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OPTIMAL HDLC I-FRAME STRUCTURE IN A TWO-WAY FILE TRANSFER AND IIASA DATA COMMUNICATION NETWORK

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Preface

The IIASA data communication network adopted the HDLC procedure, proposed by ISO in 1974, as its link protocol, because of its suitability for inter-connecting future computer networks. However, some optimization problems arose before choosing a subset of the HDLC procedure, due to the fact that the HDLC was designed for many alternative forms of usage in computer networks.

The purpose of this Memorandum is to find solutions to an important, fundamental, optimization problem of identifying the optimal length of the information part of a HDLC I-frame, when the network is offered for use in a two-way file transfer.

It is suggested that these results should be compared with the results in the previous memorandum [6], which were obtained by assuming a one-way file transfer usage of the network, since two-way and one-way file transfers cover two extremely different but typical usage schemes of the network, i.e. the former reflects the network status where the load (files to be transferred) is equally distributed among the stations and, the latter reflects the network status where the load is only partially distributed. The results of this comparison will assist the network designer in choosing a reasonable length for one HDLC I-frame.

This Memorandum also examines the effects of a modem-polarity switching time on optimal lengths and throughput of the network.

Abstract

This memorandum discusses the optimization problem that arises from adopting the HDLC procedure as the link protocol for the IIASA data communication network. In particular, the problem of identifying the optimal length of the information part of a HDLC information frame (I-frame) is solved by using a "two-way" file transfer in the network. The results show that the optimal length of the information part of a HDLC I-frame is 5, 13, 47, 160, 500 and 1,460 bytes, corresponding to the communication line error probabilities of 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7} in one bit, respectively, so that the throughput is maximized, where the modem polarity switching time is set at 250 ms. The author suggests that the results of the two-way file transfer be compared with those of a "one-way" file transfer presented in [6]; the optimal length in a two-way file transfer is about 20% less than that in a one-way file transfer. It is suggested that the network designer choose the length of the information part that lies between two values corresponding to the line quality. This is because the two-way and one-way file transfers cover two extreme cases where the load (i.e. files to be transmitted) is equally distributed among network stations, and the one-way file transfer represents the case where the load is only partially distributed.

The author also discusses the effects of the change in the modem polarity switching time on the optimal length of the information part. When the switching time is changed from 250 to 100 ms, the optimal length is about 13% less.

Optimal HDLC I-Frame Structure in a Two-Way File Transfer and IIASA Data Communication Network

I. INTRODUCTION

A link protocol is needed in a computer network to enable each of the stations to handle the communication. In 1974, the International Organization for Standardization proposed a link protocol called the "HDLC" (High level Data Link Control) procedure as the international standard. In this procedure, the communication functions are completely separate from the other functions such as the function of controlling terminal equipment [1, 2].

The IIASA data communication network adopted the HDLC procedure as its link protocol, because of its suitability for inter-connecting future computer networks that are likely to adopt the "international" link protocol. Since the HDLC was designed for many alternative forms of usage in computer networks, one should therefore examine some of the optimization problems before choosing a certain subset of the HDLC procedure. The IIASA data communication network has selected the so-called NRM and HDX subset of the HDLC procedure because of the following restrictions:

- 1,200 bps (bits per seconds) line speed,
- Asynchronous communication device, and
- Half-duplex device [3, 4, 5].

This memorandum discusses the typical optimization problem that can arise from adopting the HDLC procedure: that of finding the optimal length of the information part of HDLC information frame (I-frame) so as to maximize the throughput between two stations in the network, assuming that the network is offered for use in a two-way file transfer.

In a previous memorandum [6], the author discussed the same problem, assuming a one-way file transfer. It is reasonable to assume that a two-way file transfer reflects the network status where each of the stations is equally loaded with files to be transmitted and to assume that a one-way file transfer reflects the network status, where the load is partially distributed. The results show that the optimal length in a two-way file transfer is about 20% less than that in the one-way file transfer, but the overall line utility never decreases in a two-way file transfer, where the modem polarity switching time is set at 250 ms. The author suggests that the network designer choose the length of the information part that lies between these two values.

This memorandum also examines the effects of the change of the modem polarity switching time on the optimal length of the information part. When the switching time is changed from 250 ms to 100 ms, the optimal length is about 13% less. But no significant change occurs to the average amount of information transmitted in one second from one station to another, when the line is of high quality.

II. BASIC RESTRICTIONS ON THE IIASA DATA COMMUNICATION NETWORK AND THE NRM, HDX HDLC PROCEDURE

We summarize here some of the basic restrictions, requirements and assumptions on the IIASA data communication network, and outline the HDLC procedure [3, 4, 5, 6]:

A. Basic Physical Restrictions of the IIASA Data Communication Network

Several computer stations will be connected to the IIASA data communication network. IIASA has assumed the following basic restrictions on its physical devices:

1) 1,200 bps line speed,

2) Asynchronous communication device, and

3) Half-duplex communication device.

The reasons for the above restrictions are the following:

1) The reason for selecting 1,200 bps line speed is because IIASA plans to use the public switched telephone line as a physical communication medium.

2) The use of the asynchronous communication device means that at the minimum, one start bit and one stop bit staffed at the front and at the end of each of the bytes on the communication line are needed in order to synchronize communication. Note that at least 20% of the information (two out of ten bits) is lost through synchronization, although the mechanisms for asynchronous communication are simpler than those for synchronous communication.

3) The reason for selecting a half-duplex communication is the simplicity of both devices and the implementing softwares that support the communication.

B. Commands/Responses

To support this communication, the following HDLC subset has been selected for the IIASA data communication network:

1) Commands (Issued by Primary Station):

- I-Information for information transfer format;
- RR (Receive Ready) and RNR (Receive Not Ready) for supervisory format;
- SNRM (Set Normal Response Mode) and DISC (Disconnect) for unnumbered format;

2) Responses (Issued by Secondary Station):

- I-Information for information transfer format;
- RR and RNR for supervisory format;
- UA (Unnumbered Acknowledgement) and CMDR (Command Reject) for unnumbered format;

It should be stressed that the HDLC procedure requires that one station, called the Primary (denoted by P), assumes full responsibility for the communication between P and the other stations called Secondary stations (denoted by S) that is, P should open the communication, end the communication, sense the timeout and so on.

C. Error Recovery Procedure

Poll/Final bit error recovery procedure was adopted, and is effected by means of a numbering scheme which is measured in terms of frames. This is a typical error recovery procedure used in the HDLC subset mentioned above.

The purpose of this procedure is to ask the sender to resend by a numbering scheme all I-frames consequent to the I-frame with the error. The numbering scheme is illustrated in Figure 1.

D. Modem Polarity Switching Time

The fact that the modem needs time to switch its polarity, for example from the sending to the receiving state, should be considered in the calculations of the throughput in the network; this will be denoted by d_m, and is assumed to be 250 and 100 ms. This will be discussed in Section III.

E. Time-out Function

To simplify the discussion we assumed that the time-out function works most effectively. The time-out function is set up mainly to sense the damage of the last frame in the sequence. Since we assumed that stations are fully loaded by data and also that data are packed in seven I-frames in sequence, we can also assume that the station is able to know the time when the seven I-frames sequence will end.

III. ANALYSIS OF THE OPTIMIZATION PROBLEM OF THE I-FRAME STRUCTURE IN A TWO-WAY FILE TRANSFER

A. Frame Structure and its Error Probability

Any HDLC frame consists of at least six bytes in the following order:

- One flag byte with bit pattern 01111110 at the front of the frame;
- One address byte;

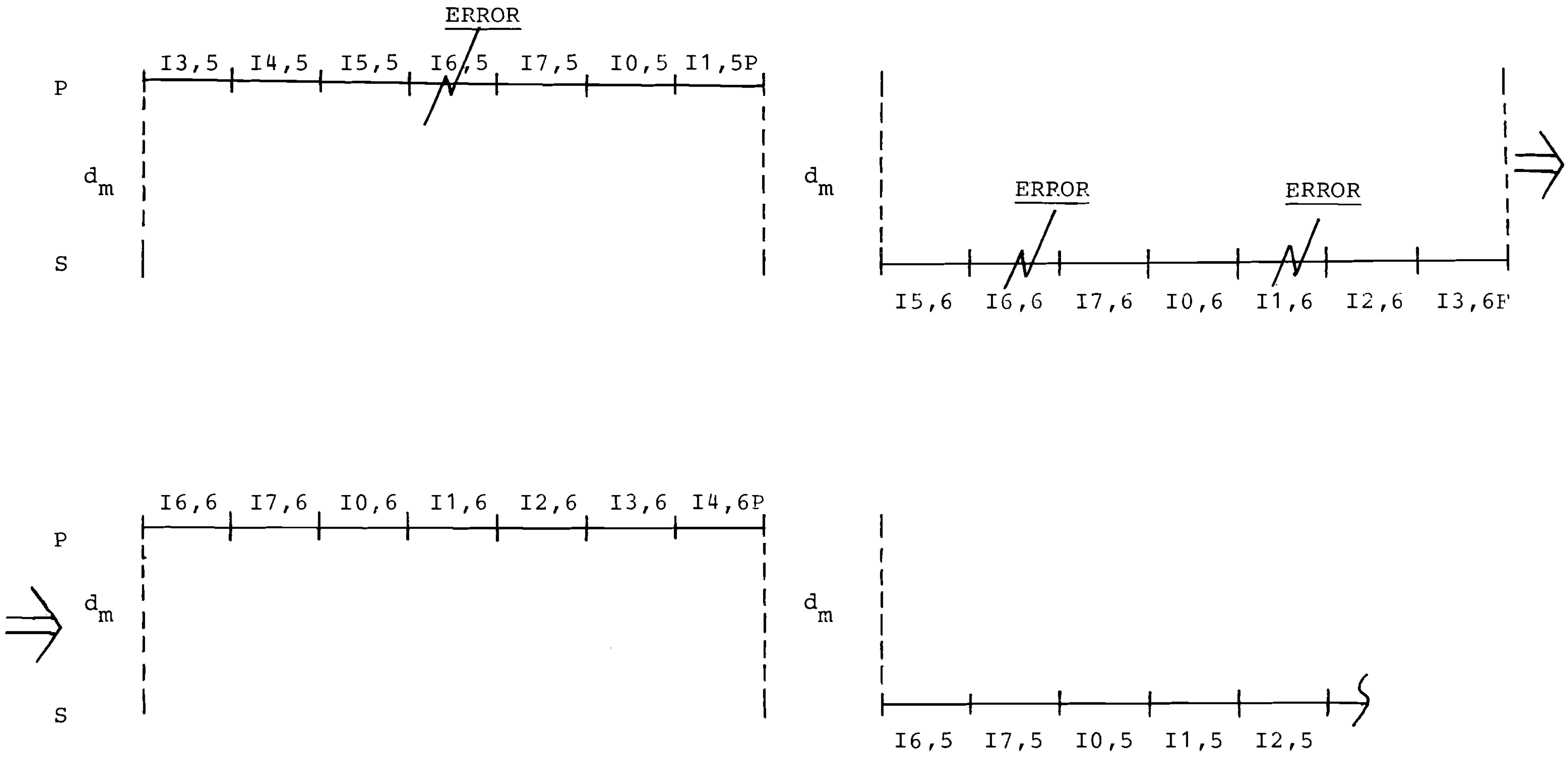

Figure 1. Typical Control Flow of a Two-Way File Transfer.

I1,5P
- Information Format Frame
- Send Sequence Count
- Poll Bit ON (Final bit ON if F)
- Receive Sequence Count

d_m = Modem Polarity Switching Time

- One control byte;
- Arbitrary byte length of the information part of an I-frame;
- Two bytes for frame check sequence; and
- One flag byte with bit pattern 01111110 at the end of the frame.

On the physical communication line, the total two bits are added to one byte for synchronization, so that the frame error probability is calculated by using the bit error probability as follows:

$$\overline{P}_f = (\overline{P}_b)^{10 \cdot (6 + L_i)} \quad ,$$

where

L_i = byte length of the information part of the I-frame;

P_b = bit error probability

$(\overline{P}_b = 1 - P_b)$;

P_f = frame error probability

$(\overline{P}_f = 1 - P_f)$.

The relationships between P_f and P_b are shown in Figure 2.

B. Control Flow of a Two-Way File Transfer

Assume that the two stations, P and S, are exchanging their data under the two-way file transfer. The following assumptions can thus be made:

- There are infinite length queues of equally sized I-frames to be transferred in both P and S stations;.
- The modules of the HDLC numbering scheme is eight, so that each of the stations always sends seven I-frames in sequence to one another.
- The flow control is managed by the functions listed in Section II under B to E.

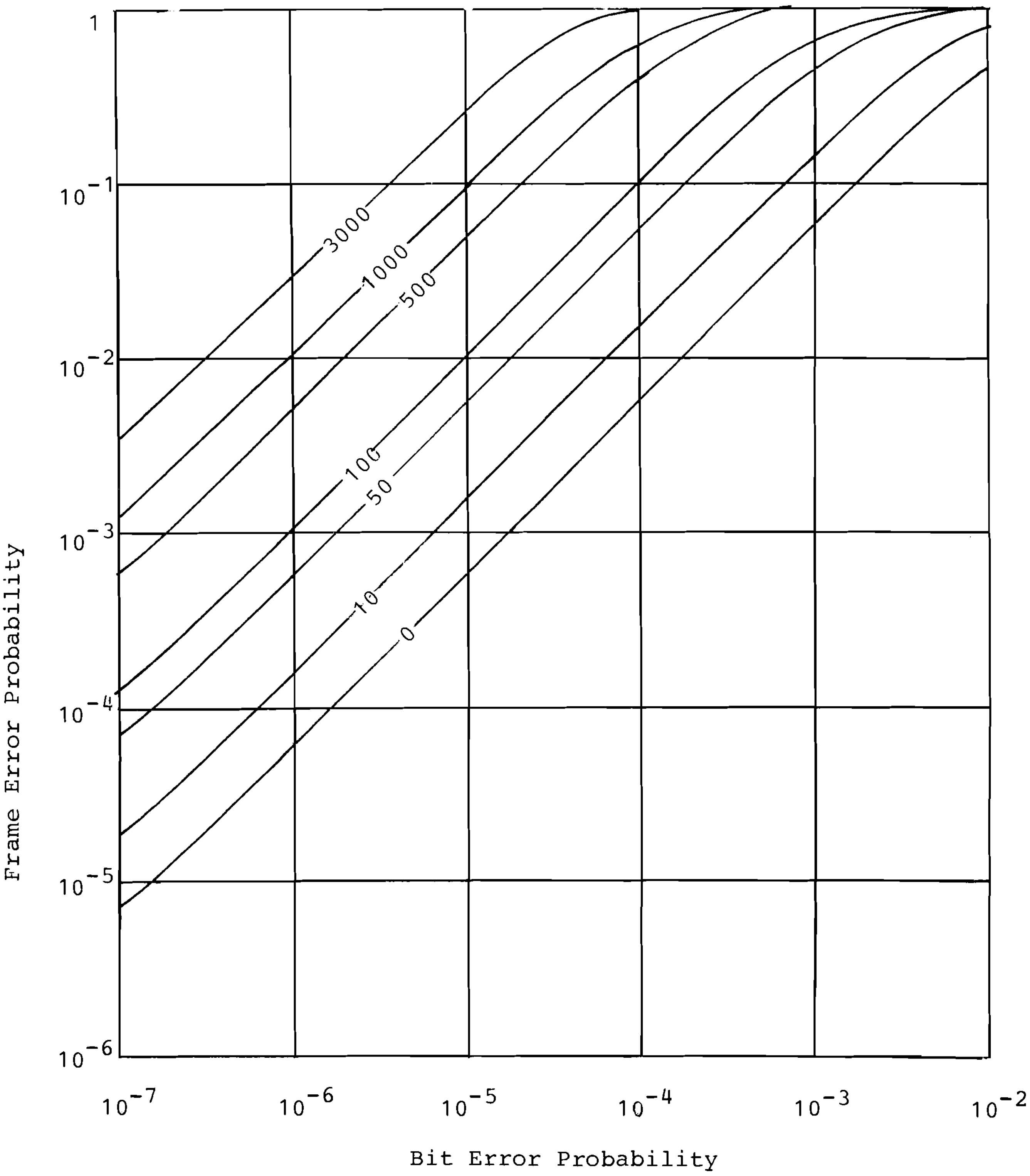

Figure 2. Relation between the Frame Error Probability and the Bit Error Probability for Various Values of Byte Length for the Information Part of One HDLC I-Frame.

Figure 1 also shows the typical control flow of a two-way file transfer.

C. Problem Explanation

The amount of information that one I-frame can carry increases with an increase in length of the information part. But, because of errors in the communication line, one should not lengthen the information part, otherwise each of the I-frames will incur errors, with the result that no information will be transferred between the two stations.

Thus, we must find the optimal length of the information part in order to maximize the throughput between the stations. This problem is solved by assuming the network use of the two-way file transfer as described below.

D. Analysis

First, let us introduce eight probabilities P_0, P_1, ..., P_7, as was also done in [6]:

P_0 : Probability of error occurrence in the first of the seven I-frames sequence.

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P_i : Probability of error occurrence in the (i + 1)th frame of the seven I-frames sequence, but not in any frame previously transmitted.

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P_7 : Probability of no error occurrence in any of the seven I-frames sequence.

P_0, P_1, ..., P_7 is calculated as follows [6]:

$$P_0 = P_f$$

$$P_i = \overline{P}_f^{\,i} \cdot P_f \quad , \text{ for } 1 \leqq i \leqq 6$$

$$P_7 = \overline{P}_f^{\,7}$$

where $\sum_{i=0}^{7} P_i = 1$ is easily checked.

Secondly, let us trace the transmission of I-frame sequences between P and S stations as is also shown in Figure 1.

Step 1

It takes t_s seconds to transmit seven I-frames sequence from P to S:

$$t_s = 7 \cdot [10 \cdot (6 + L_i)]/S_1 \quad ,$$

where

L_i : byte length of the information part of the I-frame;

S_1 : line speed in bits per second.

Within t_s seconds, the S can receive $I_1(P,S)$ amount of net information from P:

$$I_1(P,S) = \sum_{i=0}^{7} i \cdot P_i \cdot \hat{e} \quad ,$$

where $\hat{e}$ is an amount of information in bits packed into one I-frame, that is,

$$\hat{e} = 8 \cdot L_i \text{ (bits)} \quad .$$

Remark 1

Note that $I_1(P,S)$ does not include any overhead consisting of two bits for synchronization for each of the bytes transmitted, other bytes for flags (two bytes for one I-frame), an address byte, a control byte, and a frame check sequence given in Section III.A. In this sense, $I_1(P,S)$ is the net information transmitted from P to S. So, $I_1(S,P)$, $I_n(P,S)$, $I_n(S,P)$, $I(P,S)$ and $I(S,P)$ are used in the same sense below.

Step 2

S then changes its modem polarity in d_m seconds, (at the same time P also changes its modem polarity). Consequently, S transmits seven I-frames in sequence to P in t_s seconds. After receiving the seven I-frames in sequence, P changes its modem polarity in d_m seconds, (at the same time, S also changes its modem polarity). The communication status returns to its original form.

Therefore, the amounts of information $I_1(P,S)$ and $I_1(S,P)$ are transmitted from P to S and from S to P respectively within $2(t_s + d_m)$ seconds, where $I_1(S,P)$ is also defined by:

$$I_1(S,P) = \sum_{i=0}^{7} i \cdot P_i \cdot \hat{e} = I_1(P,S) \quad .$$

After n Cycles

Let us combine steps 1 and 2 and refer to them as "one cycle" of the two-way file transfer. In general, after n cycles of the two-way file transfer, it can be easily calculated that

$$I_n(P,S) = I_n(S,P)$$

$$= \sum_{i_1=0}^{7} \cdots \sum_{i_n=0}^{7} P_{i_1} \cdots P_{i_n} \cdot (i_1 + \cdots + i_n) \cdot \hat{e} \quad ,$$

this amount of information is transmitted from P to S and from S to P within $2 \cdot n \cdot (t_s + d_m)$ seconds.

I(P,S) and I(S,P) Definitions

The average amount of net information transmitted correctly from P to S and from S to P, denoted by $I(P,S)$ and $I(S,P)$, respectively, are defined as follows:

$$I(P,S) = \lim_{n \to \infty} \frac{I_n(P,S)}{2 \cdot n \cdot (t_s + d_m)}$$

$$= \lim_{n \to \infty} \frac{I_n(S.P)}{2 \cdot n \cdot (t_s + d_m)} = I(S,P) \quad .$$

I(P,S) and I(S,P) Simplifications

The above limit equations may be simplified, using the next recursive properties of $I_n(P,S)$ and $I_n(S,P)$.

$$I_n(P,S) = \sum_{i_1=0}^{7} \cdots \sum_{i_n=0}^{7} P_{i_1} \cdots P_{i_n}$$

$$\cdot (i_1 + \cdots + i_n) \cdot \hat{e}$$

$$= \sum_{i_1=0}^{7} \cdots \sum_{i_{n-1}=0}^{7} P_{i_1} \cdots P_{i_{n-1}}$$

$$\cdot (i_1 + \cdots + i_{n-1}) \cdot (\sum_{i_n=0}^{7} P_{i_n}) \cdot \hat{e}$$

$$+ \sum_{i_1=0}^{7} \cdots \sum_{i_{n-1}=0}^{7} P_{i_1} \cdots P_{i_{n-1}}$$

$$\cdot (\sum_{i_n=0}^{7} i_n \cdot P_{i_n} \cdot \hat{e})$$

$$= I_{n-1}(P,S) + I_1(P,S) \quad .$$

Therefore,

$$I_n(P,S) = n \cdot I_1(P,S) \quad .$$

By a similar calculation, we obtain the following:

$$I_n(S,P) = I_{n-1}(S,P) + I_1(S,P) \quad ,$$

$$I_n(S,P) = n \cdot I_1(S,P) \quad .$$

As a result, I(P,S) and I(S,P) are expressed as follows:

$$I(P,S) = \lim_{n \to \infty} \frac{I_n(P,S)}{2 \cdot n \cdot (t_s + d_m)}$$

$$= \lim_{n \to \infty} \frac{n \cdot I_1(P,S)}{2 \cdot n \cdot (t_s + d_m)}$$

$$= \frac{I_1(P,S)}{2 \cdot (t_s + d_m)}$$

$$= \frac{\sum_{i=0}^{7} i \cdot P_i \cdot \hat{e}}{2 \cdot (t_s + d_m)}$$

$$= I(S,P) \quad \text{(bits per second)} \quad .$$

IV. OPTIMAL SOLUTIONS AND THEIR RELATIONS TO SOLUTIONS IN ONE-WAY FILE TRANSFER

A. Optimal Solutions

We shall show here the results, based on the following assumptions:

1) Bit error probability

$$P_b = 10^{-2},\ 10^{-3},\ 10^{-4},\ 10^{-5},\ 10^{-6},\ 10^{-7};$$

2) Line speed

S_1 = 1,200 bps;

3) Modem polarity switching time

d_m = 100 and 250 ms.

Table 1 shows the optimal length of the information part of one HDLC I-frame in a two-way file transfer. In the Table, the utility of line capacity represents the following:

$$I(P,S)/S_l \cdot 100\% \; (= I(S,P)/S_l \cdot 100\%) \quad .$$

Note that the amount of information transmitted in one second from one station to another does not include any overhead in the sense described in Remark 1, III. D.

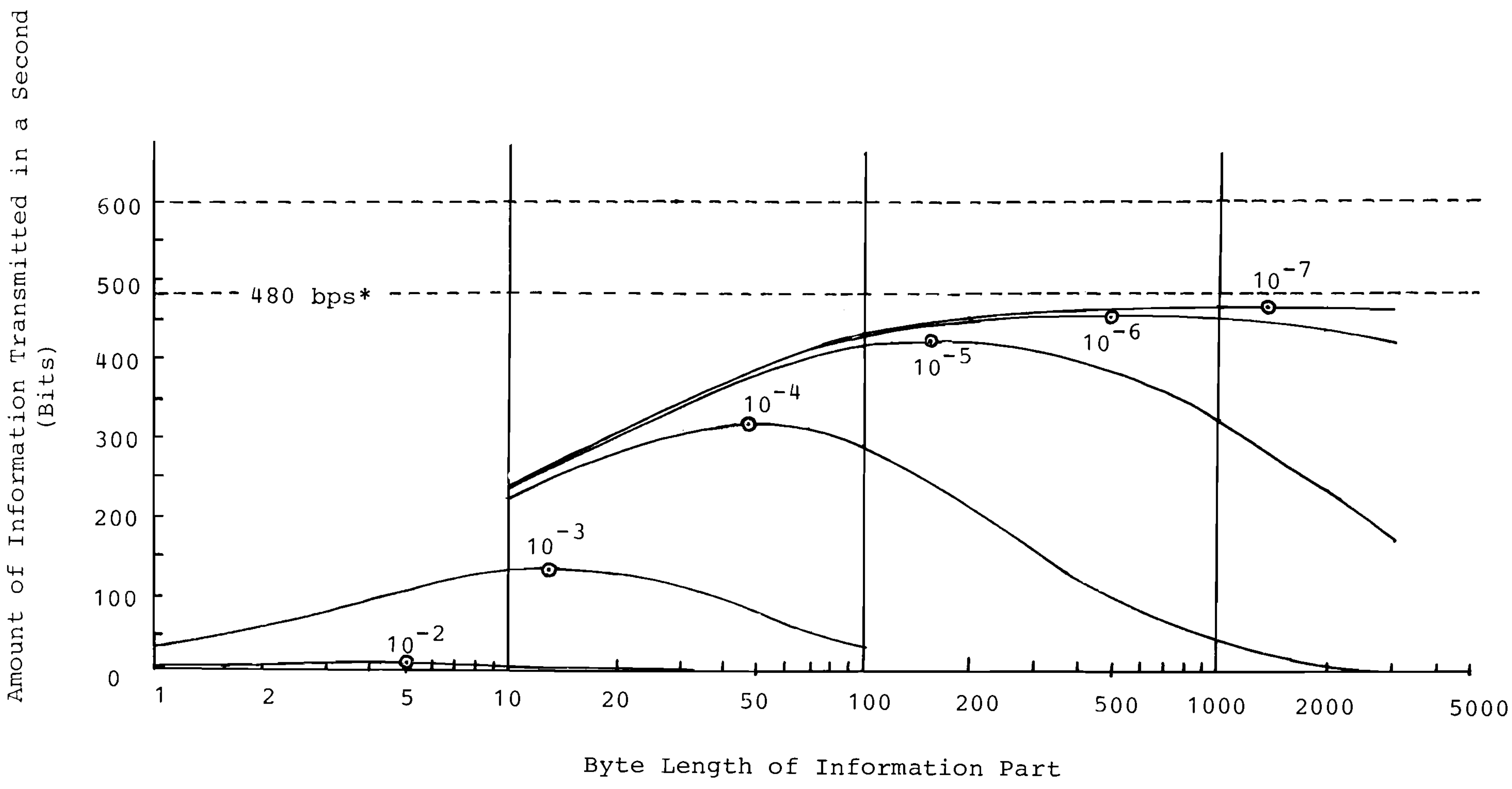
Table 1. Optimal Length of the Information Part of One HDLC I-Frame in a Two-Way File Transfer (where S_l = 1,200 bps; d_m = 250 ms)

P_b	Optimal length of information part (bytes)	Amount of information transmitted in one second from one station to another (bits/second)	Utility of line capacity (%)
10^{-2}	5	11.1	0.93
10^{-3}	13	135	11.25
10^{-4}	47	320	26.67
10^{-5}	160	422	35.17
10^{-6}	500	461	38.42
10^{-7}	1,460	473	39.42

Figures 3 and 4 show the relationship between the amount of information transmitted in one second from one station to another and the byte length of the information part of one HDLC I-frame, and the relationship between the optimal length of the information part and bit error probability, respectively.

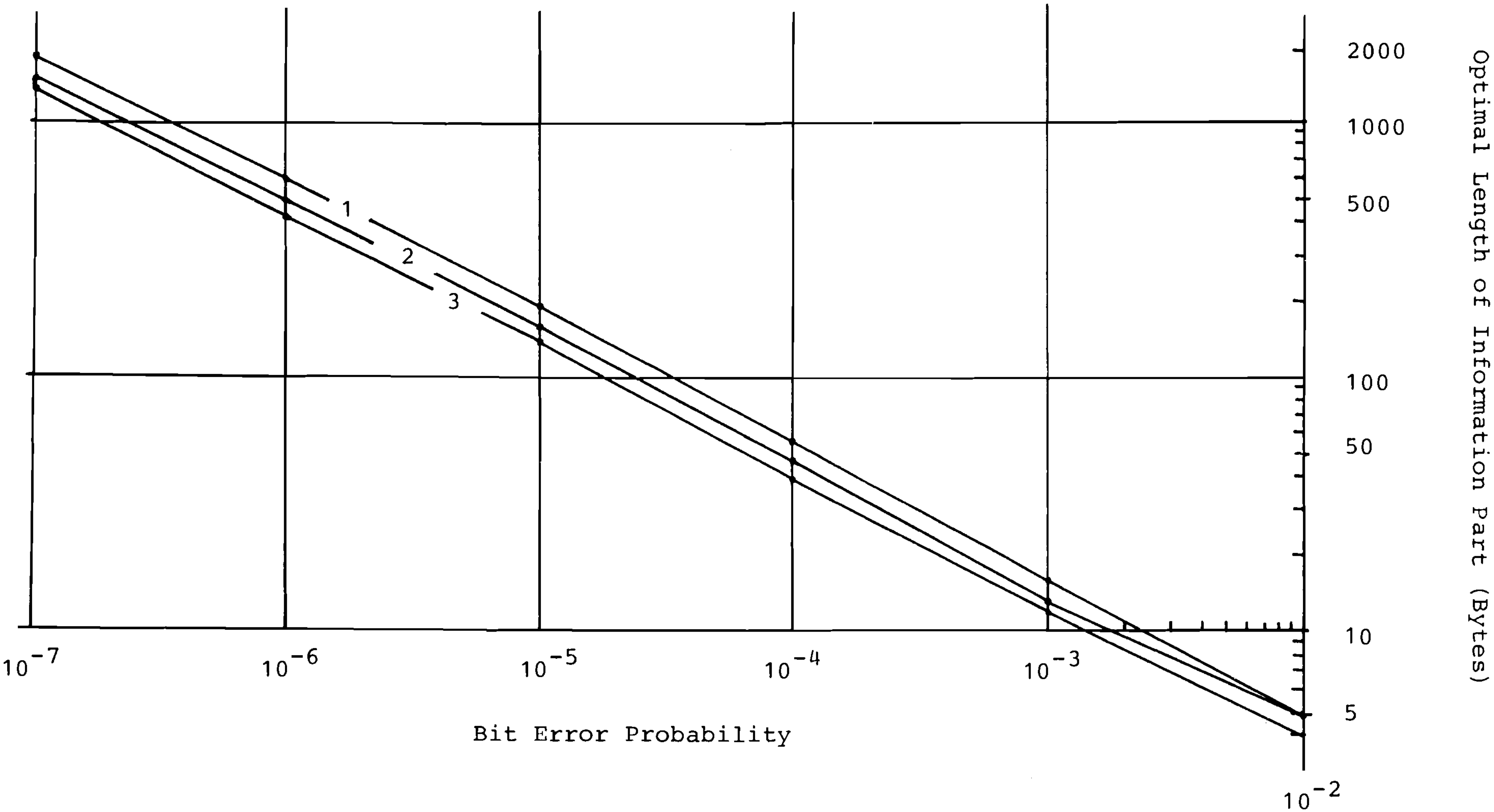
By meanings of the data in Table 2 we can examine the effects of modem polarity switching duration time both on the optimal length of the information part of one HDLC I-frame and on the amount of information transmitted in one second from one station to another. Note that in Table 2, d_m equals 100 ms.

Figure 3. Relation between the Amount of Information Transmitted in a Second and the Byte Length of the Information Part in a Two-Way File Transfer, where S_1 = 1,200 bps and dm = 250 ms.



* Theoretical Maximum ⊙ Maximum Point

Figure 4. Relation between the Optimal Length of the Information Part in Bytes and the Bit Error Probability, where S_1 = 1,200 bps.



1 = One-Way File Trans., d_m = 250 ms
2 = Two-Way File Trans., d_m = 250 ms
3 = Two-Way File Trans., d_m = 100 ms

Table 2. Optimal Length of the Information Part of One HDLC I-Frame in a Two-Way File Transfer (where S_1 = 1,200 bps; d_m = 100 ms)

P_b	Optimal length of information part (bytes)	Amount of information transmitted in one second from one station to another (bits/second)	Utility of line capacity (%)
10^{-2}	4	13.5	1.13
10^{-3}	12	152	12.67
10^{-4}	41	336	28.00
10^{-5}	140	429	35.75
10^{-6}	430	463	38.58
10^{-7}	1,270	474	39.70

The optimal lengths in a one-way file transfer are given in Table 3, in order to compare the optimal lengths in a two-way and in a one-way file transfer [6].

Table 3. Optimal Length of the Information Part of One HDLC I-Frame in a One-Way File Transfer (where S_1 = 1,200 bps; d_m = 250 ms)

P_b	Optimal length of information part (bytes)	Amount of information transmitted in one second from one station to another (bits/second)	Utility of line capacity (%)
10^{-2}	5	16.6	1.38
10^{-3}	16	223	18.6
10^{-4}	57	592	49.3
10^{-5}	190	820	68.5
10^{-6}	610	913	76.1
10^{-7}	1,800	944	78.7

B. Relationship of Optimal Lengths in Two-Way and in One-Way Transfers

In order to examine these relationships, we will compare Tables 1 and 3, because the only difference in the assumptions made in these tables is in the use of the network: Table 1 assumes a two-way file transfer, while Table 3 assumes a one-way file transfer.

The following observations can be made:

1) The optimal length of the information part of one HDLC I-frame in a two-way file transfer is about 20% less than that in a one-way file transfer.

2) In order to compare the amount of information transmitted in one second from one station to another (column 3) and the utility of line capacity (column 4), we must multiply by 2 each of the values of P_b (column 1) because this reflects the values from only one station to another. For example, if the network operating time is one minute, based on the line bit error probability of 10^{-5} and using the optimal I-frame length, an average amount of 49.32 kilo bits net information will be transferred from the source station to the destination station in a one-way file transfer; in turn an average amount of 25.32 kilo bits net information will be tranferred from one station to another in a two-way file transfer. Note, however, that during this one minute period another station also transfers the same amount of net information to the partner. Thus a total of 50.64 kilo bits net information is exchanged between the two stations. In this sense, the author would like to point out that the utility of the line is slightly more efficient in a two-way file transfer than in a one-way file transfer.

C. Effects of Modem Polarity Switching Time on the Optimal Information Length

We shall examine the effects of model polarity switching time on the optimal length of the information part of a HDLC I-frame. By comparing Tables 1 and 2, we obtain the following results:

i) The optimal length is about 13% less when the modem polarity switching time is changed from 250 to 100 ms.

ii) When the telephone line quality is high, no significant change occurs to the average amount of net information transmitted in one second from one station to another. The amount increases slightly (i.e. 5% in 10^{-4} line) when the line quality is poor.

Thus, it is recommended that network designers consider carefully their modem polarity switching time.

V. CONCLUSION

This memorandum has discussed the optimization problem which arises from adopting the HDLC procedure as the link protocol for the IIASA data communication network. In particular, the problem of identifying the optimal length of the information part of one HDLC I-frame is solved by assuming a two-way file transfer usage for the network. (Optimization here means maximizing the throughput between two stations). The results show that the optimal lengths are 5, 13, 47, 160, 500, 1,460 bytes, corresponding to the communication line error probabilities of 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} in one bit, respectively, where the modem polarity switching time is set at 250 ms.

The author has discussed in [6] the same optimization problem for a one-way file transfer usage of the network. In the present memorandum, he suggests that a comparison be made of the results of both studies since the two-way file transfer and the one-way file transfer reflect the extremely different but typical usage schemes of the network. That is, the two-way file transfer usage reflects the network status, where the load (files to be transferred) is equally distributed among the stations, and the one-way file transfer usage reflects the network status where the load is only partially distributed. The comparison shows that the optimal lengths in a two-way file transfer are about 20% less than those in a one-way file transfer, but the overall line utility increases slightly in a two-way file transfer (see Section IV. B).

Thus, it is suggested that the network designer choose the length of the information part of one HDLC I-frame as shown between those two values corresponding to the communication line error probability measured or announced. For example, if the network designer receives the quality of 10^{-5} communication line, he should choose the value between 160 and 190 for the byte length of a HDLC information part, where the modem polarity switching time is set at 250 ms.

In this memorandum, we have also discussed the effects of the change of model polarity switching time on the optimal length of the information part of a HDLC I-frame in a two-way file transfer. It has been shown that the optimal length is about 13% shorter when the switching time is changed from 250 to 100 ms. However, it has also been shown that no significant change occurs in the average amount of net information transmitted within one second from one station to another. Thus, the network designer should heed the notice on the modem polarity switching time.

However, there remain some problems that should be solved in order to build an efficient data communication network. The author has pointed out several problems in [6]; nevertheless, he would like to stress again the need to make a theoretical model for evaluating the time-out function. In nearly all cases, the author believes that the designer's choice of the length of a time-out duration is made by intuition, although the designer is often afraid that the selection might harm the efficiency of the network. Finally, it is stressed that the development of another simulation model is needed to solve both the optimization problems and other problems such as that of a time-out function.

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