ENGINEERING COMMON CHANNEL SIGNALING NETWORKS FOR ISDN

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With ISDN a broad range of signaling traffic will be carried, and this paper considers the effects of this traffic on the performance and engineering of signaling networks. We consider the delay performance for signaling links and examine engineering criteria for different traffic models. Both Basic and PCR error correction procedures specified in CCITT Signaling System No. 7 are considered. It is shown that the message length distribution has a significant effect on the engineered load for Basic error correction, but for PCR it does not. For PCR there are additional engineering considerations that must be made, and in particular it is shown that system instabilities can result if thresholds are not properly engineered.

1. Introduction

Common Channel Signaling (CCS) is an integral component of ISDN, and properly engineered networks will be critical for the provision of ISDN services. With the introduction of ISDN, signaling networks will be expected to support a wide range of message types, and this can have a significant effect on signaling link performance. A major effect that ISDN will have on the signaling network is that User-to-User Information (UUI) will be transported either in ISDN User Part (ISDN-UP) messages or as separate messages on temporary or permanent signaling connections. Carrying UUI has the potential for increasing message lengths and broadening the message length distribution. Another factor contributing to this trend is that the ISDN-UP has many optional capabilities, which when used will significantly broaden message length distributions. In this paper we examine signaling link engineering criteria and characterize the effect ISDN traffic might have on the maximum loads signaling links can support.

The signaling protocol on the network side of ISDN connections is specified by CCITT Signaling System No. 7 (SS#7). We examine the two level 2 error correction procedures specified in SS#7: Basic and Preventive Cyclic Retransmission (PCR) error correction. Engineering criteria for delay performance are developed considering both mean delay and sensitivity of delay to load variations, and the potential impact of ISDN traffic is examined. Additional engineering criteria are developed for the PCR forced retransmission procedure. It is shown how this procedure can lead to links becoming unstable in the presence of errors if not properly engineered. Finally, the performance of Basic and PCR error correction are compared, and it is shown that Basic error correction should be used for much higher loop propagation delays than currently recommended by CCITT.

2. Signaling Link Error Correction Procedures and Queueing Delays

In this section we describe the Basic method and the Preventive Cyclic Retransmission (PCR) method of error correction and explain the queueing models to be used in computing delays.

2.1 Basic Error Correction

The Basic method is a non-compelled, positive/negative acknowledgement, retransmission error correction system. Signaling information is transferred in SS#7 using a specific message format called message signal units (MSUs). New MSUs are transmitted on a first come first served (FCFS) basis, and a MSU that has been transmitted is retained in the transmitting terminal's retransmit buffer until a positive acknowledgement for that MSU is received. If a negative acknowledgment is received, the transmission of new MSUs is interrupted and the negatively acknowledged MSU and all those transmitted after it are retransmitted once in the order they were first transmitted. If there are no new MSUs to be transmitted and MSUs are not being retransmitted, fill-in signal units (FISU), which are 6 octets long, are transmitted.

We use the following notation:
The queueing delay of a MSU is defined to be the time from when the message arrives at the transmit buffer until it begins its transmission that will be received without error. Thus, this queueing delay includes the waiting time for retransmission for errored MSUs. To analyze the queueing delays of this system, it will be assumed that new MSUs arrive as a Poisson process. The delay performance can then be modeled as a M/G/1 queue, and the relationship for the mean queueing delay is given in Reference [2]. A close approximation for the queueing delay is given in Q.706. [1] When there are transmission errors, the effective link utilization, $\rho_{\text{eff}}$, is given by

$$\rho_{\text{eff}} = \frac{1 + P_m T_L / S}{1 - P_m}.$$  

### 2.2 PCR Error Correction

The PCR method is a non-compelled, positive acknowledgement, cyclic retransmission, forward error correction system. It is intended for use on signaling links with long propagation delay. New MSUs are transmitted FCFS with non-preemptive priority, except in the case of forced retransmission described below. When a MSU has been transmitted, it is placed in a retransmit buffer and remains there until it is positively acknowledged. If there are no new MSUs to be transmitted, MSUs in the retransmit buffer are retransmitted in the order of their original sequence. When a retransmission cycle is completed, another one is started as long as there are MSUs in the retransmit buffer. If there are neither new MSUs to be transmitted nor MSUs in the retransmit buffer, then FISUs are transmitted.

A forced retransmission procedure has been defined in PCR to ensure that forward error correction takes place when errors have occurred and needed retransmissions are slowed because of a high MSU arrival rate. For this procedure, both the number of MSUs, $N_1$, and the number of MSU octets available for retransmission, $N_2$, are monitored continuously. If one of them reaches its set limit, $N_1$ or $N_2$, no new MSUs are sent and the retransmission cycle is continued with priority up to the last MSU placed in the retransmit buffer. Then, if neither $N_1$ nor $N_2$ is at its limit, the normal PCR procedure is resumed. If not, all MSUs available for retransmission are sent again with priority. $N_1$ is limited to 127 by the maximum numbering capacity for forward sequence numbers.

A queueing model for the PCR method has been developed by Watanabe and Ikeda[3]. The major assumptions in this model are the same as used in [2] for the Basic error correction method, with the exception that the effects of multiple errors of MSU transmission and retransmission are ignored. This additional assumption has a negligible effect for error rates below the range where a changeover (described below) will occur, and if the error rate is high enough to cause a changeover the link is removed from service and so it does not matter.

### 2.3 Changeover Procedure

When transmission errors occur, the effective link utilization is increased for both Basic and PCR error correction, and if the error rate is high enough it will have a significant effect on delay. SS#7 protects against serious degradation in performance by removing traffic from a link when its error rate becomes too high. This procedure is called a Changeover (CO). If $P_{\text{su}}$ denotes the signal unit error rate, including FISUs, [1] COs will occur when $P_{\text{su}} > .004$ (see Q.704). At some error rates a sizable queue will build up before CO. The size of this queue build-up will depend on $\rho$ and the message length distribution. Since this queue must be transferred to alternate signaling links, the changeover transients can have a significant effect on delays and can affect the link engineering. These issues are discussed in References[23] and[4] and will not be considered here. The main consideration here in regards to changeover is to identify the maximum error rate that must be considered for sustained signaling link operation.

### 3. Signaling Link Engineering Criteria

Signaling networks provide the high availability required by providing diverse extra capacity to handle the
load of any failed component. The amount of redundant capacity depends on the network architecture. We will assume that the network architecture is such that 100 percent redundancy is required, and therefore signaling links must be engineered to handle twice their normal load. The approach proposed to engineer signaling links is to determine a maximum utilization, \( \rho_{\text{max}} \), that the link should have when there are no failures in the network. To handle failures, the link should then be able to support a utilization of \( 2\rho_{\text{max}} \).

One approach to determining \( \rho_{\text{max}} \) is to establish upper bounds on the mean and 95% queueing delay, where the queueing delay is what would be seen at a random point in time during a random busy hour. Since the probability of having a failure in the network at a random point in time is small, the probability distribution for this delay is determined by the steady state behavior of the link with no failures, and thus when the link is operating at \( \rho_{\text{max}} \). To prevent significant degradation in delay performance under failure conditions, delay objectives must also be established for signaling links operating at \( 2\rho_{\text{max}} \). Since \( \rho_{\text{max}} < 0.5 \), the delays at \( \rho_{\text{max}} \) lie on the flat portion of the delay curve, and consequently the delay criteria for \( \rho_{\text{max}} \) are not critical. As a result, the delay criteria for \( 2\rho_{\text{max}} \) are the ones that usually dominate and establish \( \rho_{\text{max}} \), and this will be assumed here.

The delay objectives for the link operating at \( 2\rho_{\text{max}} \) could be stated as upper bounds on the mean and 95% delays, but this is not enough of a constraint. Simply looking at delay can lead to operating points that are on the steep portion of the delay vs utilization curve. Thus it is also necessary to impose an upper bound on the delay sensitivity.

Another factor that must be considered in establishing link engineering criteria is what error rate to assume. Digital facilities generally operate with background bit error rates (BER) below \( 10^{-6} \), and higher error rates tend to occur in bursts and be higher than \( 10^{-3} \). If such error bursts last long enough (greater than 200-300 ms), the signaling link will changeover and be out of service so delay performance is irrelevant. Signaling links operating at BERs higher than \( 10^{-4} \) but below the changeover threshold appear to be rare events. Nevertheless, signaling links must be engineered to handle these situations. One way to deal with these situations is to provide congestion control, so that if signaling link delays get too large, controls are exercised to reduce the traffic. Since this happens rarely, this is a reasonable strategy. The use of congestion controls and their engineering considerations are discussed in Reference [2]. In this Section we will assume congestion control is not used to control these situations and examine the engineering alternatives.

### 3.1 Engineering for Normal Error Conditions

We will consider normal error conditions to be random bit errors that occur at the rate of one error in \( 10^6 \) bits transmitted. At these error rates the mean queueing delay for both Basic and PCR error correction is increased a negligible amount from errors. The delays for errored MSUs and those affected by retransmission can be significant, and this situation is discussed in Section 5 in connection with the choice of using Basic or PCR error correction. The engineering criterion that will be examined for normal error conditions is to set an upper bound on the mean queueing delay and the sensitivity of the mean queueing delay when the link is operating at utilization \( 2\rho_{\text{max}} \). The specific criterion is:

Criterion 1: Choose \( \rho_{\text{max}} \) so that for links operating with a BER of \( 10^{-6} \),

\[
\begin{align*}
(2) &; Q(2\rho_{\text{max}}) < D_1 \\
(3) &; \frac{dQ}{d\rho}(2\rho_{\text{max}}) < L_1
\end{align*}
\]

### 3.2 Engineering for Extreme Error Conditions

We define the extreme error condition to be when the signaling link is operating at an error rate that puts it at the boundary of the changeover region, which is at a signal unit error probability \( P_{su} = 0.004 \). For PCR the link will not be sending FISUs when the error rate is high enough to cause CO, and therefore all signal units sent will be new or retransmitted MSUs. As a result, the error probability for MSUs, \( P_m \), will be 0.004 at the CO boundary. For Basic error correction, FISUs will be present and the bit error probability, \( P_b \), and the average signal unit error probability, \( P_{su} \), are related by \( P_b = \frac{(1 - \rho_{\text{eff}})M + \rho_{\text{eff}}/6}{P_{su}} \), where \( \rho_{\text{eff}} \) is given by (1). Thus, at the CO boundary, \( P_{su} = 0.004 \) and the corresponding MSU error probability is given by

\[
P_m = 0.004(\rho_{\text{eff}} + (1 - \rho_{\text{eff}})M/6). \tag{2}
\]

From (2) it follows that the value of \( P_m \) at the CO boundary with Basic error correction depends on the mean message length. Equation (2) yields a quadratic equation that is easily solved to determine the corresponding MSU error probability, \( P_m \).

Since the extreme error condition is a rare situation, the delay and sensitivity constraints can be relaxed from those used in Criterion 1. The proposed engineering criterion for the extreme error condition is the
Criterion 2: Choose $p_{\text{max}}$ such that for links operating at the changeover boundary,

\[ \frac{dQ}{dp}(2p_{\text{max}}) < \frac{(T_L/2)}{D_1} \]

3.3 Application of Signaling Link Engineering Criteria

To illustrate the above engineering criteria and examine the potential impact of ISDN traffic, we consider 64 kb/s links and apply Criterion 1 and 2 to three traffic models:

Traffic Model I

This model assumes that there are ISDN-UP trunk signaling messages and Transaction Capability messages for database query and response. There is no UUI and the ISDN-UP messages use no optional capabilities. The ISDN-UP MSUs are assumed to be 80% of the MSUs. ISDN-UP and TC MSUs are assumed to have message lengths of 20 and 100 octets, respectively. For this model, $S = 4.5$ ms and $S^2 = 36.25$ ms$^2$.

Traffic Model II

This model includes UUI in the Model I ISDN-UP messages, and we consider having 40% of the ISDN-UP messages contain 128 octets of UUI. For this model, $S = 9.6$ ms and $S^2 = 144$ ms$^2$.

Traffic Model III

This model adds UUI carried on TSCs or PSCs to Model I traffic. It is assumed that 20% of the message load is TSC/PSC UUI with message length of 256 octets. For this model, $S = 10$ ms and $S^2 = 234$ ms$^2$.

For Criterion 1 we choose the limit $D_1$ to be max[15 ms, 0.05$T_L$] and $L_1$ to be 100 ms. $T_L$ is set at 60 ms for Basic error correction, which corresponds to a 3000 mile terrestrial link, and it is set at 600 ms for PCR, which corresponds to a satellite link. The results of applying Criteria 1 and 2 for both Basic and PCR error correction are shown in Table 1.

<table>
<thead>
<tr>
<th>Traffic Model</th>
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<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>Basic</td>
<td>.78/.79</td>
<td>.65/.72</td>
</tr>
<tr>
<td>PCR</td>
<td>.46/.40</td>
<td>.44/.38</td>
</tr>
</tbody>
</table>

Table entries = (delay limit)/(sensitivity limit)

For Basic error correction both Criterion 1 and 2 show a significant reduction in $p_{\text{max}}$ as message lengths and variability increase. This points out the need for careful forecasting of message lengths in an ISDN environment so that links can be properly engineered. For the examples shown the delay limit determines $p_{\text{max}}$, but the sensitivity limit would dominate if the delay limit were increased. Also, for these examples, Criterion 2 requires lower utilization than Criterion 1, and it is also less sensitive to message length distribution.

The behavior for PCR is different from Basic error correction. The sensitivity limit dominates and there is little variability with message length distribution. This behavior results from PCR systems becoming unstable for $p > 0.5$ if there are any transmission errors, and this instability causes the delay curve to rise steeply near $p = 0.5$. The reason for the instability is that after a transmission error there is a period of time, $\tau$, that the retransmissions have not caught up with the arriving MSUs, and arriving MSUs will then have to be retransmitted because their first transmission was out of sequence. Since each of these MSUs requires two service times, the link utilization is doubled during time interval $\tau$. If $p > 0.5$ these MSUs cause the link utilization to be greater than one, and $\tau$ becomes infinite. The result is that the number of MSUs in the retransmission buffer grows, and without forced retransmission delays become infinite.

4. Engineering Considerations for Forced Retransmissions in PCR

The purpose of the forced retransmission procedure is to prevent long delays from occurring after a MSU error. Long delays would result if a traffic surge made $p$ close to 0.5. As described above, forced retransmission is triggered when the retransmit buffer has reached either $N_1$ MSUs or $N_2$ octets. From the standpoint of minimizing delays it is desirable to make the limits $N_1$ and $N_2$ as small as possible. However,
these limits cannot be made too small since this would cause forced retransmissions when they are not needed and unnecessarily increase delays. There are three considerations to be made in choosing \( N_1 \) and \( N_2 \):

i. When a link is operating at its engineered load of \( 2 \rho_{\text{max}} \) and there are no MSU errors, the expected length of time to go into forced retransmission should be large (hours).

ii. When a link is operating at its engineered load of \( 2 \rho_{\text{max}} \) and there is an MSU error, the probability of going into forced retransmission should be small (about .05).

iii. The limits \( N_1 \) and \( N_2 \) must be chosen large enough that the system does not become unstable when it goes into a forced retransmission.

The engineering criteria for each of these considerations follow.

### 4.1 Engineering for Steady State Conditions

We assume the link is operating in steady state with no MSU errors. The number of messages in the retransmit buffer, \( N_1 \), is Poisson distributed with mean \( \lambda T_L \). To approximate the mean time to go into forced retransmission, we divide time into \( T_L \) increments. Let \( p \) denote the probability that there are more than \( N_1 \) MSU arrivals in time \( T_L \). The number of arrivals in each \( T_L \) increment are independent since the arrival process is Poisson. Therefore, the probability that interval \( k \) is the first to have more than \( N_1 \) arrivals is \( p(1-p)k^{-1} \), and the expected value of \( k \) is \( 1/p \). Thus, the expected time for \( N_1 \) to exceed \( N_1^* \) is \( T_L/p \), and \( p \) can be chosen to make this any desired value. If we approximate the Poisson distribution by a Normal distribution, and define \( \alpha \) by \( p = 1 - \Phi(\alpha) \), where \( \Phi() \) is the Standard Normal distribution function, then \( N_1^* \) must satisfy

\[
\lambda T_L + \alpha(\lambda T_L)^{\lambda} < N_1^*. \tag{3a}
\]

Similar reasoning leads to the following relationship for \( N_2^* \):

\[
\lambda T_L M + \alpha(\lambda T_L M)^{\lambda} < N_2^*. \tag{3b}
\]

As an example let \( T_L = 600 \) ms and \( p = 10^{-5} \) \((\alpha = 4.56)\). This gives a mean time to go into forced retransmission of about 17 hours. Applying this to Traffic Model I with a link utilization of 0.35 (see Table I) gives \( N_1^* > 78 \) and \( N_2^* > 3180 \).

### 4.2 Engineering for Errored MSUs

Consider an errored MSU that is transmitted after a MSU that is received correctly, and let the time the errored MSU ends its first transmission be \( t = 0 \). When there is an errored MSU, there will be a random time, \( r \), before the errored MSU begins retransmission. As a result, \( T_L + r \) seconds after the errored MSU is first transmitted there is a break for \( r \) seconds in receiving acknowledgements, and this results in an increase in the retransmission buffer occupancy at time \( T_L + r \). The number of MSU arrivals over the time interval \((0, r)\). It is desirable to keep the probability small of this increased retransmission buffer occupancy from causing a forced retransmission when the link utilization is at the engineered level \( 2 \rho_{\text{max}} \) discussed above.

Let \( N_r \) denote the number of MSUs that arrive during the time interval \((0, r)\), and let \( N \) denote the number of MSUs that would be in the retransmit buffer at time \( T_L + r \) if there were no MSU errors. We want to choose \( N_1^* \) so that \( Pr[N + N_r > N_1^*] < \epsilon \) for some desired probability, \( \epsilon \) (e.g., \( \epsilon = 0.05 \)). The mean and variance of \( N \) is \( \lambda T_L \), and using a normal approximation for \( N + N_r \), leads to the constraint

\[
\lambda T_L + \bar{N}_r + \alpha(\lambda T_L + Var(N_r))^{\lambda} < N_1^*, \tag{4a}
\]

where \( 1 - \Phi(\alpha) = \epsilon \) (e.g., \( \alpha = 1.65 \) for \( \epsilon = 0.05 \)). Similarly, for \( N_2^* \) we have the constraint

\[
\lambda T_L M + \bar{N}_r M + \alpha(\lambda T_L M + Var(N_r) M^2 + \bar{N}_r, Var(M))^{\lambda} < N_2^*. \tag{4b}
\]

The expressions for \( \bar{N}_r \) and \( Var(N_r) \) will be determined from the probability generating function \( N_r^*(z) \). If \( R^*(x) \) is the Laplace-Stieltjes transform (LST) of the distribution for \( r \), then \( N_r^*(z) = R^*(\lambda \alpha \lambda) \). The time \( r \) for the retransmission of the errored MSU is the length of a \( M/G/1 \) queue busy period starting with the MSUs to be retransmitted before the errored MSU in the \( M/G/1 \) queue. If \( F^*(z) \) is the LST for the combined service time of all MSUs retransmitted before the errored MSU, then \( R^*(z) = F^*(z + \lambda(1 - G^*(z))) \), where \( G^*(z) \) is the LST for the \( M/G/1 \) busy period distribution. Reference [3] gives the expression for \( F^*(z) \), and the corresponding first and second moments, \( f^{(1)} \) and \( f^{(2)} \), are:

\[
f^{(1)} = \lambda T_L \bar{S}/2 + \lambda T_L (\bar{S}/2 + \lambda \bar{S}^2 T_L/3). \tag{5}
\]

Differentiating \( N_r^*(z) \) and making the appropriate evaluations leads to the result
Simulations have shown that the utilization must be kept low to avoid forced retransmissions. Applying (4), (5), and (6) to Traffic Model I with a link utilization of 0.35 gives $N_1 > 87$ and $N_2 > 3076$, which gives a higher value for $N_1$ and a lower value for $N_2$ than obtained for the steady state condition.

### 4.3 Engineering to Ensure System Stability

With the above engineering criteria for $N_1$, the probability of going into forced retransmission is kept small. However, forced retransmissions can occur, particularly when errors occur under traffic surges causing the link utilization to be over engineered loads. When forced retransmissions occur, it is necessary that the system recover and not stay in the forced retransmission mode. We will show that if either $T_L/(N_1S) \geq 1$ or $T_L/(N_2/C) \geq 1$ there are link utilizations above which the system continues to go into forced retransmissions and is unstable.

Assume $T_L/(N_1S) \geq 1$, and consider a system with an empty retransmit buffer and a large number of MSUs in the transmit buffer at $t=0$. To simplify the discussion, we will also assume all MSUs have the same service time, $S$. At time $t=N_1S$ the system will go into forced retransmission. Refer to Figure 1, which illustrates the case for which $\xi < T_L < 2\xi$. Acknowledgements will begin to be received at time $T_L$, but the forced retransmission will continue until $t=2\xi$ because the acknowledgements begin at the front of the retransmit queue. At $t=2\xi$ the retransmit buffer occupancy will be below $N_1$, and so new MSUs will be transmitted. The rate new MSUs are transmitted is the same as the rate of acknowledgements, and so the retransmit buffer occupancy stays fixed. At $t=T_L+\xi$ the acknowledgements stop, the retransmit buffer occupancy increases, and it reaches $N_1$ at $t=3\xi$. A forced retransmission begins and this pattern will continue if the MSU arrival rate is sufficiently large.

Generalizing from the above example, it is seen that the period of the oscillation in and out of forced retransmission is $(\gamma_1+1)N_1S$, where $\gamma_1$ is the integer part of $T_L/(N_1S)$. The fraction of the time that new MSUs are sent is $1/(\gamma_1+1)$, and this is the critical utilization, $\rho_{crit}$, such that if $\rho \geq \rho_{crit}$ the periodic solution will be sustained because MSUs arrive faster than the throughput of the periodic solution. Therefore, the links must be engineered so that $2\rho_{max} < 1/(\gamma_1+1)$. Also, they should be engineered so that $2\rho_{max}$ is not too close to this limit, for otherwise it can take a considerable time to get out of the forced retransmission mode once it is started. A similar analysis for $N_2$ shows that $\rho_{crit} = 1/(\gamma_2+1)$, where $\gamma_2$ is the integer part of $T_L/(N_2/C)$. Simulations studies have shown that the periodic solutions are not unique, and the periodic behavior depends on the initial conditions at the first entry into forced retransmission.

The safest way to engineer the links is to choose $N_1$ to satisfy the conditions $T_L/(N_1S) < 1$ and $T_L/(N_2/C) < 1$. For then no matter what the load, the system will not get stuck in a forced retransmission mode. Choosing lower values somewhat defeats the purpose of forced retransmission, for at the lower values errors can drive the system into forced retransmission and rather than clear an unstable condition the forced retransmission makes the situation worse if the load is too high.

Consider again the example with Traffic Model I and $T_L = 600$ ms. To avoid instabilities at all loads, we need $N_1 > 133$ MSUs and $N_2 > 4800$ octets. Since $N_1$ has an upper bound of 127, it is not possible to protect against instabilities at all loads. For $N_1 = 127$, and also for the values obtained in Sections 4.2 and 4.3 for $N_1$ and $N_2$, the link utilization would have to be less than 0.5 Erlang to avoid unstable behavior. Since the links were engineered to 0.35 Erlang, they are safely in the stable zone at engineered load, but instabilities would result if the load increased above 0.5 Erlang and errors occurred. For smaller message lengths, the upper bound on $N_1$ leads to instabilities at lower utilizations. For example, with TUP messages having $S=1.8$ ms on 64 kb/s links, $\gamma_1 = 2$ and the links are unstable at utilizations greater than 0.33 Erlang. Simulations have shown that the utilization must be below about 0.28 Erlang to have reasonable assurance the system will leave the retransmission mode after one retransmission.
5. Choosing Between Basic and PCR Methods of Error Correction

The PCR method of error correction is intended to be used when the loop propagation delay $T_L$ is large. The question is, what is the threshold value for $T_L$, $T_L^*$, above which PCR should be used? Two methods are considered for determining $T_L^*$. The first method uses the engineered load $\rho_{\text{max}}$ obtained from Criteria 1 and 2, and $T_L^*$ is chosen such that for $T_L > T_L^*$ the $\rho_{\text{max}}$ obtained for PCR is higher than that obtained for Basic. Criterion 2 always gives a lower value for $T_L$ because it considers higher error rates, and the differences between PCR and Basic are more pronounced at higher error rates. The second method for determining $T_L^*$ looks at the delay performance after an errored MSU. When a MSU is transmitted in error with Basic, the effect can be viewed as the link stopping transmission for time $T_L$, since it takes $T_L$ seconds to receive the negative acknowledgement. Considering the busy period following the retransmission of the errored MSU, it lasts an expected time $\rho T_L/(1-\rho)$ and the mean delay for the MSUs sent during this busy period is $T_L/2$.\(^6\)

For PCR the mean delay for MSUs affected by an errored MSU is derived in Reference [3]. $T_L^*$ is chosen such that for PCR the mean delay for MSUs affected by an errored MSU is less than $T_L/2$ when $T_L > T_L^*$. Using Traffic Model I it is found that $T_L^*$ is around 300 ms or 250 ms depending on whether Criterion 1 or 2, respectively, is used to engineer the links. Recommendation Q.703 \(^{[1]}\) states that PCR should be used for $T_L > 30$ ms, which is considerably less than the above results indicate.

6. Conclusions

In this paper we have developed engineering criteria for SS#7 signaling links and examined these criteria for both Basic and PCR error correction procedures considering potential ISDN loads. With Basic error correction the message length distribution can have a significant effect on the engineered load, and therefore careful forecasting of message lengths is needed in an ISDN environment. For PCR the engineered loads are much less sensitive to message length distribution. Additional engineering considerations for PCR have been discussed, and in particular it has been shown that the forced retransmission procedure can lead to system instabilities if the thresholds are not properly engineered. We have also considered the choice between using Basic and PCR error correction and have found that PCR should only be used when the loop propagation delays exceed 250 to 300 ms, rather than the 30 ms recommended in Q.703. \(^{[1]}\)

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REFERENCES