論 文

ISDN D－채널 Access Protocol의 Delay 분석

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Delay Analysis of the ISDN D-channel Access Protocol

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要 約 본 논문에서는 CCITT에서 권고한 ISDN D-채널 access protocol의 queueing 모델을 제시하였으며 그 모델을 이용하여 signalling message와 packet message의 delay의 Laplace transform을 구하였다. 그 분석결과는 simulation을 통하여 검증하였으며, 또한 D-채널 access 시스템에서의 packet 및 signalling message의 delay 특성에 대하여 비교 설명하였다.

ABSTRACT In this paper a queneing model for the D-channel access protocol recommended by CCITT is developed, and delays of the signalling and packet messages are analyzed using the model. Behaviors of packet and signalling messages in the D-channel access system are also investigated. The analytical results have been verified by simulation.

I. INTRODUCTION

During the past few years, there has been a significant progress toward the implementa tion of integrated services digital networks (ISDN). Although networks for a particular type of traffic(e.g., voice or packetized data) already exist, an ISDN that accommodates various types of traffics is still in the process of being actively evolved from the existing networks. In accordance with this trend, International Consultative Committee for Telegraphy and Telephony (CCITT) recommended a user-network interface protocol of ISDN in the CCITT red book.[1]

According to the protocol recommended by CCITT, the basic access structure of the user-network interface consists of two B-channels, each operating at 64 kbits/s, and one D-channel operating at 16 kbits/s. Both voice and high speed data are transmitted by the two B-channels. The primary function of the D-channel is the transmission of signalling

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messages needed for the control of circuit-switching of B-channels. Low-speed packet messages and telemetry messages may share the D-channel with the signalling messages. But, the signalling messages are given higher priority class over the packet and telemetry messages.

On the whole, the D-channel access protocol includes the fairness of a polling system and adopts the collision detection scheme of CSMA/CD (Carrier Sense Multiple Access with Collision Detection). But, neither model can be applied to the analysis of the D-channel access protocol. Furthermore, little analysis on the D-channel access protocol has been done. Wong and Hwa did brief analysis on the delay of signalling message of the D-channel access protocol.[2]

In this paper, we perform an approximate analysis of the average message delay for the queueing model of the D-channel access protocol with a finite number of stations, each of which has a buffer of infinite capacity.In our analysis we assume that the arrival process of messages at each station is independent and Poisson, and the service time is arbitrary.

Following this Introduction, Section Ⅱ presents the D-channel access protocol of CCITT [1]. In Section Ⅲ, a queueing model for the access protocol and delay analysis are given. In Section Ⅳ, we compare our simulation results with the numerical results and discuss some behaviors of packet and signalling messages in the D-channel access system. Finally, we make conclusions in Section Ⅴ.

Ⅱ. DESCRIPTION OF THE D-CHANNEL ACCESS PROTOCOL

The D-channel is a synchronous channel. Multiple terminals can be connected to one D-channel. The bit value of the logical AND of the latest transmitted bits from all terminals connected to the D-channel is recognized at the receiving end, and the bit value is echoed back to all terminals through the D-echo channel. A terminal will send binary 1's on the D-channel when it has no layer-2 frame to transmit. Therefore, the consecutive 1's are echoed back, while the channel is idle.

While in active condition (i.e., power "on" condition), a terminal monitors the D-echo channel to count the number of consecutive 1's. If a binary 0 is detected, the terminal resets the counter and starts again. The value of the counter cannot be increased over 11. It is important to note that a terminal goes on counting the number of 1's even when it has no message to transmit. A terminal having frames of layer-2 to send begins to transmit the frame on the D-channel if it has found the channel idle. A layer-2 frame is delimited by flags consisting of the binary pattern '01111110'.

While transmitting messages on the D-channel, a terminal goes on monitoring the D-echo channel and compares the last transmitted bit with the next available D-echo bit. If the two bits are identical, it continues to transmit the frame until completion. But, if not, it ceases transmitting the frame immediately and returns to the D-channel monitoring state. Therefore, one of the competing terminals will always transmit successfully.

A terminal is permitted to transmit a frame on the D-channel by detecting consecutive 1's on the D-echo channel. The required length of a sequence is determined by the status of the terminal and the type of a frame to be transmitted. The signalling message is given high priority, and packet and telemetry messages are given low priority. The high-priority class message is sent in a non-preemptive mode over the low-priority class. Furthermore, each priority class is again divided into two levels, normal and lower levels.

Each terminal has the counter C which counts the number of consecutive 1's. A terminal can start frame transmission when C equals or exceeds the value 'x1' for signalling message and the value 'x2' for packet and telemetry messages. The value of 'x1' is set to 8 for the normal level and 9 for the lower level. The value of 'x2' is set to 10 for the normal level and 11 for the lower level.

For a priority class, normal-level priority is changed into lower-level priority when a terminal has successfully transmitted a frame of that priority class on the D channel. The lower-level priority in a priority class returns back to the normal-level priority when the counter C has reached the value of the lower level of that priority class.

Ⅲ. QUEUEING MODEL AND DELAY ANALYSIS

A. Queueing Model

In this paper, telemetry messages are not dealt with separately becaue their behavior is conformable to that of packet messages. Moreover, error-free transmission is assumed. Our analyses of signalling delay and packet delay will be done using the same model which will be called the reference system. We first analyze the delay of the reference system and apply the results to the delay analyses of both signalling and packet messages of the D-channel access protocol.

Let us consider a system model of the

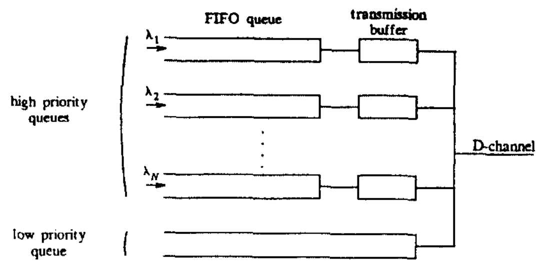

Fig. 1. Queueing model for the reference system

reference system shown in Fig. 1. In this system there are two priority classes. The number of high priority queues is N, and the arrival distributions of the high priority queues are assumed to be Poisson. For the low-priority queues, the number of queues is only one, and the arrival distribution is arbitrary. Both the high priority and low priority queues are assumed to have an infinite waiting room. The high-priority queues send their messages in conformity to the D-channel access protocol except for the value of the counter C required to transmit a message. In this system, the required value of C is zero for the normal level and one for the lower level. The service time of the message in the ith high-priority queue is represented by the random variable (r.v.) b_i, and the arrival rate of the queue is λ_i. The utilization of the channel by the ith queue messages only is then $\rho_i=\lambda_i E(b_i)$ where $E(\cdot)$ denotes expectation. And ρ is the total utilization by all high-priority queue messages.

Here we analyze the queueing delay of high priority messages. In our analysis, we divide a high priority queue into two parts, a FIFO (first-in first-out) queue and a transmission buffer. The transmission buffer is an extension of the FIFO queue, and only one message is permitted to enter the transmission buffer. In the high priority queues the message at the head of the FIFO queue will enter the transmission buffer when it is empty. This message in the transmission buffer will be in contention for channel acess. Accordingly, the queueing delay of high priority queues consists of two delay factors. One is the delay from which a message suffers in the FIFO queue (this delay will be referred to the pure queueing delay), and the other is the delay from which a message suffers in the transmission buffer(this delay will be called the contention delay). The pure queueing delay is expressed as a r.v. w, and the contention delay is expressed as a r.v. s. The total queueing delay, represented by a r.v. d, is the sum of pure queueing delay and contention delay. That is, $d=w+s$. w and s are assumed to be independent. Therefore, we have $D(s)=W(s)\ S(s)$ where $D(s)$, $W(s)$ and $S(s)$, are, respectively, the Laplace transforms (LT) of probability density functions (pdf) of d, w and s.

B. Distribution of Pure Queueing Delay

We now define a cycle as a time interval of a busy period during which the high priority messages of the normal level are served continuously. Therefore, at most one message from a high priority queue can be served in each cycle. Let us define the jth conditinal cycle as the cycle which includes the service of the j th queue message. Let us assume that the tagged message belongs to the N th queue without the loss of generality. Since at most one message can be sent from a high priority queue in each cycle, the tagged message moves one position forward in queue after each cycle. There may exist some waiting time of high-priority messages due to the service of low-priority messages because the service is non-preemptive. Then the service time of a message which is in front of the tagged message in the Nth queue can be considered as c, that is, the Nth conditional cycle time plus the time which may be generated by low-priority messages. Let α_i be the probability for the service of ith queue message $(j=N)$ during the time c, and a r.v. f be the contribution of a low-priority message to c. Then, the mean value of c can be expressed as

$$E(c)=1+E(b_N)+\sum_{i=1}^{N-1} \alpha_i E(b_i)+E(f) \qquad (1)$$

Approximatong α_i by $\lambda_i\ E(c)$, we have

$$E(c)=[1+E(b_N)+E(f)]\ /\ (1-\rho+\rho_N). \qquad (2)$$

It should be mentioned that the above solution holds only for $\alpha_i \leqq 1$. If we have $\alpha_i > 1$, α_i can no longer be interpreted as probability. This can be overcome by limiting the maximum value of α_i to be less than 1. Based on the independence assumption, we can obtain the LT of the pdf of c as

$$C(s)=e^{-s}B_N(s) \prod_{i=1}^{N-1} (\alpha_i B_i(s)+(1-\alpha_i))F(s) \qquad (3)$$

where $B_i(s)$ and $F(s)$ are the LT's of pdf's of b_i, and f, respectively. We apply the M/G/1 queueing model with service time c to the Nth queue. Then, we have

$$W(s)=[(1-\tilde{\rho}_N)sE(c)]\ /\ [sE(c)-\tilde{\rho}_N+\tilde{\rho}_N C(s)] \qquad (4)$$

where

$$\tilde{\rho}_N=\lambda_N E(c). \qquad (5)$$

C. Distribution of Contention Delay

There exist three types of cycles, and these are shown in Fig. 2. Type 1 cycle is generated when a high-priority message arrives during the service of a low-priority message. Type 2 cycle is generated when a high-priority message arrives when the channel is idle. At the end of any type of cycles, type 3 cycle may be generated. Type 3 cycle has its genesis in the messages queued in FIFO queues. N th conditional cycles are also classified into three types in the same way. Type 3 N th conditional cycles are again divided into two types, type 3a and type 3b N th conditional cycles, depending upon the arrival time of the tagged message. A type 3a N th conditional cycle can be made in the case that the tagged message served in the cycle arrived prior to that cycle. A type 3b N th conditional cycle can be made in the case that the tagged message served in the cycle arrived during that cycle. Before proceeding further, we define the notationa to be used as follows.

- L_x Mean value of the duration of type x cycle(x=1, 2, 3)
- $\tilde{b}_L$ Service time of the low priority message served prior to type 1 cycle
- r Duration from the first arrival of high-priority messages during the service of a low-priority message to the beginning of type 1 cycle.
- n_x Average number of type x cycles occurred in unit time(x=1, 2, 3)
- $\hat{n}_x$ Average number of type x N th conditional cycles occured in unit time(x= 1, 2, 3a, 3b)

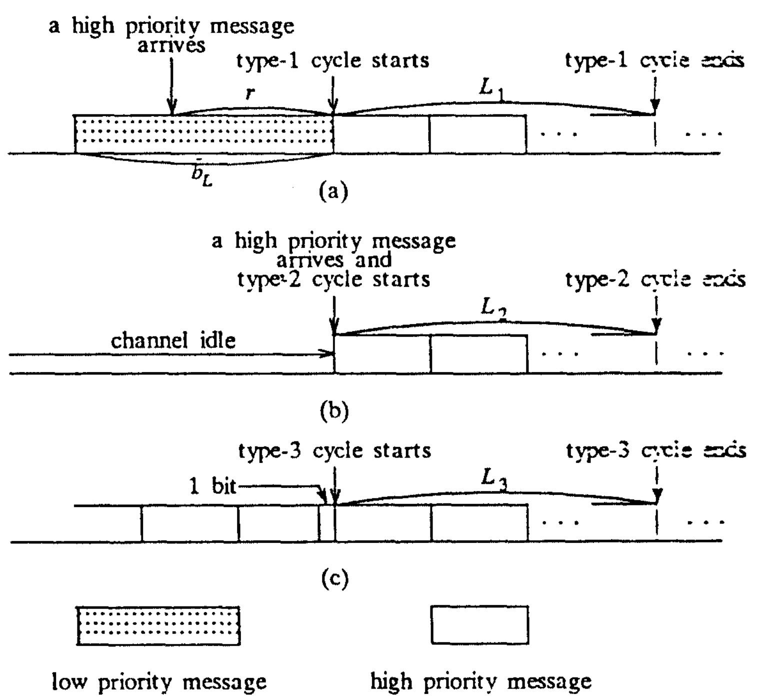

Fig. 2. Diagrams of three different cycles
(a) Type 1 cycle (b) Type 2 cycle (c) Type 3 cycle

$\hat{P}_x$ Probability that a tagged message belongs to type x N th conditional cycle (x=1, 2, 3a, 3b)

$\hat{P}_{xi}$ Probability that a tagged message in a type x N th conditional cycle will be i th message served in that cycle (x=1, 2, 3a, 3b)

$S_x(s)$ LT of the contention delay of the tagged message served in type x N th conditional cycle(x=1, 2, 3a, 3b)

$S_{xi}(s)$ LT of the contention delay of the tagged message served for the i th time in type x N th conditional cycle (x=1, 2, 3a, 3b)

We then find

$$S_x(s)=\sum_{i=1}^{N}\hat{P}_{xi}S_{xi}(s) \quad (x=1,\ 2,\ 3a,\ 3b) \tag{6}$$

and

$$\hat{P}_1=\frac{\hat{n}_1}{\hat{n}_1+\hat{n}_2+\hat{n}_3},\ \hat{P}_2=\frac{\hat{n}_2}{\hat{n}_1+\hat{n}_2+\hat{n}_3} \tag{7}$$

where we note $\hat{n}_3=\hat{n}_{3a}+\hat{n}_{3b}$.

A tagged message will belong to type 3a cycle when it arrives at the queue and finds it not empty. Hence, $\hat{P}_{3a}$ can be considered as $\tilde{\rho}_N$ from(5). Consequently, $\hat{P}_{3b}$ is given by

$$\hat{P}_{3b}=\frac{\hat{n}_3}{\hat{n}_1+\hat{n}_2+\hat{n}_3}-\tilde{\rho}_N. \tag{8}$$

It should be mentioned that $\hat{P}_{3b}$ must be nonnegative. If it happens that $\hat{P}_{3b}<0$, $\hat{P}_{3b}$ is no longer probability. Hence, we must have

$$\hat{P}_{3b}=\frac{\hat{n}_3}{\hat{n}_1+\hat{n}_2+\hat{n}_3},\ \hat{P}_{3b}=0 \tag{9}$$

Thus, the LT of contention delay is

$$S(s)=\hat{P}_1S_1(s)+\ \hat{P}_2S_2(s)+\hat{P}_{3a}\ S_{3a}(s)+\ \hat{P}_{3b}S_{3b}(s) \tag{10}$$

Now the variables and functions to be used in this Section are calculated or approximated.

(i) Distribution of random variable $\tilde{b}_L$: Let the r.v. b_L represennt the service time of a low-priority message, and $P_{b_L}(t)$ and $P_{\tilde{b}_L}(t)$ be the pdf's of b_L and $\tilde{b}_L$, respectively. Also let $B_L(s)$ and $\tilde{B}_L(s)$ represent the LT of $P_{b_L}(t)$ and $P_{\tilde{b}_L}(t)$, respectively. When the service of a low-priority message starts, there is no high-priority message present. While it is being served, a high-priority message may or may not arrive. The probabiltiy that one or more high-priority messages arrive during the service of low-priority message should be proportional to the value of $(1-e^{-\lambda b_L})$ as well as to the relative occurrence of such durations. Thus, we may write

$$P_{\tilde{b}_L}(t)=K(1-e^{-\lambda t})P_{b_L}(t) \tag{11}$$

where

$\lambda=\sum_{i=1}^{N}\lambda_i$, and K is a proportionality constant.

The constant K can be evaluated so as to properly normalize the pdf$P_{\tilde{b}_L}(t)$. Then we have

$$P_{\tilde{b}_L}(t)=\frac{1-e^{-\lambda t}}{1-B_L(\lambda)}P_{b_L}(t),$$

$$\tilde{B}_L(s)=\frac{B_L(s)-B_L(s+\lambda)}{1-B_L(\lambda)} \tag{12}$$

(ii) Distribution of random variable r : The r.v. r is the residual service time of the low--priority message at the first arrival time of high-priority messages. If we have $\tilde{b}_L=t_L$, the probability that r does not exceed the value t_r, is given by

$$P[r \le t_r | b_L = t_L] = \frac{A}{B} \tag{13}$$

where

A= The probability that the first arrival time of the high-priority message is in the interval from $t_L - t_r$ to t_L

B= The probability that at least one high--priority message arrives in t_L.

Then

$$P[r \leqq t_r | \tilde{b}_L = t_L] = \frac{e^{-\lambda t_L}(e^{\lambda t_r} - 1)}{1 - e^{-\lambda t_L}} \tag{14}$$

Thus, we may write the joint probability density of r and $\tilde{b}_L$ as

$$P[t_r < r \leqq t_r + dt_r,\ t_L < \tilde{b}_L \leqq t_L + dt_L] = \frac{\lambda e^{-\lambda t_L} e^{\lambda t_r}}{1 - B_L(\lambda)} \quad P_{b_L}(t_L) dt_r,\ dt_L. \tag{15}$$

It is noted that (15) is valid only for $0 \leqq t_r \leqq t_L$. Integrating (15) over t_L, we can obtain $p_r(t_r)$, the pdf of r as

$$P_r(t_r)dt_r = \frac{\lambda e^{\lambda t_r}}{1 - B_L(\lambda)} \ dt_r \int_{t_r}^{\infty} e^{-\lambda t_L} P_{b_L}(t_L) dt_L. \tag{16}$$

The LT of $P_r(t)$, $R(s)$, can be obtained as

$$R(s) = \frac{\lambda}{(1 - B_L(\lambda)) \ (s - \lambda)} \ [B_L(\lambda) - B_L(s)]. \tag{17}$$

(iii) L_x (Mean value of the duration of type x cycle(x=1, 2) : Let us define the following function :

$$A_{i_1 i_2 \cdots i_n}(s) \equiv R(s) B_{i_1}(s) B_{i_2}(s) \cdots B_{i_n}(s) \ \text{for type 1}$$
$$\equiv B_{i_1}(s) \ B_{i_2}(s) \cdots B_{i_n}(s) \ \text{for type 2} \tag{18}$$

The probability that the message served for the first time in type x cycle is from the i_1 th queue will be $\frac{\lambda_{i_1}}{\lambda}$. After serving the i_1 th queue message for the first time, the type x cycle may be terminated or continue. The termination occurs when the queues except for the i_1 th queue have no new arrival during the interval of $r + b_{i1}$ for type 1 cycle, b_{i1} for type 2 cycle. Thus, the probability of termination is assumed to be A_{i1} $(\lambda - \lambda_{i1})$. Consequently, the probability of continuation is $1 - A_{i1}$ $(\lambda - \lambda_{i1})$. In case of continuation, the probability that the following message belongs to the $_{i2}$th queue is assumed to be $\frac{\lambda_{i_2}}{\lambda - \lambda_{i1}}$. After the second service, the type x cycle may be terminated or continus. Similarly, the probability of termination is assumed to be $A_{i1i2}(\lambda - \lambda_{i1} - \lambda_{i2})$. Hence, the probability of continuation is $1 - A_{i1i2}(\lambda - \lambda_{i1} - \lambda_{i2})$. In this way, the distribution of messages in type x cycle can be known. We can find L_x from the distribution of messages in type x cycle as

$$Lx = \sum_{i_1=1}^{N} \frac{\lambda_{i1}}{\lambda} \ A_{i1}(\lambda - \lambda_{i1}) E(b_{i1})$$

$$+ \sum_{i_1=1}^{N} \frac{\lambda_{i1}}{\lambda} \ (1 - A_{i1}(\lambda - \lambda_{i1}))$$

$$\sum_{\substack{i_2=1 \\ \neq i_1}}^{N} \frac{\lambda_{i2}}{\lambda - \lambda_{i1}} A_{i1i2}(\lambda - \lambda_{i1} - \lambda_{i2}) E(b_{i1} + b_{i2})$$

$$+ \sum_{i_1=1}^{N} \ \sum_{\substack{i_2=1 \\ \neq i_1}}^{N} \cdots \sum_{\substack{i_N=1 \\ \neq i_1 \\ \vdots \\ \neq i_{N-1}}}^{N}$$

$$\frac{\prod_{k=1}^{N} \lambda_{ik} \prod_{k=1}^{N-1} (1-A_{i_1 \cdots i_k}(\lambda - \sum_{j=1}^{k} \lambda_{ij}))\, E(\sum_{k=1}^{N} b_{ik})}{\lambda \prod_{k=1}^{N-1} (\lambda - \sum_{j=1}^{k} \lambda_{ij})} \tag{19}$$

(iv) L_3(Mean value of the duration of type 3 cycle) : Since the type 3 cycle will be generated during the busy period of the high-priority message, the low-priority message has little influence on the type 3 cycle. Therefore, we calculate L_3 approximately by assuming that there are no low-priority message arrivals. Then the busy period of high-priority messages consists of one type 2 cycle and some type 3 cycles, but there are no type 1 cycles in it. Let α_i be the probability for the service of the ith message($i \neq j$) during a j th conditional cycle. Then the mean value of j th conditional cycle time can be expressed as

$$E(c_j)=1+E(b_j)+\sum_{\substack{i=1 \\ \neq j}}^{N} \alpha_i E(b_i) \tag{20}$$

Assuming $\alpha_i=\lambda_i E(c_j)$, we find

$$E(c_j)=\frac{1+E(b_j)}{1-\rho+\rho_j} \tag{21}$$

Note that α_i should be equal to or less than 1 to be interpreted as a probability. The mean cycle time is approximately given as

$$E(\bar{c})=\sum_{i=1}^{N} \frac{\lambda_i}{\lambda}\ E(c_i). \tag{22}$$

When $E(b) \gg 1$, where $b=\sum_{i=1}^{N} \frac{\lambda_i}{\lambda} b_i$, the mean value of the busy period is approximately given by

$$g_1=\frac{E(b)}{1-\rho} \tag{23}$$

In one busy period, there are a mean number of cycles, $\frac{g_1}{E(\bar{c})}$. A busy period consists of one type 2 cycle and $\frac{g_1}{E(\bar{c})}-1$ type 3 cycles in the mean. Then, we have

$$g_1=1 \cdot L_2+\left(\frac{g_1}{E(\bar{c})}-1\right) L_3, \tag{24}$$

from which we obtain

$$L_3=\frac{g_1-L_2}{\frac{g_1}{E(\bar{c})}-1} \tag{25}$$

(v) n_3(Average number of type 3 cycles occurred in unit time) : The values of n_1 and n_2 will be given later. The utilization of the channel by high priority messages is ρ. Hence, we have

$$n_3=\frac{\rho-n_1L_1-n_2L_2}{L_3} \tag{26}$$

(vi) The value of $\hat{n}_X$ and the probability $\hat{P}_{X1}(x=1,\ 2)$: Let p_{X1} be the probability that in a type x th cycle N th queue messages will be served for the i th time. p_{X1} is obviously

$$p_{X1}=\frac{\lambda_N}{\lambda} \tag{27}$$

p_{X2} is the product of the probability that the message served for the first time in a type x cycle is not from the Nth queue and the probability that the cycle continues more than one message and the probability that the following message belongs to the N th quene. Then.

$$p_{X2}=\sum_{i_1=1}^{N-1} \frac{\lambda_{i1}}{\lambda}\ (1-A_{i1}(\lambda-\lambda_{i1}))\frac{\lambda_N}{\lambda-\lambda_{i1}} \tag{28}$$

Similarly, p_{xn} will be given as

$$p_{xn}=\sum_{i_1=1}^{N-1}\ \sum_{\substack{i_2=1\\ \neq i_1}}^{N-1}\cdots\sum_{\substack{i_{n-1}=1\\ \neq i_1\\ \vdots\\ \neq i_{n-2}}}^{N-1}\frac{\lambda_N\prod_{k=1}^{n-1}\lambda_{i_k}\prod_{k=1}^{n-1}\left(1-A_{i_1\cdots i_k}\left(\lambda-\sum_{j=1}^{k}\lambda_{i_j}\right)\right)}{\lambda\prod_{k=1}^{n-1}\left(\lambda-\sum_{j=1}^{k}\lambda_{i_j}\right)} \quad (29)$$

The probability that a type x cycle has an N th queue message is given by

$$p_x=p_{x1}+p_{x2}+\cdots+p_{xN} \quad (30)$$

From the definitions of $\hat{n}_x$ and $\hat{P}_{xi}$, we have

$$\hat{n}_x=n_x p_x,\ \hat{P}_{xi}=\frac{p_{xi}}{p_x}\ (x=1,\ 2) \quad (31)$$

(vii) The value of $\hat{n}_3$, the probability $\hat{P}_{3ai}$ and the probability $\hat{p}_{3bi}$: When the utilization by high priority messages, ρ, is low, the distribution of type 3 cycle is similar to that of type 2 cycle. Thus, we can apply the results from the type 2 cycle to the type 3 cycle. Then, we have

$$\hat{n}_3=n_3 p_2,\ \hat{P}_{3ai}=\hat{P}_{2i} \quad (32)$$

From the definition of type 3b cycle, we know that an N th queue message cannot be served for the first time in the type 3b cycle. Then, it is approximately given by

$$\hat{P}_{3b1}=0,\ \hat{P}_{3bi}=\frac{\hat{P}_{2i}}{1-\hat{P}_{21}}\ \text{ for } 2\leqq i\leqq N \quad (33)$$

(viii) $S_{xi}(s)(x=1,\ 2,\ 3a,\ 3b)$: A type 1 cycle diagram is shown in Fig. 3. The r.v. b_N^c is defined as

$$b_N^c=\sum_{i=1}^{N-1}\frac{\lambda_i}{\lambda}b_i \quad (34)$$

The service time of high priority messages served prior to the tagged message in type 1 cycle is assumed to be equally represented by b_N^c. The probability that the tagged message served for the i th time in type 1 cycle arrived in the region K $(0\leqq K\leqq i-1)$ is assumed to be proportional to the average length of the region. In each region, the arrival of the tagged message is assumed to be uniformly

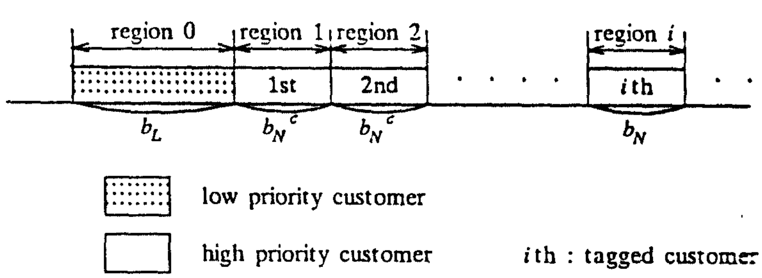

Fig. 3. Type 1 cycle diagram

distributed. From the renewal theory [5], we have

$$S_{1i}(s)=\frac{E(b_L)}{E(b_L)+(i-1)E(b_N{}^c)}\ \frac{1-B_L(s)}{sE(b_L)}[B_N(s)]^{i-1}$$

$$+\sum_{k=1}^{i-1}\frac{E(b_N{}^c)}{E(b_L)+(i-1)E(b_N{}^c)}\ \frac{1-B_N{}^c(s)}{sE(b_N{}^c)}[B_N{}^c(s)]^{i-k-1} \quad (35)$$

The distribution of type 2 cycle can be obtained from the distribution of type 1 cycle by setting the r.v. b_L zero. Thus, $S_{2i}(s)$ can be obtained from (35) by setting $E(b_L)$ zero.

Then,

$$S_{21}(s)=1,$$

$$S_{2i}(s)=\sum_{k=1}^{i-1}\frac{1}{i-1}\ \frac{1-B_N{}^c(s)}{sE(b_N{}^c)}\ [B_N{}^c(s)]^{i-k-1}$$

$$\text{for } 2\leqq i\leqq N. \quad (36)$$

In type 3a cycle, the tagged message contends for channel access from the beginning of the cycle. Thus, we have

$$S_{3ai}(s)=[B_N{}^c(s)]^{i-1} \quad (37)$$

In type 3b cycle, the tagged message cannot be served for the first time, and we have

$$S_{3bi}(s)=S_{2i}(s),\ 2\leqq i\leqq N. \quad (38)$$

(ix) Distribution of random variable f: For the type 1 cycle in which the N th queue message is served for the first time, the contribution of low-priority message to c is assumed to be r. When the N th queue message is served for the ith $(i=1)$ time in type 1 cycle, the probability that the message arrives during the residual time r is approximately given by

$$v_i=\frac{E(r)}{E(r)+(i-1)E(b_N{}^c)} \text{ for } 2\leqq i\leqq N \quad (39)$$

For the type 1 cycle in which the N th queue message is served for the i th $(i\neq 1)$ time, we approximate the contribution of low-priority message to c by $\frac{1}{2}$ r. Moreover, f can be considered only in type 1 cycle. Thus, $F(s)$ is approximately given by

$$F(s)=\frac{\hat{n}_1}{\hat{n}_1+\hat{n}_2+\hat{n}_3}\ [\hat{P}_{11}+\frac{1}{2}\sum_{i=2}^{N}v_i\hat{P}_{1i}]\ [R(s)-1]+ \quad (40)$$

D. Analysis of Signalling and Packet Delay

It is assumed that all stations generate signalling and packet messages independently, according to Poisson distribution processes. The symbols to be used are defined as follows.

- N Number of stations.
- λ_{si} Signalling arrival rate of the i th station.
- λ_{pi} Packet arrival rate of the i th station.
- m_{si} r.v. representing the signalling service time of the ith station.
- m_{pi} r.v. representing the packet service time of the i th station.
- ρ_s Utilization of all signalling messages (It is not a server utilization but a utilization by messages).
- ρ_p Utilization of all packet messages(It is not a sever utilization but a utilization by messages).
- S_i i th station.

We note that the following relations hold :

$$\lambda_S=\sum_{i=1}^{N}\lambda_{Si} \qquad \lambda_P=\sum_{i=1}^{N}\lambda_{Pi}$$

$$m_S=\frac{1}{\lambda_S}\sum_{i=1}^{N}\lambda_{Si}m_{Si} \qquad m_P=\frac{1}{\lambda_P}\sum_{i=1}^{N}\lambda_{Pi}m_{Pi}$$

(i) Signalling delay : We consider all packet queues as a single queue with the arrival rate λ_P. Considering the signalling message as a high-priority message and a packet message as a low-priority message, this system is similar to the reference system. We have the following relations :

$$b_i=m_{Si}+8,\ b_L=m_P+10 \tag{41}$$

$$\lambda_i=\lambda_{Si},\ \lambda=\sum_{i=1}^{N}\lambda_i \text{ and } \rho=\sum_{i=1}^{N}\lambda_i E(b_i) \tag{42}$$

A low-priority message with the service time, b_L, may or may not generate the type 1 cycle. The probability of generating the type 1 cycle is $1-B_L(\lambda)$. Then, the average number of type 1 cycle occurred in unit time is given by

$$n_1=\lambda_P(1-B_L(\lambda)) \tag{43}$$

A type 2 cycle can be generated when a signalling message arrives when the channel is idle. Hence, the average number of type 2 cycle occurred in unit time is given by

$$n_2=\lambda(1-\rho-\lambda_P E(b_L)). \tag{44}$$

(ii) Packet delay: We consider all signalling queues as a single queue with the arrival rate λ_S, and the service time distribution b_S, that is $b_S=m_S+8$. Adding the required counter value C of the packet queues for the normal level, 10, to the service time of the i th packet queue m_{Pi}, we can obtain virtual service time of the i th packet queue b_{Pi}, that is $b_{Pi}=m_{Pi}+10$. This system can be interpreted as follows. When a packet message gets service, there is no signalling message present. While it is being served, signalling messages may arrive. Before the next packet message is served or until the system is idle, these arriving signalling messages and their successors must be served. To a packet message waiting in queue, the service time of a packet message ahead of it consists of b_{Pi}, for the i th packet queue and the time required to get the system free of signalling messages. This time interval will be called the blocking time. Denoting the LT of the distribution of blocking time b_i as $B_i(s)$, we have from the renewal theory

$$B_i(s)=B_{Pi}(s+\lambda_S-\lambda_S T(s)) \tag{45}$$

where

$T(s)=B_S(s+\lambda_S-\lambda_S T(s))$, and $B_S(s)$, $B_{Pi}(s)$ are the LT's of the pdf's of b_S, b_{Pi}, respectively.

Then, b_i can be equivalently considered as the service time of the i th packet queue message. Considering the packet message as a high priority message with an equivalent service time of b_i, this system is similar to the reference system. Hence, we have the following relations :

$$B_i(s)=B_{Pi}(s+\lambda_S-\lambda_S T(s)) \tag{46}$$

$$\lambda_i=\lambda_{Pi},\ \lambda=\sum_{i=1}^{N}\lambda_i \text{ and}$$

$$\rho=\sum_{i=1}^{N}\lambda_i E(b_i) \tag{47}$$

Now, we obtain the LT of the distribution of random variable b_L and the values n_1, and

n_2, b_L is effectively the busy period of the signalling message generated only when the channel is idle. Then, from the renewal theory, we find

$$B_L(s)=B_s(s+\lambda_s-\lambda_s B_L(s)) \tag{48}$$

A type 1 cycle can be generated when a signalling message arrives when the channel is idle and a packet message arrives during the signalling busy period. Then, the average number of the type 1 cycle occurred in unit time is given by

$$n_1=\lambda_s(1-\rho_T)(1-B_L(\lambda)) \tag{49}$$

where

$$\rho_T=\sum_{i=1}^{N}\lambda_i E(b_{pi})+\lambda_s E(b_s) \tag{50}$$

A type 2 cycle can be generated if a packet message arrives when the channel is idle. Hence, the average number of type 2 cycle occurred in unit time is given by

$$n_2=\lambda(1-\rho_T) \tag{51}$$

Ⅳ. SIMULATION RESULTS AND DISCUSSION

In this section we compare numerical results with the simulation results for the D-channel access protocol. To get the results, we have made the following assumptions :

- For signalling and packet messages, a layer 2 frame consists of an information field and additional 7 octets(56 bits) for the layer 2 header and trailer.
- Each station generates signalling and packet messages independently, according to the Poisson distribution process.
- The number of stations is 4.
- The elementary time unit is a bit.
- The mean length of the packet information field is 128 octets(1024 bits), and the mean length of the signalling information field is 9 octets(72 bits).
- Since the traffic of signalling messages is normally low, the signalling utilization, ρ_s, is considered up to 0.4.
- All the signalling queue messages have the same service time distrihution, and also all the packet queue messages have the same service time distribution.

Fig. 4. shows the mean delays in case of a symmetric system, that is, when all packet queues have the same arival rates and all signalling queues have the same arrival rates,

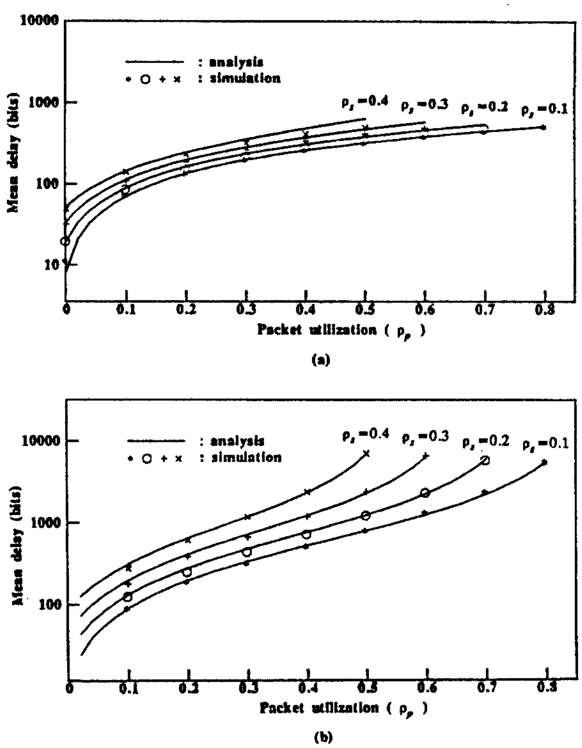

Fig. 4. Signalling and packet delays in 4 symmetric queues with constant length information field
(a) Mean signalling delay (b) Mean packet delay

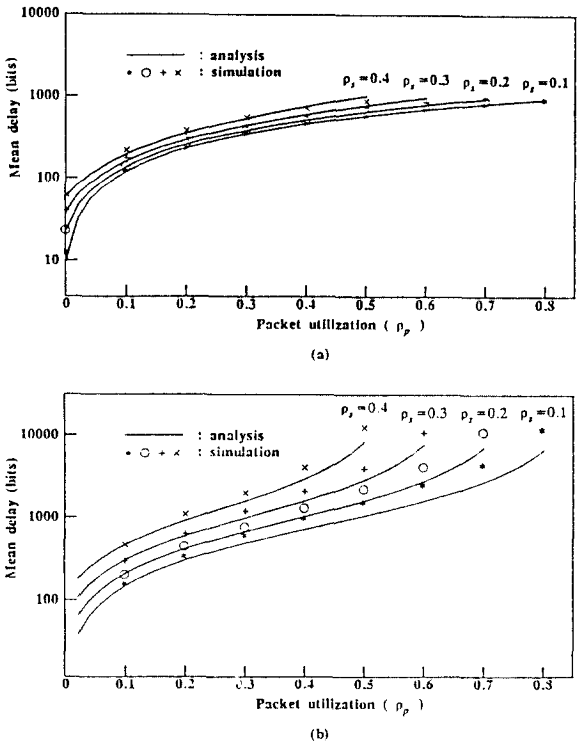

Fig. 5 Signalling and packet delays in 4 symmetric queues with exponential length information field
(a) Mean signalling delay (b) Mean packet delay

and each queue message has a constant length information field. Fig. 4. (a) and (b) shows the delays of signalling mssages and packet messages, respectively, as a function of channel utilization of packet and signalling messages. Fig. 5. shows the mean delays in case of a symmetric system and when each queue message has an exponential length information field. Fig. 5. (a) and (b) is the delay of signalling messages and packet messages, respectively. It is noted that ρ_S and ρ_P in Fig. 4. and Fig. 5. mean not server utilization but message utilization.

In Figs. 4. and 5., we find that the constant-length information field case has a better agreement between numerical and simulation results than the exponential-length information field case. In the exponential length information field case, the numerical results are underestimated primarily due to the use of the conditional cycle time approach. The use of conditional cycle time approach generally underestimates the delay, and this underestimation increases when the variance of the message service time becomes large.

We note another tendency in the figures. The increase of the type 1 cycles causes the overestimation of the delay. In Fig. 4. (a) and Fig. 5. (b), it is seen that the numerical results are overestimated as the packet utilization increases. The increase of the packet utilization means the increase of type 1 cycles. In (49), we know that in the analysis of packet delay the number of type 1 cycles increases as ρ_S (or λ_S) increases in the small region of ρ_S(or λ_S). And we also see the same tendency in Figs. 4.(b) and 5.(b). The primary reason of this tendency is due to the approximation of L_3. We have approximated L_3 by the assumption that there are no type 1 cycles. Accordingly, the value of L_3 is underestimated. The underestimation of L_3 causes the overestimation of the number of type 3 cycles and the overestimation of the number of type 3 cycles causes the overestimation of the delay.

In these figures, we observe that the numerical results have good agreement with the simulation results for low-to-medium value of ρ_S for the signalling delay and $\rho_S+\rho_P$ for the packet delay.

The signalling message always has non-preemptive priority over to the packet message in the D-channel. Therefore, the signalling message will receive service before any waiting packet message even though it might arrive later. Consequently, when the signalling utilization is fixed, the signalling delay approaches a constant value although the total utilization tends to be unity.

Once the D-channel is occupied by a packet message, the signalling messages have to wait till the packet message has finished transmission. Therefore, if the length of the packet message is longer, the value of the signalling delay will be higher.

It is also observed that the delay of messages increases when the variance of the message service time becomes large.

Ⅴ. CONCLUSIONS

In this paper, delay distributions of signalling and packet messages of the D-channel in ISDN have been studied. For the analytical model, we have assumed general message service time distribution. We divided the delay from which each signalling and packet messages suffers into two factors, i.e., pure queueing delay and contention delay, and these two delay factors have been analyzed. The numerical results of the mean delay of messages have been compared with the simulation results. It has been found that the analysis results agree closely with the simulation results for low-to-medium values of total utilizations.

To conclude, the packet utilization has little effect on the signalling delay and the best way for a non-preemptive implementation of the D-chanel access protocol to ensure short signalling delay is to restrict the maximum length of a packet message and to choose constant information fields.

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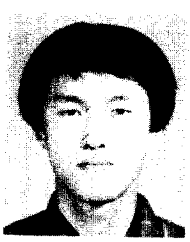

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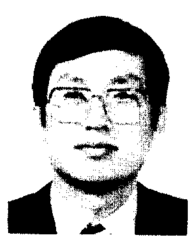

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