaling point which means that the number of MSUs or FISUs being transferred during a certain time duration is decreased. This decrease, and from the way of defining η_{system} mentioned above, leads to a decrease in the value of η_{system}.

From Table 3.6 it can be concluded that the effect of the threshold value at each signaling point is very clear. For example, let us consider any of the columns in Table3.6. It is very clear that for any values for P_e and LLEF, η_{system} will be decreasing with an increaase in the value of V_{thi},.

One way of understanding the physical or practical effect of the threshold value is by considering it as a method of describing the capability of a certain signaling point *to handle* the signal units arriving at it. That is, a threshold value of 0.01 means that the signaling point under consideration is capable of handling more links than it would if it has a threshold value of 0.1.

The term *"handle"* refers to the probability of direct forwarding the MSUs or FISUs arriving at the signaling point being above a certain value.

CHAPTER FIVE

CONCULSIONS

Signaling System No. 7 is a specification developed by the International Telegraph and Telephone Consultative Committee. A comprehensive study of the system is made. Next, a mathematical description for the system efficiency is presented. The effect of the probability of error, P_e, the Initial Threshold Value (V_{thi}) , and the Link Loading Effect Factor (LLEF) is studied. The results are compared and the following conclusions can be made:

1- The LLEF has a clear effect on the system efficiency; the larger its value is, the lower the efficiency will be. The value of this factor can help us in finding the amount of degradation in the network efficiency we are ready to accept. That is, if we have a signaling point capable of handling 100 links, then the choice of a suitable routing algorithm to minimize the actual number of links passing through this point, and therefore, making the value of the LLEF as small as possible, will lead to an increase in system efficiency.

2- The probability of error, P_e, is a factor that has a great influence on the system efficiency, that is, the higher the value of this factor is, the higher the number of retransmitted signal units, and the lower the efficiency will be.

3- The effect of the Initial Threshold Value (V_{thi}) is very clear. The lower this value is, the more the signaling point will be able to handle the signal units arriving at it, and the higher the system efficiency will be.

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APPENDIX A

The program shown is only for one single link, the programs for the other links are similar to this.

```
% Main Program %
clear all;

% Setting the simulation  values
dely=[-3 -3 -3 -3 -3 -3 -3 -3 -3]; % setting the threshold values
menchg(1)=0.1;                     % setting the LLEF value
prber(1)=95;                       % setting the Pe value

% Setting the number of bits transmitted on each link call
bitsth(1)=15000;bitsth(2)=16000;bitsth(3)=17000;bitsth(4)=16500;
bitsth(5)=12000;bitsth(6)=11300;bitsth(7)=15800;bitsth(8)=14500;
bitsth(9)=19300;bitsth(10)=10450;

% Setting the No. of Hups
nohps=[4 4 4 4 4 4 4 4 4 4];

% Defining necessary matrices
iammat(9,9)=zeros;cotmat(9,9)=zeros;sammat(9,9)=zeros;
acmmat(9,9)=zeros;ansmat(9,9)=zeros;cbkmat(9,9)=zeros;
clfmat(9,9)=zeros;rlgmat(9,9)=zeros;

iammats(9,9)=zeros;cotmats(9,9)=zeros;sammats(9,9)=zeros;
acmmats(9,9)=zeros;ansmats(9,9)=zeros;cbkmats(9,9)=zeros;
clfmats(9,9)=zeros;rlgmats(9,9)=zeros;

datab(30,512)=zeros;fillb(30,56)=zeros;datamov1(9,9)=zeros;
datamov2(9,9)=zeros;fillmov1(9,9)=zeros;fillmov2(9,9)=zeros;
posack(9,9)=zeros;negack(9,9)=zeros;posackf(9,9)=zeros;
negackf(9,9)=zeros;

% Setting the initial values
vva=[8 9 10 11];vvd=[8 9 10 11];vvg=[8 9 10 11];vvk=[8 9 10 11];
vvb=[8 9 10 11];vve=[8 9 10 11];vvh=[8 9 10 11];
vvc=[8 9 10 11];vvf=[8 9 10 11];vvi=[8 9 10 11];
pr=[2 2 3 3];cr=[4 5 4 5];
bitcount(1)=0;
poss=[0 0 0 0 0 0 0 0 0 0];
negs=[0 0 0 0 0 0 0 0 0 0];
sumbits=[0 0 0 0 0 0 0 0 0 0 ];
kkk=[0 0];
mk(9)=zeros;mj(9)=zeros;
flg=[0 1 1 1 1 1 1 0];
li=[1 0 0 1 1 1];
spr=[0 0];
sio=[0 0 1 0 0 0 0 0];
li1=[0 0 0 0 0 0];
```

```
sa(1)=1;sb(1)=1;sc(1)=1;sd(1)=1;se(1)=1;sf(1)=1;sg(1)=1;sh(1)=1;
si(1)=1;sk(1)=1;

chana=[1 0 0];chanb=[1 0 0];chanc=[1 0 0];chand=[1 0 0];
chane=[1 0 0];chanf=[1 0 0];chang=[1 0 0];chanh=[1 0 0];
chani=[1 0 0];chank=[1 0 0];

wa(1)=1;wb(1)=1;wc(1)=1;wd(1)=1;we(1)=1;wf(1)=1;wg(1)=1;
wh(1)=1;wi(1)=1;wk(1)=1;

za(1)=1;zb(1)=1;zc(1)=1;zd(1)=1;ze(1)=1;zf(1)=1;zg(1)=1;
zh(1)=1;zi(1)=1;zk(1)=1;

ackta=[0 0 0 0];acktb=[0 0 0 0];acktc=[0 0 0 0];acktd=[0 0 0 0];
ackte=[0 0 0 0];acktf=[0 0 0 0];acktg=[0 0 0 0];ackth=[0 0 0 0];
ackti=[0 0 0 0];acktk=[0 0 0 0];

na=[1 1 1 1];nb=[1 1 1 1];nc=[1 1 1 1];nd=[1 1 1 1];ne=[1 1 1 1];
nf=[1 1 1 1];ng=[1 1 1 1];nh=[1 1 1 1];ni=[1 1 1 1];nk=[1 1 1 1];

pa=[1 1 1 1];pb=[1 1 1 1];pc=[1 1 1 1];pd=[1 1 1 1];pe=[1 1 1 1];
pf=[1 1 1 1];pg=[1 1 1 1];ph=[1 1 1 1];pi=[1 1 1 1];pk=[1 1 1 1];

repa=[0 0];repd=[0 0];repg=[0 0];repk=[0 0];
repb=[0 0];repe=[0 0];reph=[0 0];
repc=[0 0];repf=[0 0];repi=[0 0];

fib(1)=1;bib(1)=1;
bbb(1)=0;lll(1)=0;

ua=[1 1 1 1 1 1 1 1 1];uf=[1 1 1 1 1 1 1 1 1];
ub=[1 1 1 1 1 1 1 1 1];ug=[1 1 1 1 1 1 1 1 1];
uc=[1 1 1 1 1 1 1 1 1];uh=[1 1 1 1 1 1 1 1 1];
ud=[1 1 1 1 1 1 1 1 1];ui=[1 1 1 1 1 1 1 1 1];
ue=[1 1 1 1 1 1 1 1 1];uk=[1 1 1 1 1 1 1 1 1];

couna=[0 0 9 9 9 0 9 9 9];counb=[0 0 9 9 9 0 9 9 9];counc=[0 0 9 9 9 0 9 9 9];
cound=[0 0 9 9 9 0 9 9 9];coune=[0 0 9 9 9 0 9 9 9];counf=[0 0 9 9 9 0 9 9 9];
coung=[0 0 9 9 9 0 9 9 9];counh=[0 0 9 9 9 0 9 9 9];couni=[0 0 9 9 9 0 9 9 9];
counk=[0 0 9 9 9 0 9 9 9];

a1=[0 0 0 0 0 0 0 0 0];f1=[0 0 0 0 0 0 0 0 0];
b1=[0 0 0 0 0 0 0 0 0];g1=[0 0 0 0 0 0 0 0 0];
c1=[0 0 0 0 0 0 0 0 0];h1=[0 0 0 0 0 0 0 0 0];
d1=[0 0 0 0 0 0 0 0 0];i1=[0 0 0 0 0 0 0 0 0];
e1=[0 0 0 0 0 0 0 0 0];k1=[0 0 0 0 0 0 0 0 0];
```

```
a1(1)=1;b1(1)=1;c1(1)=1;d1(1)=1;e1(1)=1;f1(1)=1;g1(1)=1;h1(1)=1;
i1(1)=1;k1(1)=1;

ra=[1 0 0];rb=[1 0 0];rc=[1 0 0];rd=[1 0 0];re=[1 0 0];rf=[1 0 0];
rg=[1 0 0];rh=[1 0 0];ri=[1 0 0];rk=[1 0 0];

% Creating the Reference matrix
rfc(1,1)=1;rfc(1,2)=0;rfc(1,3)=0;rfc(1,4)=0;
rfc(2,1)=0;rfc(2,2)=1;rfc(2,3)=0;rfc(2,4)=0;
rfc(3,1)=1;rfc(3,2)=1;rfc(3,3)=0;rfc(3,4)=0;
rfc(4,1)=0;rfc(4,2)=0;rfc(4,3)=1;rfc(4,4)=0;
rfc(5,1)=1;rfc(5,2)=0;rfc(5,3)=1;rfc(5,4)=0;
rfc(6,1)=0;rfc(6,2)=1;rfc(6,3)=1;rfc(6,4)=0;
rfc(7,1)=1;rfc(7,2)=1;rfc(7,3)=1;rfc(7,4)=0;
rfc(8,1)=0;rfc(8,2)=0;rfc(8,3)=0;rfc(8,4)=1;

%Creating the Recognition Matrix
rfc1(1,1)=1;rfc1(1,2)=0;rfc1(1,3)=0;rfc1(1,4)=0;
rfc1(2,1)=0;rfc1(2,2)=1;rfc1(2,3)=0;rfc1(2,4)=0;
rfc1(3,1)=1;rfc1(3,2)=1;rfc1(3,3)=0;rfc1(3,4)=0;
rfc1(4,1)=0;rfc1(4,2)=0;rfc1(4,3)=1;rfc1(4,4)=0;
rfc1(5,1)=1;rfc1(5,2)=0;rfc1(5,3)=1;rfc1(5,4)=0;
rfc1(6,1)=0;rfc1(6,2)=1;rfc1(6,3)=1;rfc1(6,4)=0;
rfc1(7,1)=1;rfc1(7,2)=1;rfc1(7,3)=1;rfc1(7,4)=0;
rfc1(8,1)=0;rfc1(8,2)=0;rfc1(8,3)=0;rfc1(8,4)=1;
rfc1(9,1)=1;rfc1(9,2)=0;rfc1(9,3)=0;rfc1(9,4)=1;


% Node Identification Matrix

nodeidf(9,9)=zeros;
nodeidf(1,1)=1; nodeidf(2,2)=2; nodeidf(3,3)=3; nodeidf(4,4)=4;
nodeidf(5,5)=5; nodeidf(6,6)=6; nodeidf(7,7)=7; nodeidf(8,8)=8;
nodeidf(9,9)=9;


% Main program loop

while T0 > 0,

% Link A
if ra(1)==1;
ra(2)=round(rand*10);
end
```

```
if ra(2) > 2,
diala            % Sub program
ra(3)=1;
ra(1)=0;
ra(2)=0;
end

if ra(3)==1;
person4a         % Sub program
end

% Link B

if rb(1)==1;
rb(2)=round(rand*10);
end

if rb(2) > 2;
dialb            % Sub program
rb(3)=1;
rb(1)=0;
rb(2)=0;
end

if rb(3)==1;
person4b         % Sub program
end

% Link C

if rc(1)==1;
rc(2)=round(rand*10);
end

if rc(2) > 2;
dialc            % Sub program
rc(3)=1;
rc(1)=0;
rc(2)=0;
end

if rc(3)==1;
person4c         % Sub program
end
```

```
%Link D

if rd(1)==1;
rd(2)=round(rand*10);
end

if rd(2) > 2;
diald              % Sub program
rd(3)=1;
rd(1)=0;
rd(2)=0;
end

if rd(3)==1;
person4d           % Sub program
end

% Link E

if re(1)==1;
re(2)=round(rand*10);
end

if re(2) > 2;
diale              % Sub program
re(3)=1;
re(1)=0;
re(2)=0;
end

if re(3)==1;
person4e           % Sub program
end

% Link F

if rf(1)==1;
rf(2)=round(rand*10);
end

if rf(2) > 2;
dialf              % Sub program
rf(3)=1;
rf(1)=0;
rf(2)=0;
end
```

```
if rf(3)==1;
person4f        % Sub program
end

% Link G

if rg(1)==1;
rg(2)=round(rand*10);
end

if rg(2) > 2;
dialg           % Sub program
rg(3)=1;
rg(1)=0;
rg(2)=0;
end

if rg(3)==1;
person4g        % Sub program
end

% Link H

if rh(1)==1;
rh(2)=round(rand*10);
end

if rh(2) > 2;
dialh
rh(3)=1;
rh(1)=0;
rh(2)=0;
end

if rh(3)==1;
person4h
end

% Link I

if ri(1)==1;
ri(2)=round(rand*10);
end
```

```
if ri(2) > 2;
diali
ri(3)=1;
ri(1)=0;
ri(2)=0;
end

if ri(3)==1;
person4i
end

% Link K

if rk(1)==1;
rk(2)=round(rand*10);
end

if rk(2) > 2;
dialk
rk(3)=1;
rk(1)=0;
rk(2)=0;
end

if rk(3)==1;
person4k
end

% Calculation of Ψ

if bbb(1)==4;
mk(8)=zeros;mj(7)=zeros;mmm(1)=0;

for ss=1:4
% What is being transmitted
mk(1)=mk(1)+196*iammats(pr(ss),cr(ss));
mk(2)=mk(2)+128*sammats(pr(ss),cr(ss));
mk(3)=mk(3)+112*acmmats(pr(ss),cr(ss));
mk(4)=mk(4)+104*ansmats(pr(ss),cr(ss));
mk(5)=mk(5)+512*(datamov1(pr(ss),cr(ss))+datamov2(pr(ss),cr(ss)))+56*(negack(pr(ss
),cr(ss))+posack(pr(ss),cr(ss))+fillmov1(pr(ss),cr(ss))+fillmov2(pr(ss),cr(ss))+negackf(pr
(ss),cr(ss))+posackf(pr(ss),cr(ss)));
mk(6)=mk(6)+104*cbkmats(pr(ss),cr(ss));
mk(7)=mk(7)+104*clfmats(pr(ss),cr(ss));
mk(8)=mk(8)+104*rlgmats(pr(ss),cr(ss));
```

```
%    What should be transmitted
 mj(1)=mj(1)+196*iammat(pr(ss),cr(ss));
 mj(2)=mj(2)+128*sammat(pr(ss),cr(ss));
 mj(3)=mj(3)+112*acmmat(pr(ss),cr(ss));
 mj(4)=mj(4)+104*ansmat(pr(ss),cr(ss));
 mj(5)=mj(5)+104*cbkmat(pr(ss),cr(ss));
 mj(6)=mj(6)+104*clfmat(pr(ss),cr(ss));
 mj(7)=mj(7)+104*rlgmat(pr(ss),cr(ss));
 end

    res(1)=0;rqs(1)=0;
    for rr=1:8
    res(1)=res(1)+mk(rr);
    end

    for rr=1:7
    rqs(1)=rqs(1)+mj(rr);
    end


  for ss=1:4
  mmm(1)=mmm(1)+568*posack(pr(ss),cr(ss))+112*posackf(pr(ss),cr(ss));
  end

  uuu(1)=(rqs(1)+mmm(1))/res(1);
  disp('normalized throughput')
  uuu(1)

 % Setting the values back to the intial values
  bbb(1)=0;
  mk(8)=zeros;mj(7)=zeros;mmm(1)=0;bitcount(1)=0;
  iammat(9,9)=zeros; cotmat(9,9)=zeros;  sammat(9,9)=zeros;
  acmmat(9,9)=zeros;  ansmat(9,9)=zeros;  cbkmat(9,9)=zeros;
  clfmat(9,9)=zeros;  rlgmat(9,9)=zeros;  posack(9,9)=zeros;
  negack(9,9)=zeros;

  iammats(9,9)=zeros;  cotmats(9,9)=zeros;  sammats(9,9)=zeros;
  acmmats(9,9)=zeros;  ansmats(9,9)=zeros;  cbkmats(9,9)=zeros;
  clfmats(9,9)=zeros;  rlgmats(9,9)=zeros;  posackf(9,9)=zeros;
  negackf(9,9)=zeros;
  datamov1(9,9)=zeros;  datamov2(9,9)=zeros;  fillmov1(9,9)=zeros;
  fillmov2(9,9)=zeros;
  pause
 end
 end  % while T0
```

```
% cicgen  Sub-program  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Generation of the Check bits

clear crc;
for p=1:488
  crc(17)=msu1(p);
  op(1)=crc(1);
  crc(1)=crc(2);
  crc(2)=crc(3);
  crc(3)=crc(4);
  crc(4)=xor(crc(5),op(1));
  crc(5)=crc(6);
  crc(6)=crc(7);
  crc(7)=crc(8);
  crc(8)=crc(9);
  crc(9)=crc(10);
  crc(10)=crc(11);
  crc(11)=xor(crc(12),op(1));
  crc(12)=crc(13);
  crc(13)=crc(14);
  crc(14)=crc(15);
  crc(15)=crc(16);
  crc(16)=xor(crc(17),op(1));
end

% Decideal sub-program %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Generation of MSU and FISU /forward direction

if xxa(1)==1;
    for t=1:456
      data1(t)=round(rand);
    end
  sumbits(1)=sumbits(1)+512;
  bitcount(1)=bitcount(1)+512;
  y1(1)=y1(1)+1;
  msu1=[bsn(y1(1),:) bib(1) fsn(y1(1),:) fib(1) li spr sio data1];
  cicgen % Subroutine
  useful=[flg msu1 crc(1:16)];
  datab(1,1:512)=useful(1:512);
  usefl1fa=useful;
end
```

```
if xxa(2)==1;
  y1(1)=y1(1)+1;
  msu2=[bsn(y1(1),:) bib(1) fsn(y1(1),:) fib(1) li1 spr sio];
  cicgen2 % subroutine
  fill=[flg msu2 crc2(1:16)];
  fillb(1,1:56)=fill(1:56);
  fill1fa(1:56)=fill(1:56);
  sumbits(1)=sumbits(1)+56;
  bitcount(1)=bitcount(1)+56;
end


% decida2 sub-program %%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Generation of MSU and FISU / backward direction
if yya(1)==1;
    for t=1:456
      data1(t)=round(rand);
    end
  bitcount(1)=bitcount(1)+512;
  y1(1)=y1(1)+1;
  msu1=[bsn(y1(1),:) bib(1) fsn(y1(1),:) fib(1) li spr sio data1];
  cicgen % Subroutine
  useful=[flg msu1 crc(1:16)];
  datab(2,1:512)=useful(1:512);
  usefl1ba(1:512)=useful(1:512);

end

if yya(2)==1;
  bitcount(1)=bitcount(1)+56;
  y1(1)=y1(1)+1;
  msu2=[bsn(y1(1),:) bib(1) fsn(y1(1),:) fib(1) li1 spr sio];
  cicgen2 % subroutine
  fill=[flg msu2 crc2(1:16)];
  fillb(2,1:56)=fill(1:56);
  fill1ba(1:56)=fill(1:56);

end
```

```
% decis1a  sub-program  %%%%%%%%%%%%%%%%%%%%%%%%
%
%
abdec(1)=round(rand*100);
xxa=[0 0];
 if abdec(1) > 50,
  xxa(1)=1;
  xxa(2)=0;
 else
  xxa(1)=0;
  xxa(2)=1;
 end


% decis2a sub-program  %%%%%%%%%%%%%%%%%%%%%%%%
%
%
badec(1)=round(rand*100);
yya=[0 0];
 if badec(1) > 50,
  yya(1)=1;
  yya(2)=0;
 else
  yya(1)=0;
  yya(2)=1;
 end

% diala sub-program %%%%%%%%%%%%%%%%%%%%%%%%
%
% First line dialed number formation
 Bna(1)=1;Bna(2)=1;
 qq(1)=round(rand+2);
 Bna(3)=qq(1);Bna(4)=qq(1);
 qq(2)=round(rand+4);
 Bna(5)=qq(2);Bna(6)=qq(2);
 qq(3)=round(rand+6);
 Bna(7)=qq(3);Bna(8)=qq(3);
 qq(4)=round(rand+8);
 Bna(9)=qq(4);Bna(10)=qq(4);
 Bna(11)=round(rand+2);
 Bna(12)=round(rand+6);
```

```
 sourcea(1:20)=[rfc1(Bna(1),:) rfc1(Bna(2),:) rfc1(Bna(3),:) rfc1(Bna(4),:)
rfc1(Bna(5),:)];
  sourcea(21:32)=[rfc1(Bna(6),:) rfc1(Bna(7),:) rfc1(Bna(8),:)];
  sourcea=[sourcea rfc1(Bna(9),:) rfc1(Bna(10),:)];
  sourcea=[sourcea 0 0 0 0 0 0 0 0];

  sourcea1(1:20)=[rfc1(Bna(1),:) rfc1(Bna(2),:) rfc1(Bna(3),:) rfc1(Bna(4),:)
rfc1(Bna(5),:)];
  sourcea1(21:32)=[rfc1(Bna(6),:) rfc1(Bna(7),:) rfc1(Bna(8),:)];
  sourcea1=[sourcea1 rfc1(Bna(9),:) rfc1(Bna(10),:)];
  sourcea1=[sourcea1 0 0 0 0 0 0 0 0];

  subseqa=[rfc1(Bna(11),:) rfc1(Bna(12),:)];
  sa(1)=1;

  dely(nodeidf(Bna(1),Bna(2)))=dely(nodeidf(Bna(1),Bna(2)))+menchg(1);
  dely(nodeidf(Bna(3),Bna(4)))=dely(nodeidf(Bna(3),Bna(4)))+menchg(1);
  dely(nodeidf(Bna(5),Bna(6)))=dely(nodeidf(Bna(5),Bna(6)))+menchg(1);
  dely(nodeidf(Bna(7),Bna(8)))=dely(nodeidf(Bna(7),Bna(8)))+menchg(1);
  dely(nodeidf(Bna(9),Bna(10)))=dely(nodeidf(Bna(9),Bna(10)))+menchg(1);


% Number Recognition Subroutine %%%%%%%%%%%%%%%%%%%%%%%%%%
% for  Link A
%

for y=1:9
   if snum1(1:4)==rfc1(y,1:4);
   dna(ua(1))=y;

   end
end

for y=1:9
   if snum2(1:4)==rfc1(y,1:4);
   dna(ua(1)+1)=y;

   end
end

for y=1:9
   if dnum1(1:4)==rfc1(y,1:4);
   dna(ua(1)+2)=y;

   end
end
```

```
for y=1:9
   if dnum2(1:4)==rfc1(y,1:4);
   dna(ua(1)+3)=y;

   end
end


% Link A sub-program  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% IAM & COT

if couna(1) < nohps(1);

     a1(3)=0;
     a1(1)=1;
 end

 if couna(1)==nohps(1);

     a1(1)=0;
     a1(3)=1;
     couna(3)=0;
     couna(1)=9;
 end

if couna(3) < nohps(1);

     a1(4)=0;
     a1(3)=1;
  end

 if couna(3)==nohps(1);
     a1(1)=0;
     a1(3)=0;
     a1(4)=1;
     couna(3)=9;
     couna(4)=0;
 end

 if couna(4) < nohps(1);
    a1(5)=0;
    a1(4)=1;
 end
```

```
 if couna(4)==nohps(1);

   a1(1)=0;
   a1(3)=0;
   a1(4)=0;
   a1(5)=1;
   couna(4)=9;
   couna(5)=0;
 end

if couna(5) < nohps(1);
    a1(7)=0;
    a1(5)=1;
 end

 if couna(5)==nohps(1);
   a1(1)=0;
   a1(3)=0;
   a1(4)=0;
   a1(5)=0;
   a1(6)=1;
   couna(5)=9;
   couna(7)=0;
 end

 if couna(6) < nohps(1),
   a1(7)=0;
   couna(7)=5;
 end

 if couna(6)==nohps(1);
  a1(1)=0;
  a1(3)=0;
  a1(4)=0;
  a1(5)=0;
  a1(6)=0;
  a1(7)=1;
  couna(6)=9;
  couna(7)=0;
 end

if couna(7) < nohps(1);
    a1(8)=0;
    a1(7)=1;
 end
```

```
if couna(7)==nohps(1);

    a1(1)=0;
    a1(3)=0;
    a1(4)=0;
    a1(5)=0;
    a1(7)=0;
    a1(6)=0;
    a1(8)=1;
    couna(7)=9;
    couna(8)=0;
end

if couna(8)< nohps(1);
    a1(9)=0;
    a1(8)=1;
 end
 if couna(8)==nohps(1);
    a1(1)=0;
    a1(3)=0;
    a1(4)=0;
    a1(5)=0;
    a1(7)=0;
    a1(8)=0;
    a1(9)=1;
    couna(8)=9;
    couna(9)=0;
end

if couna(9) < nohps(1);

    a1(9)=1;
end

if a1(1) > 0,

  clear snum1;
  clear snum2;
  clear dnum1;
  clear dnum2;
  clear NAS;
  clear ADS;
```

```
snum1=sourcea1(sa(1):sa(1)+3);
snum2=sourcea1(sa(1)+4:sa(1)+7);
dnum1=sourcea1(sa(1)+8:sa(1)+11);
dnum2=sourcea1(sa(1)+12:sa(1)+15);


numrcga % for link A

kkk(1)=dely(nodeidf(dna(ua(1)+2),dna(ua(1)+3)));
if rand > kkk(1),
 fff(1)=1;
else
 fff(1)=0;
end

  iamdeca(1)=nodeidf(dna(ua(1)),dna(ua(1)+1));
  iamdeca(2)=nodeidf(dna(ua(1)+2),dna(ua(1)+3));
  iammats(iamdeca(1),iamdeca(2))=iammats(iamdeca(1),iamdeca(2))+1; % IAM
  cotmats(iamdeca(1),iamdeca(2))=cotmats(iamdeca(1),iamdeca(2))+1; % COT

  if fff(1)==1;
  disp('iam1&cot1')
  sa(1)=sa(1)+8;
  iamdeca(1)=nodeidf(dna(ua(1)),dna(ua(1)+1));
  iamdeca(2)=nodeidf(dna(ua(1)+2),dna(ua(1)+3));

  ua(1)=ua(1)+2;

  iammat(iamdeca(1),iamdeca(2))=iammat(iamdeca(1),iamdeca(2))+1; % IAM
  cotmat(iamdeca(1),iamdeca(2))=cotmat(iamdeca(1),iamdeca(2))+1; % COT
  couna(1)=couna(1)+1;

 end
 fff(1)=0;

end

% SAM

if a1(3) > 0,

 kkk(1)=dely(nodeidf(dna(ua(3)+2),dna(ua(3)+3)));
 if rand > kkk(1),
  fff(1)=1;
 else
  fff(1)=0;
 end
```

```
    fff(1)=0;

  end

  % ANS

  if a1(5) > 0,

   kkk(1)=dely(nodeidf(dna(vva(1)-ua(5)),dna(vva(2)-ua(5))));
    if rand > kkk(1),
     fff(1)=1;
    else
     fff(1)=0;
    end

      ansdeca(1)=nodeidf(dna(vva(1)-ua(5)),dna(vva(2)-ua(5)));
      ansdeca(2)=nodeidf(dna(vva(3)-ua(5)),dna(vva(4)-ua(5)));
      ansmats(ansdeca(1),ansdeca(2))=ansmats(ansdeca(1),ansdeca(2))+1;

    if fff(1)==1;

      disp('ans1')
      ansdeca(1)=nodeidf(dna(vva(1)-ua(5)),dna(vva(2)-ua(5)));
      ansdeca(2)=nodeidf(dna(vva(3)-ua(5)),dna(vva(4)-ua(5)));
      ansmat(ansdeca(1),ansdeca(2))=ansmat(ansdeca(1),ansdeca(2))+1;

      couna(5)=couna(5)+1;
      ua(5)=ua(5)+2;

    end

    fff(1)=0;

  end


  if a1(6) > 0,

   if chana(1)==1;
      decis1a
      decis2a
      decidea1
      decidea2

      chana(1)=0;chana(2)=1;
     end % for chana(1)
```

```
if chana(2)==1;
  repa(1)=repa(1)+1;
   if xxa(1)==1;  % DATA
     ackta(1)=1;

     nod(1)=nodeidf(dna(wa(1)),dna(wa(1)+1));
     nod(2)=nodeidf(dna(wa(1)+2),dna(wa(1)+3));
     datamov1(nod(1),nod(2))=datamov1(nod(1),nod(2))+1;
     wa(1)=wa(1)+2;
     msg1fa(1:512)=usefl1fa(1:512);
      jka(1)=round(rand*100000);
         if jka(1) > prber(1),
           msg1fa(200)=~msg1fa(200);
           negs(1)=negs(1)+1;
                else
                poss(1)=poss(1)+1;
         end
     datapoint1(1)=1;

    disp('DFa')
   end

   if xxa(2)==1;
     ackta(2)=1;

     nod(1)=nodeidf(dna(wa(1)),dna(wa(1)+1));
     nod(2)=nodeidf(dna(wa(1)+2),dna(wa(1)+3));
     fillmov1(nod(1),nod(2))=fillmov1(nod(1),nod(2))+1;
     fillpoint1(1)=1;
     wa(1)=wa(1)+2;
     fls1fa(1:56)=fill1fa(1:56);
    disp('FFa')
   end

   if yya(1)==1;  % DATA
     ackta(3)=1;
     nod(3)=nodeidf(dna(vva(1)-za(1)),dna(vva(2)-za(1)));
     nod(4)=nodeidf(dna(vva(3)-za(1)),dna(vva(4)-za(1)));
     datamov2(nod(3),nod(4))=datamov2(nod(3),nod(4))+1;
     za(1)=za(1)+2;
     msg1ba(1:512)=usefl1ba(1:512);
      jka(2)=round(rand*100000);
         if jka(2) > prber(1),
           msg1ba(200)=~msg1ba(200);
                negs(1)=negs(1)+1;
                else
                poss(1)=poss(1)+1;
         end
```

```
      datapoint2(1)=1;
      disp('DBa')
    end

    if yya(2)==1;
      ackta(4)=1;
      nod(3)=nodeidf(dna(vva(1)-za(1)),dna(vva(2)-za(1)));
      nod(4)=nodeidf(dna(vva(3)-za(1)),dna(vva(4)-za(1)));
      fillmov2(nod(3),nod(4))=fillmov2(nod(3),nod(4))+1;
      fillpoint2(1)=1;
      za(1)=za(1)+2;
      fls1ba(1:56)=fill1ba(1:56);
      disp('FBa')
    end

      if repa(1)==nohps(1);
        chana(2)=0;
        chana(3)=1;
        repa(1)=0;
      end

end % for chana(2)

if chana(3)==1;
    repa(2)=repa(2)+1;
    ran=[0 0 0 0];
    if ackta(1)==1;
        zzz=msg1fa(9:496);
        crcc=msg1fa(497:512);
        cicgen4 % subroutine
      if crcc(1:16)==crcm(1:16);

        nop(1)=nodeidf(dna(vva(1)-pa(1)),dna(vva(2)-pa(1)));
        nop(2)=nodeidf(dna(vva(3)-pa(1)),dna(vva(4)-pa(1)));
        posack(nop(1),nop(2))=posack(nop(1),nop(2))+1;
        pa(1)=pa(1)+2;
        ran(1)=1;
        xya(1)=1;
        disp('posackDFa')
      else

        nop(1)=nodeidf(dna(vva(1)-na(1)),dna(vva(2)-na(1)));
        nop(2)=nodeidf(dna(vva(3)-na(1)),dna(vva(4)-na(1)));
        negack(nop(1),nop(2))=negack(nop(1),nop(2))+1;
        na(1)=na(1)+2;
        ran(1)=2;
        disp('negackDFa')
      end
```

```
 end % for ackta(1)

if ackta(2)==1;
     yyy=fls1fa(9:40);
     crcz(1:16)=fls1fa(41:56);
     cicgen6
  if crct(1:16)==crcz(1:16);

     nop(1)=nodeidf(dna(vva(1)-pa(2)),dna(vva(2)-pa(2)));
     nop(2)=nodeidf(dna(vva(3)-pa(2)),dna(vva(4)-pa(2)));
     posackf(nop(1),nop(2))=posackf(nop(1),nop(2))+1;
     pa(2)=pa(2)+2;
     ran(2)=1;
     xya(1)=1;

     disp('posackFFa')
   else

     nop(1)=nodeidf(dna(vva(1)-na(2)),dna(vva(2)-na(2)));
     nop(2)=nodeidf(dna(vva(3)-na(2)),dna(vva(4)-na(2)));
     negackf(nop(1),nop(2))=negackf(nop(1),nop(2))+1;
     na(2)=na(2)+2;
     ran(2)=2;

     disp('negackFFa')
   end
end  % for ackta(2)

if ackta(3)==1;
     zzz=msg1ba(9:496);
     crcc=msg1ba(497:512);
     cicgen4 % subroutine
  if crcc(1:16)==crcm(1:16);
     nop(1)=nodeidf(dna(pa(3)),dna(pa(3)+1));
     nop(2)=nodeidf(dna(pa(3)+2),dna(pa(3)+3));
     posack(nop(1),nop(2))=posack(nop(1),nop(2))+1;
     pa(3)=pa(3)+2;
     ran(3)=1;
     xya(2)=1;
     disp('posackDBa')
   else
     nop(1)=nodeidf(dna(na(3)),dna(na(3)+1));
     nop(2)=nodeidf(dna(na(3)+2),dna(na(3)+3));
     negack(nop(1),nop(2))=negack(nop(1),nop(2))+1;
     na(3)=na(3)+2;
     ran(3)=2;
     disp('negackDBa')
   end
```

```
end % for ackta(3)

 if ackta(4)==1;
     yyy=fls1ba(9:40);
     crcz(1:16)=fls1ba(41:56);
     cicgen6
   if crct(1:16)==crcz(1:16);
     nop(1)=nodeidf(dna(pa(4)),dna(pa(4)+1));
     nop(2)=nodeidf(dna(pa(4)+2),dna(pa(4)+3));
     posackf(nop(1),nop(2))=posackf(nop(1),nop(2))+1;
     pa(4)=pa(4)+2;
     ran(4)=1;
     xya(2)=1;
     disp('posackFBa')
    else
     nop(1)=nodeidf(dna(na(4)),dna(na(4)+1));
     nop(2)=nodeidf(dna(na(4)+2),dna(na(4)+3));
     negackf(nop(1),nop(2))=negackf(nop(1),nop(2))+1;
     na(4)=na(4)+2;
     ran(4)=2;
     disp('negackFBa')
    end
 end % for ackta(4)

 if repa(2)==nohps(1);
   chana(3)=0;repa(2)=0;
   ackta=[0 0 0 0];

     if ran(1)==1;
       decis1a
       decidea1
       wa(1)=1;
       chana(2)=1;
       pa=[1 1 1 1];
     end

     if ran(1)==2;
       chana(2)=1;
       xxa(1)=1;
       wa(1)=1;
       na=[1 1 1 1];
     end
```

```
if ran(2)==1;
  decis1a
  decidea1
  wa(1)=1;
  chana(2)=1;
  pa=[1 1 1 1];
end

if ran(2)==2;
  chana(2)=1;
  xxa(2)=1;
  wa(1)=1;
  na=[1 1 1 1];
end

if ran(3)==1;
  decis2a
  decidea2
  za(1)=1;
  chana(2)=1;
  pa=[1 1 1 1];
end

if ran(3)==2;
  chana(2)=1;
  yya(1)=1;
  za(1)=1;
  na=[1 1 1 1];
end

if ran(4)==1;
  decis2a
  decidea2
  za(1)=1;
  chana(2)=1;
  pa=[1 1 1 1];
end

if ran(4)==2;
  chana(2)=1;
  yya(2)=1;
  za(1)=1;
  na=[1 1 1 1];
end

ran=[0 0 0 0];
```

```
                if sumbits(1) > bitsth(1),
                 couna(6)=nohps(1);

                 end

          end % for repa(2)
 end % for chana(3)

 end

 % CBK

 if a1(7) > 0,

  kkk(1)=dely(nodeidf(dna(vva(1)-ua(7)),dna(vva(2)-ua(7))));
   if rand > kkk(1),
    fff(1)=1;
   else
    fff(1)=0;
   end

    cbkdeca(1)=nodeidf(dna(vva(1)-ua(7)),dna(vva(2)-ua(7)));
    cbkdeca(2)=nodeidf(dna(vva(3)-ua(7)),dna(vva(4)-ua(7)));
    cbkmats(cbkdeca(1),cbkdeca(2))=cbkmats(cbkdeca(1),cbkdeca(2))+1;

   if fff(1)==1;

   disp('cbk1')

    cbkdeca(1)=nodeidf(dna(vva(1)-ua(7)),dna(vva(2)-ua(7)));
    cbkdeca(2)=nodeidf(dna(vva(3)-ua(7)),dna(vva(4)-ua(7)));

    cbkmat(cbkdeca(1),cbkdeca(2))=cbkmat(cbkdeca(1),cbkdeca(2))+1;

    couna(7)=couna(7)+1;
    ua(7)=ua(7)+2;

   end
   fff(1)=0;

  end

% CLF
if a1(8) > 0,

  kkk(1)=dely(nodeidf(dna(ua(8)+2),dna(ua(8)+3)));
  if rand > kkk(1),
   fff(1)=1;
  else
```

```
    fff(1)=0;
   end

    clfdeca(1)=nodeidf(dna(ua(8)),dna(ua(8)+1));
    clfdeca(2)=nodeidf(dna(ua(8)+2),dna(ua(8)+3));
    clfmats(clfdeca(1),clfdeca(2))=clfmats(clfdeca(1),clfdeca(2))+1;
   if fff(1)==1;
     disp('clf1')

     clfdeca(1)=nodeidf(dna(ua(8)),dna(ua(8)+1));
     clfdeca(2)=nodeidf(dna(ua(8)+2),dna(ua(8)+3));
     clfmat(clfdeca(1),clfdeca(2))=clfmat(clfdeca(1),clfdeca(2))+1;
     couna(8)=couna(8)+1;
     ua(8)=ua(8)+2;
   end
   fff(1)=0;
end

% RLG

if a1(9) > 0,

   kkk(1)=dely(nodeidf(dna(vva(3)-ua(9)),dna(vva(4)-ua(9))));
   if rand > kkk(1),
    fff(1)=1;
   else
    fff(1)=0;
   end
    rlgdeca(1)=nodeidf(dna(vva(1)-ua(9)),dna(vva(2)-ua(9)));
    rlgdeca(2)=nodeidf(dna(vva(3)-ua(9)),dna(vva(4)-ua(9)));
    rlgmat(rlgdeca(1),rlgdeca(2))=rlgmat(rlgdeca(1),rlgdeca(2))+1;

   if fff(1)==1;
    disp('rlg1')
    rlgdeca(1)=nodeidf(dna(vva(1)-ua(9)),dna(vva(2)-ua(9)));
    rlgdeca(2)=nodeidf(dna(vva(3)-ua(9)),dna(vva(4)-ua(9)));
    rlgmat(rlgdeca(1),rlgdeca(2))=rlgmat(rlgdeca(1),rlgdeca(2))+1;
    couna(9)=couna(9)+1;
    ua(9)=ua(9)+2;
    bbb(1)=bbb(1)+1;
   end
   fff(1)=0;
end
```

```
if couna(9)==nohps(1);
  ra(1)=1;
  ra(2)=0;
  ra(3)=0;
  couna=[0 0 9 9 9 0 9 9 9];
  ua=[1 1 1 1 1 1 1 1 1];
  a1=[0 0 0 0 0 0 0 0 0];
  a1(1)=1;
  sumbits(1)=0;

  for hh=1:2:9
  dely(nodeidf(dna(hh),dna(hh+1)))=dely(nodeidf(dna(hh),dna(hh+1)))-menchg(1);
  end
end
```

APPENDIX B

1. What is Signaling?

Signaling refers to the exchange of information between call components required to provide and maintain service.

As users of the public switched telephone network, we exchange signaling with network elements all the time. Examples of signaling between a telephone user and the telephone network include: dialing digits, providing dial tone, accessing a voice mailbox, sending a call-waiting tone, dialing *66 (to retry a busy number), etc.

Signaling System 7 is a means by which elements of the telephone network exchange information. Information is conveyed in the form of messages. Signaling System 7 messages can convey information such as:

- **I'm forwarding to you a call placed from 212-555-1234 to 718-555-5678. Look for it on trunk 067.**
- **Someone just dialed 800-555-1212. Where do I route the call?**
- **The called subscriber for the call on trunk 11 is busy. Release the call and play a busy tone.**
- **The route to XXX is congested. Please don't send any messages to XXX unless they are of priority 2 or higher.**
- **I'm taking trunk 143 out of service for maintenance.**

SS7 is characterized by **high-speed packet data**, and **out-of-band signaling**.

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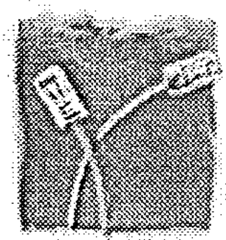
2. What is Out-of-Band Signaling?

Out-of-band signaling is signaling that does not take place over the same path as the conversation.

We are used to thinking of signaling as being in-band. We hear dial tone, dial digits, and hear ringing over the same channel on the same pair of wires. When the call completes, we talk over the same path that was used for the signaling. Traditional telephony used to work in this way as well. The signals to set up a call between one switch and another always took place over the same trunk that would eventually carry the call. Signaling took the form of a series of multifrequency (MF) tones, much like touch tone dialing between switches.



Out-of-band signaling establishes a separate digital channel for the exchange of signaling information. This channel is called a signaling link. Signaling links are used to carry all the necessary signaling messages between nodes. Thus, when a call is placed, the dialed digits, trunk selected, and other pertinent information are sent between switches using their signaling links, rather than the trunks which will ultimately carry the conversation. Today, signaling links carry information at a rate of 56 or 64 kilobits per second (kbps).

It is interesting to note that while SS7 is only used for signaling between network elements, the ISDN D channel extends the concept of out-of-band signaling to the interface between the subscriber and the switch. With ISDN service, signaling that must be conveyed between the user station and the local switch is carried on a separate digital channel called the D channel. The voice or data which comprise the call is carried on one or more B channels.

Why Out-of-Band Signaling?

Out-of-band signaling has several advantages that make it more desirable than traditional in-band signaling:

- It allows for the transport of more data at higher speeds (56 kbps can carry data much faster than MF outpulsing).
- It allows for signaling at any time in the entire duration of the call, not only at the beginning.
- It enables signaling to network elements to which there is no direct trunk connection.

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9. Layers of the SS7 Protocol

As the call-flow examples show, the SS7 network is an interconnected set of network elements that is used to exchange messages in support of telecommunications functions. The SS7 protocol is designed to both facilitate these functions and to maintain the network over which they are provided. Like most modern protocols, the SS7 protocol is layered.

The underlying layers of the SS7 protocol are as follows:

Physical Layer

This defines the physical and electrical characteristics of the signaling links of the SS7 network. Signaling links utilize DS0 channels and carry raw signaling data at a rate of 56 kbps or 64 kbps (56 kbps is the more common implementation).

Message Transfer Part - Level 2

The level 2 portion of the message transfer part (MTP Level 2) provides link-layer functionality. It ensures that the two end points of a signaling link can reliably exchange signaling messages. It incorporates such capabilities as error checking, flow control, and sequence checking.

Message Transfer Part - Level 3

The level 3 portion of the message transfer part (MTP Level 3) extends the functionality provided by MTP level 2 to provide network layer functionality. It ensures that messages can be delivered between signaling points across the SS7 network regardless of whether they are directly connected. It includes such capabilities as node addressing, routing, alternate routing, and congestion control.

Collectively, MTP levels 2 and 3 are referred to as the message transfer part (MTP).

Signaling Connection Control Part

The signaling connection control part (SCCP) provides two major functions that are lacking in the MTP. The first of these is the capability to address applications within a signaling point. The MTP can only receive and deliver messages from a node "as a whole"; it does not deal with software applications within a node.

While MTP network management messages and basic call-setup messages are addressed to a node as a whole, other messages are used by separate applications (referred to as subsystems) within a node. Examples of subsystems are 800 call processing, calling-card processing, advanced intelligent network (see the Bell Atlantic Web ProForum tutorial), and CLASS services (e.g., Repeat Dialing and they address, they use the SCCP for transport.

Operations, Maintenance and Administration Part (OMAP)

The operations, maintenance, and administration part defines messages and protocol designed to assist administrators of the SS7 network. To date, the most fully developed and deployed of these capabilities are procedures for validating network routing tables and for diagnosing link troubles. OMAP includes messages that use both the MTP and SCCP for routing.

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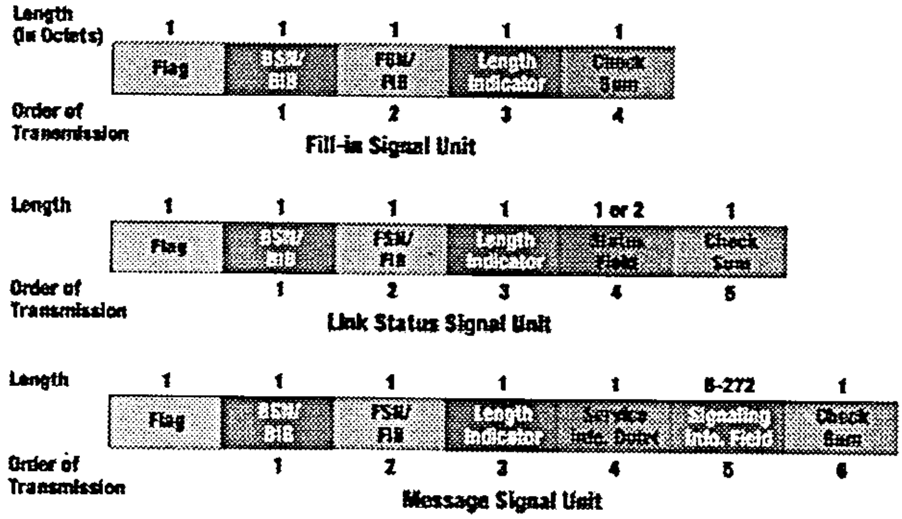
12. Signal Unit Structure

Signal units of each type follow a format unique to that type. A high-level view of those formats is shown in *Figure 8*.

Figure 8: **Signaling Unit Formats**



All three SU types have a set of common fields that are used by MTP Level 2. They are as follows:

Flag

Flags delimit SUs. A flag marks the end of one SU and the start of the next.

Checksum

The checksum is an 8-bit sum intended to verify that the SU has passed across the link error-free. The checksum is calculated from the transmitted message by the transmitting signaling point and inserted in the message. On receipt, it is recalculated by the receiving signaling point. If the calculated result differs from the received checksum, the received SU has been corrupted. A retransmission is requested.

Length Indicator

The length indicator indicates the number of octets between itself and the checksum. It serves both as a check on the integrity of the SU and as a means of discriminating between different types of SUs at level 2. As can be inferred from *Figure 8*, FISUs have a length indicator of 0; LSSUs have a length indicator of 1 or 2 (currently all LSSUs have a length indicator of 1), and MSUs have a length-indicator greater than 2. According to the protocol, only 6 of the 8 bits in the length indicator field are actually used to store this length; thus the largest value that can be accommodated in the length indicator is 63. For MSUs with more than 63 octets following the length indicator, the value of 63 is used.

BSN/BIB FSN/FIB

These octets hold the backwards sequence number (BSN), the backwards indicator bit (BIB), the forward sequence number (FSN), and the forward indicator bit (FIB). These fields are used to confirm receipt of SUs and to ensure that they are received in the order in which they were transmitted. They are also used to provide flow control. MSUs and LSSUs, when transmitted, are assigned a sequence number that is placed in the forward sequence number field of the outgoing SU. This SU is stored by the transmitting signaling point until it is acknowledged by the receiving signaling point.

Since the 7 bits allocated to the forward sequence number can store 128 distinct values, it follows that a signaling point is restricted to sending 128 unacknowledged SUs before it must await an acknowledgment. By acknowledging an SU, the receiving node frees that SU's sequence number at the transmitting node, making it available for a new outgoing SU. Signaling points acknowledge receipt of SUs by placing the sequence number of the last correctly received and in-sequence SU in the backwards sequence number of every SU they transmit. In that way, they acknowledge all previously received SUs as well. The forward and backwards indicator bits are used to indicate sequencing or data-corruption errors and to request retransmission.

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13. What are the Functions of the Different Signaling Units?

FISUs themselves have no information payload. Their purpose is to occupy the link at those times when there are no LSSUs or MSUs to send. Because they undergo error checking, FISUs facilitate the constant monitoring of link quality in the absence of signaling traffic. FISUs can also be used to acknowledge the receipt of messages using the backwards sequence number and backwards indicator bit.

LSSUs are used to communicate information about the signaling link between the nodes on either end of the link. This information is contained in the status field of the SU (see *Figure 8*). Because the two ends of a link are controlled by independent processors, there is a need to provide a means for them to communicate. LSSUs provide the means for performing this function. LSSUs are used primarily to signal the initiation of link alignment, the quality of received signaling traffic, and the status of the processors at either end of the link. Because they are sent only between the signaling points at either end of the link, LSSUs do not require any addressing information.

MSUs are the workhorses of the SS7 network. All signaling associated with call setup and tear down, database query and response, and SS7 network management takes place using MSUs. MSUs are the basic envelope within which all addressed signaling information is placed. As will be shown below, there are several different types of MSUs. All MSUs have certain fields in common. Other fields differ according to the type of message. The type of MSU is indicated in the service-information octet shown in *Figure 8*; the addressing and informational content of the MSU is contained in the signaling information field.

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Call Return). The SCCP allows these subsystems to be addressed explicitly.

Global Title Translation

The second function provided by the SCCP is the ability to perform incremental routing using a capability called global title translation. Global title translation frees originating signaling points from the burden of having to know every potential destination to which they might have to route a message. A switch can originate a query, for example, and address it to an STP along with a request for global title translation. The receiving STP can then examine a portion of the message, make a determination as to where the message should be routed, and then route it.

For example, calling-card queries (used to verify that a call can be properly billed to a calling card) must be routed to an SCP designated by the company that issued the calling card. Rather than maintaining a nationwide database of where such queries should be routed (based on the calling-card number), switches generate queries addressed to their local STPs, which, using global title translation, select the correct destination to which the message should be routed. Note that there is no magic here; STPs must maintain a database that enables them to determine to where a query should be routed. Global title translation effectively centralizes the problem and places it in a node (the STP) that has been designed to perform this function.

In performing global title translation, an STP does not need to know the exact final destination of a message. It can, instead, perform "intermediate global title translation," in which it uses its tables to find another STP further along the route to the destination. That STP, in turn, can perform "final global title translation," routing the message to its actual destination.

Intermediate global title translation minimizes the need for STPs to maintain extensive information about nodes which are far removed from them. Global Title Translation is also used at the STP to share load among mated SCPs in both normal and failure scenarios. In these instances, when messages arrive at an STP for final global title translation and routing to a database, the STP can select from among available redundant SCPs. It can select an SCP on either a priority basis (referred to as primary -- backup) or so as to equalize the load across all available SCPs (referred to as load sharing).

ISDN User Part (ISUP)

The ISDN user part defines the messages and protocol used in the establishment and tear down of voice and data calls over the public switched network, and to manage the trunk network on which they rely. Despite its name, ISUP is used for both ISDN and non-ISDN calls. In the North American version of SS7, ISUP messages rely exclusively on MTP to transport messages between concerned nodes.

Transaction Capabilities Application Part (TCAP)

The transaction capabilities application part defines the messages and protocol used to communicate between applications (deployed as subsystems) in nodes. It is used for database services such as calling card, 800, and AIN as well as switch-to-switch services including Repeat Dialing and Call Return. Because TCAP messages must be delivered to individual applications within the nodes

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14. Message Signal Unit Structure

The functionality of the message signal unit lies in the actual content of the service information octet and the signaling information field (see *Figure 8*).

The service information octet is an 8-bit field (as might be inferred from its name) that contains three types of information as follows:

1. Four bits are used to indicate the type of information contained in the signaling information field. They are referred to as the service indicator. The values most commonly used in American networks are outlined in *Table 2*.

***Table 2*: Common Signaling Indicator Values**

Value	Function
0	Signaling Network Management
1	Signaling Network Testing and Maintenance
3	Signaling Connection Control Part (SCCP)
5	ISDN User Part (ISUP)

2. Two bits are used to indicate whether the message is intended (and coded) for use in a national or international network. They are generally coded with a value of 2, national network.
3. The remaining 2 bits are used (in American networks) to identify a message priority, from 0 to 3, with 3 being the highest priority. Message priorities do not control the order in which messages are transmitted; they are only used in cases of signaling network congestion. In that case, they indicate whether a message has sufficient priority to merit transmission during an instance of congestion and/or whether it can be discarded en route to a destination.

The format of the contents of the signaling information field is determined by the service indicator. (Within user parts, there are further distinctions in message formats, but the service indicator provides the first piece of information necessary for routing and/or decoding the message.)

The first portion of the signaling information field is identical for all MSUs currently in use. It is referred to as the routing label. Simply stated, the routing label identifies the message originator, the intended destination of the message, and a field referred to as the signaling-link selection field which is used to distribute message traffic over the set of possible links and routes. The routing label consists of 7 octets that are outlined below in *Table 3* (in order of transmission):

Table 3: Routing Label

Octet Group	Function	Number of Octets Involved
Destination Point Code (DPC)	Contains the address of the node to which the message is being sent	3 octets
Originating Point Code (OPC)	Contains the address of message originator	3 octets
Signaling Link Selection (SLS)	Distributes load among redundant routes	1 octet

Point codes consist of the three-part identifier (network #, cluster #, member #), which uniquely identifies a signaling point.

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