SDLC PROTOCOL THROUGHPUT ANALYSIS

Richard W. Plummer, Member IEEE
General Electric Company
Ground Systems Programs Department

ABSTRACT

A mathematical model is presented to determine large message throughput utilizing Synchronous Data Link Control (SDLC) protocol in local or long haul networks. The model includes provisions for wait time which includes processor service times, plus satellite and/or land based propagation delays. Other inputs include the probability of ACK/NACK timeout, block size, and assumed bit error rate.

Bit errors may be precipitated by electromechanical equipment malfunctions, lightning, power surges, crosstalk, thermal noise, and numerous other causes. Although bit errors are, therefore, bursty in nature, this analysis assumes that the bit error rate is random rather than bursty which will provide conservative results.

Basic feedback theory is applied to both clarify and simplify the analysis. A detailed example illustrates use of the model in a Communication Satellite application to illustrate large message throughput degradation caused by the Satellite propagation delay for various bit error rates.

An empirically derived simple expression to determine optimum block size for maximum throughput as a function of bit error rate is presented for the stated assumptions.

INTRODUCTION

SDLC is one of the more common network protocols available. One of its uses is with local or long haul terrestrial communication networks. Transmission of data via a Communication Satellite using SDLS protocol is another application. Although modulo 8 SDLC is not the most efficient protocol for a Comsat link, it is more efficient than Asynchronous Communication (ASC) protocol. More efficient protocols from a throughput standpoint are those which facilitate a greater number of frames per block such as modulo 128, and require retransmission of only those frames in error. The improved throughput efficiency usually is obtained at the expense of a more complex protocol with additional overhead. Modulo 128 has been available for the 3725 communications controller since June 29, 1984. It is considered appropriate to develop algorithms which can be utilized with Simulation models of SDLC or BSC protocols. The techniques used in this analysis may prove beneficial in developing mathematical models for other protocols of interest.

ASSUMPTIONS

- Bit errors are random, rather than "bursty" as they actually occur. This assumption will produce conservative results.
- Maximum frames per block may be set from 1 to 7 inclusive for modulo 8 analysis. The algorithms may be appropriately modified to facilitate other modules, such as modulo 128.
- "Nominal" frame size for this analysis is 1024 bytes. The first frame of the SDLC block of this analysis will contain 977 bytes of message content and 11 bytes of overhead. Subsequent frames of each block will contain 1024 bytes of message content and 7 bytes of overhead.
- Messages are sent via a 3705 Communication Controller over a 56 kilobaud Communication Satellite channel to a 3271 dumb terminal.
- Size of acknowledgment frame is 11 bytes.
- On receipt of a negative acknowledgment (NAKJ), the retransmission will consist of the frame in error plus all remaining frames of the block. For example, when using a 7-frame block size, a NAKJ would result in frames 5, 6, and 7 being retransmitted. In the event of more than one bad frame per block, retransmission will be requested starting with the lowest numbered bad frame.
- Round trip propagation delay of 640 milliseconds plus a mean service time of 250 milliseconds constitutes the wait time contribution to wasted bandwidth. This value of service time may be too large for most applications, and will, therefore, produce conservative results in this analysis.
- Unlimited retransmissions on request (NAKJ's). In reality, a maximum number of attempts may be specified.
- Undetected errors as a function of the CRC polynomial utilized is not considered in this analysis.
- No network or equipment contention. The only factors affecting transmission time are transmission frequency, propagation delay, mean service time, and retransmissions due to bit errors or timeout as defined herein.
- Impact of SDLC zero bit insertion algorithm is negligible. This implies that the occurrence of a 01111110 bit pattern imbedded in the message content is minimal or non-existent.
- Partial frames not considered in this analysis.
Analysis based on large, multimegabyte messages.

ANALYSIS

The message block and frame structure described in the Assumptions will be used for this analysis. The key variables which influence message transmission efficiency are:

- Frame size of first and subsequent frames of block.
- Frame overhead of first and subsequent frames of block.
- Maximum frames per block considered (up to 7)
- ACK/NAK frame size
- Channel capacity
- Bit error rate
- Wait time (equals propagation delays plus service times)
- Probability of timeout

The channel capacity is assumed to be 56 kilobaud for the examples considered herein since this is the highest channel capacity normally available for commercial terrestrial communications use, and will facilitate direct comparison at the same frequency to illustrate the degrading effect of propagation delay for satellite transmissions.

Message transmission efficiency, for this analysis, equals the time required for error free continuous transmission of the referenced message without overhead, service times, or propagation delays divided by the calculated time to transmit the message with the specified overhead, service time, propagation delay, bit error rate, and protocol assumptions.

Figure 1 illustrates the effect of a large message composed of many single frame message blocks, such as used with BSC protocol, being transmitted originally (input stage), and then defectively transmitted blocks being retransmitted indefinitely with as many additional stages as required to obtain a completely correct output message which must equal the input message. In reality, each stage is the same portion of a communication network, but repeated stages as illustrated help visualize the process and the equation derivation.

Equation (1) states that the output message equals the input message times a function of the probability of a successful message transmission and the probability of an unsuccessful message transmission. Equation (1) reduces to equation (2), which contains a portion (in parentheses) of one of the Macaulay Power Series. Equation (3) represents the input/output transfer function of the network, and includes the closed equation form of the referenced Power Series. The value of equation (3) must always equal 1, providing the probability of success plus the probability of failure equals 1. This is true for the single message block format of BSC protocol, as well as multiframe block protocols such as SDL.

It is observed that equation (3), resembles the closed loop output/input transfer function of a feedback amplifier; namely, \( A' = C' \cdot E' = A'(1-A'B) \), where \( A' \) is the closed circuit gain, \( E' \) is the closed circuit output, \( E \) is the input, \( A \) is the open circuit gain, and \( B \) is the portion of the output which is fed back into the input in the closed loop configuration.

Equation (4) represents the total expected number of equivalent complete message transmissions including retransmissions. Equation (5) represents the expected number of equivalent complete retransmissions required to obtain exactly one good output message identical to the input message.

The equivalent equation for the model of Figure 2 is \( OM'/IM = PS/(1-PF) \), where \( B = PF/PS \), and by substitution \( OM'/IM = PS/(1-PF) \) which is identical to equation (3).

Equations (6) and (7) are defined by inspection of Figure 2. Equation (8) is derived by substitution.
SDLG Protocol Throughput Analysis

\[ \text{OM}' = \text{I2} \times \text{PS} \]
\[ \text{I2} = \text{IM} + \beta \times \text{OM}' \]
\[ \frac{\text{OM}'}{\text{IM}} = \frac{\text{PS}(1-\beta\text{PS})}{\text{PS}(1-\beta\text{PS})} \]
\[ \beta = \frac{\text{PP}/\text{PS}}{\text{PS}(1-\beta\text{PS})} = \frac{\text{PS} \times 1/(1-\beta\text{PS})}{1} \]

Equation (9) is derived by realizing that equation (8) must equal 1 for successful receipt of one good output message. Substitution yields equation (10), and the equivalent network is illustrated on the right side of Figure 2. Observe that equation (10) is identical to equation (3).

Figure 2 may be used with protocols such as Bisynchronous which transmit single frame blocks originally and retransmit the entire block upon receipt of a negative acknowledgment. Protocols such as SDLG which retransmit only the portion of a block starting with the frame in error through and including the last frame of the block, require additional definition.

Figure 3 illustrates reduction of the repeated message transmission model as applied to SDLG protocol for ease of more concisely and comprehensively portraying the SDLG multiframe block model. Equation (11) is the SDLG first frame equivalent of equation (10). Equation (12) is the SDLG equivalent of equation (10) for frames other than Frame 1. Observe that the numerator is the probability of a NAKJJX acknowledgement which requests a retransmission of all remaining block frames including frame K of the original Frame block.

Equation (13) states that the open loop probability of a successful transmission (ACK) of a J frame block plus the summation of open loop probabilities from NAKJJX through and including NAKJJX equals 1 in accordance with basic probability theory (PS + PF = 1). Note that the integer J denotes the number of frames which constitute an SDLG block of data. The number of frames per block for SDLG modulo 8 protocol

\[ \frac{\text{OM}'}{\text{IM}} = \text{PSJ1}(1-\text{PNJ1}) = \text{PSJ1'} \text{ (REFER TO FIGURE 3B)} \]
\[ \frac{\text{OM}'}{\text{IM}} = \text{PNJK}(1-\text{PNJ1}) = \text{PNJK'} \text{ (REFER TO FIGURE 3D)} \]
\[ \begin{align*}
\text{PSJ1} + \sum_{k=1}^{J} \text{PNJK} &= 1 \\
\text{PSJ1'} + \sum_{k=2}^{J} \text{PNJK'} &= 1
\end{align*} \]

J FRAME SDLG BLOCK OPEN LOOP PROBABILITY VALUES:

\[ \text{PNJK} = \text{OPEN LOOP PROBABILITY OF SUCCESSFUL 1ST FRAME Transmission} \]
\[ \text{PNJK} = \text{OPEN LOOP PROBABILITY OF A NAKJJX FOR FRAME K OF J FRAME BLOCK} \]
\[ \text{RETRANSMIT FRAMES K THROUGH J} \]

J FRAME SDLG BLOCK CLOSED LOOP PROBABILITY VALUES:

\[ \text{PNJK'} = \text{CLOSED LOOP PROBABILITY OF A NAKJJX FOR FRAME K OF J FRAME BLOCK} \]

NOTE: J REPRESENTS THE NUMBER OF FRAMES WHICH COMprise THE BLOCK IN QUESTION

Figure 3: Repeated Message Transmission Model Reduction (SDLG Protocol)
may be set to any integer value from 1 to 7, inclusive, by the user.

When the loop is closed and feedback applied, equation (14) states that for the closed loop condition, the probability of a successful transmission of a frame block plus the summation of probabilities from NAKi through and including NAKij equals 1 in accordance with basic probability theory. Observe that in this equation NAKije is incorporated in the closed loop equation by means of PSij, which is defined in equation (11).

\[ \text{PS3' + PN32' + PN33' = 1; PER EQUATION (14)} \]
\[ \text{O3 + O32 + O33 = IM; MULTIPLYING EQUATION (25) BY IM} \]
\[ \text{O3 + O2 + O1 = IM; FOR OM = IM} \]
\[ \text{O32 + O33 = O2 - O1} \]
\[ \text{O2 = PN33'} \]
\[ \text{O1 = PN22' = PN32'} \]

Figure 4: SDLC Three-Frame Block Model (Stage 1)

THREE FRAME SDLC BLOCK MODEL DEVELOPMENT (Stage 1)

The algorithm development for the 3-frame SDLC block model will consist of two stages. The first stage will determine a set of variables which have a recognizable pattern and may be easily derived for blocks of larger frame sizes such as the 7-frame SDLC block of this example, or the 128-frame SDLC modulo 28 block referenced earlier. These variables can then be readily applied to the final algorithms developed in the second stage. It is believed that this two-stage approach makes the analysis as well as the software coding more manageable for the larger frame sizes encountered with both similar and different type protocols. It is emphasized that the values obtained in the stage 1 development are not all actual protocol values, but rather represent a convenient method to facilitate stage 2 algorithm development.

Figure 4 illustrates the closed loop message flow for a 3-frame SDLC block. The equations for the open loop output/input transfer functions of the one, two and three frame block are derived from Table 1. Observe that in each case, equation (13) is satisfied.

\[ \text{S31 = (1-(0.0001)**7904 = 0.924002598} \]
\[ \text{S32 = S33 = (1-(0.0001)**8248 = 0.920829475} \]

There are 7904 bits in the first frame, and 8248 bits in frames 2 and 3 of this example.

The probability of a successful acknowledgment being received prior to timeout is expressed as:

\[ \text{SA = PNT(1-(1-e)**afb)} \]

where PNT is the probability of no timeout occurring, and afb represents the number of bits contained in the ACK/NAK frame, 88 in this example.

\[ \text{SA = (0.99)((1-(0.0001)**88) = 0.989129179} \]

The probability of an unsuccessful frame transmission is expressed as:

\[ \text{FJK = 1-SJK = 1-(1-e)**b} \]
\[ \text{FJ1 = 1-SJ1 = 0.075997402} \]
\[ \text{FJ2 = FJ3 = 1-SJ3 = 0.079170526} \]
The probability of an unsuccessful ACK/NAK frame or a timeout is expressed as:

\[ FA = 1-SA = 1-(PNT(1-e)^{**a/f}) \]  
\[ FA = 1-SA = 0.010870821 \]  
(18)

For any given J frame SDLC block model, only the first frame of the J frame block configuration will contain a different number of bytes than all of the other frames. For example, when considering the entire 3-frame block SDLC model of Figure 4, only the first frame of the 3-frame block contains a different number of bytes (398 compared to 1031 in this example) than either of the other 2 frames illustrated. S31 and F31 of Tables 1 and 2, for this reason, have different values than any other SJK's or FJK's of these tables.

Table 1 illustrates the probability breakdown for all possible transmission event occurrences for a 3, 2 and 1 frame block, respectively. The total number of event occurrences for a block is 2^*(J+1), where J represents the number of frames per block. Each of the individual event probabilities represents the combined product of each SJK, FJK, SA or FA associated with that event. The probability of a NAKJK in Table 1 for a given J frame block is the sum of the individual probabilities associated with the NAKJK consequences of the block size in question. The probability of a successful J frame block transmission plus the probability of an unsuccessful transmission (summed of NAKJK's) equals 1 according to equation (13), and basic probability theory.

The closed loop output/input transfer functions are readily derived by dividing the open loop output/input transfer functions by the "feedback divisor", (1-PMJ) for each J frame block per equations (11) and (12). Accordingly, for this example:

\[ PS'3 = PS3/(1-PMJ) = 0.847926921 \]  
\[ PN32' = PN32/(1-PMJ) = 0.079170526 \]  
\[ PN33' = PN33/(1-PMJ) = 0.072902553 \]  
\[ PS2' = PS2/(1-PMJ) = 0.920829475 \]  
\[ PS22' = PS22/(1-PMJ) = 0.079170526 \]  
\[ PS1' = PS1/(1-PMJ) = 1.000000000 \]  
(24)

Observe that PS'1 = PS2' + PN22' = PS3' + PN32' + PN33' = 1 per equation (14).

Equation (25) of Figure 4 results directly from equation (14). Equation (25) multiplied by IM yields equation (26). By inspection of Figure 4, O3+O2+O1 = 0M = IM for the output message to exactly equal the input message. This results in equation (27). Subtracting equation (27) from (26) results in equation (28).

By setting the input message equal to 1:

\[ O3 = PS3' = 0.847926921 \]  
\[ O32 = PN32' = 0.079170526 \]  
\[ O33 = PN33' = 0.072902553 \]  
\[ O2 = O22 = 0.079170526 \]  
\[ O2 = O22 = 0.079170526 \]  
\[ O1 = O1 = 0.079170526 \]  
(34)

Observe that equations (25) through (28) of Figure 4 are satisfied. Also, observe that O1 = PN22' = PN33', and that O2 = PN33'. This pattern appears to indicate the possibility of an inductive solution for larger frame blocks.

By substituting the appropriate probability equations of Table 2 and then replacing occurrences of FJK with (1-SJK), it can be demonstrated that:

\[ PN33' = O2 = PN32' * PS2' \]  
\[ PN32' = PN22' = O1 \]  
(37)

THREE FRAME SDLC BLOCK MODEL DEVELOPMENT (Stage 2)

The OJK (NAKJK) outputs of Figure 4 are each illustrated going to a single point. In reality, each output is split into two portions. One part
goes to the output (O1) of the block, and the other part goes to the same point as indicated in Figure 4. Figure 5 illustrates the statistical message flow for a 3-frame SDLC block with a "nominal" frame size of 1024 bytes. Observe, for example, that O32 results in a good first frame being transmitted to the output in the form of the lower input to the O3 summing point, and the remaining two frames (NAK32) being retransmitted in the form of the input equation of the 2-frame block. The one-frame block, in this analysis, continues to retransmit NAK1 messages until the output of this block equals the input to the block.

As illustrated in Figure 5, the output message consists of the O3 output plus approximately 1/3 of the O32 output, plus approximately 2/3 of the O33 output, plus approximately 1/3 of the O34 output, plus approximately 1/3 of the O4 01 output, and is represented by equation (41). If all frames were the same size, rather than the differently sized frame of the SDLC block caused by greater first frame overhead but less first frame message content, then all occurrences of the word "approximately" in the last sentence would be replaced with "exactly".

Table 2 illustrates the frame-by-frame breakdown at a byte and partial byte level of message transmission and retransmission due to NAKs. It is realized that frames will not be altered as indicated, nor will partial bytes be transmitted, but these values represent the statistical expected average values for a large message transmission of 1024 byte "nominal" frames in three block blocks, and may, therefore, be utilized to determine large message throughput.

The same probability values are used as those of Table 1. Column 1 contains the frames per block which may vary from 3 to 1, inclusive. Column 2 contains the input message and overhead bytes for each of the frames in column 1. Note that the input to the 2-frame block consists of the 3-frame block NAK 2 output, and the input to the 1-frame blocks consists of the 3-frame block NAK 3 output plus the 2-frame block NAK 2 output.

Column 3 contains the probability equation plus the actual probability value used to determine the message throughput. Column 4 contains the consequence of the probability equation of column 3 which may be a good block or partial block transmission attempt resulting from a NAKJ2 or a NAKJ3. In the case of a NAKJX, the remaining frame or frames of the original block will be retransmitted as smaller blocks. NAKJ1's are not illustrated directly in Table 2 since they are accounted for in the feedback factors R3, R2, and R1. The variable R was selected to represent Retransmission. Observe that the value of RJ is obtained by utilizing equation (4) of Figure 1, where PF (probability of failure) is PAJ1, the probability of a NAKJ resulting from a failure to correctly transmit the first frame of a J-frame block, or the ACK frame.

Columns 5, 6 and 7 contain the frame 1, 2 and 3 message and overhead bytes received at the output for each of the applicable block transmission configurations. Finally, the individual good frame sums of column 5, column 6 and column 7 equal the originally transmitted message and overhead bytes for each of the respective frames.

SEVEN-FRAME SDLC BLOCK MODEL DEVELOPMENT

The SDLC 7-frame "stage 1" block model is illustrated in Figure 6. The same values will be used in this example as in the previous example, namely:

- bit error rate = 0.00001
- frame 1 = 988 bytes
- frames 2 to 7, inclusive, = 1031 bytes
- wait time value = 0.80 seconds
- PNT = 0.99

![Figure 5: SDLC Three-Frame Block Model (Stage 2)](image-url)
Table 2: Three-Frame SDLC Block Example

<table>
<thead>
<tr>
<th>FRAMES PER BLOCK</th>
<th>INPUT BYTES FRAME 1</th>
<th>FRAME 2</th>
<th>FRAME 3</th>
<th>OUTPUT BYTES FRAME 1</th>
<th>FRAME 2</th>
<th>FRAME 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

These values result in the same preliminary probabilities as the previous example, namely:

\[
S71 = 0.924002596
\]

\[
S72=S73=S74=S75=S76=S77 = 0.920829475
\]

\[
SA = 0.989129179
\]

\[
F71 = 0.075957402
\]

\[
F72=F73=F74=F75=F76=F77 = 0.079170526
\]

\[
FA = 0.010870821
\]

A program was coded on the HP-41C to determine the output/input transfer functions and the 7 differently sized block output messages which produce the final total output message. Inspection of the final results confirm the inductive solution pattern previously hypothesized, namely:

\[
O1=PN22'\cdot PN32'\cdot PN42'\cdot PN52' = 0.079170526 (42)
\]

\[
O2=PN33'\cdot PN43'\cdot PN53' = 0.072902553 (43)
\]

\[
O3=PN44'\cdot PN54'\cdot PN64' = 0.067130820 (44)
\]

\[
O4 = PN55' \cdot PN65' = 0.061816038 (45)
\]

\[
O5 = PN66' = 0.065922029 (46)
\]

\[
O6 = PN77' = 0.062415482 (47)
\]

\[
O7 = 1-02+02=04+05+06 = 0.696942552 (48)
\]

Figure 6: SDLC Seven-Frame Block Model

transfer functions in descending order is constant, and is equal to the open loop probability of a successful frame transmission for each but the first frame of a J-frame block. The transfer function of the maximum size block equals one minus the sum of all other size block transfer functions.

As before, the following equations represent the various block and overall output/input transfer functions assuming a 1024 byte "nominal" frame size.

\[
07'/IM = 07 + (988\times(5x103))x077/7174 + (988\times(4x103))x076/7174 + (988\times(3x103))x075/7174 + (988\times(2x103))x074/7174 + (988\times(1x103))x073/7174 + 988x072/7174
\]

\[
06'/IM = (6x103)x06/7174 + (5x103)x05/7174 + (4x103)x05/7174 + (3x103)x05/7174 + (2x103)x06/7174 + (x103)x06/7174
\]

Observe that except for the maximum size block (7 frames in this example), the ratio of adjacent block
\begin{equation}
05' / IM = \frac{(5 \times 10^3) \times 05}{7174} + \frac{(4 \times 10^3) \times 055}{7174} + \frac{(3 \times 10^3) \times 054}{7174} + \frac{(2 \times 10^3) \times 053}{7174} + \frac{1031 \times 052}{7174}
\end{equation}

\begin{equation}
04' / IM = \frac{(4 \times 10^3) \times 04}{7174} + \frac{(3 \times 10^3) \times 044}{7174} + \frac{(2 \times 10^3) \times 043}{7174} + \frac{1031 \times 042}{7174}
\end{equation}

\begin{equation}
03' / IM = \frac{(3 \times 10^3) \times 03}{7174} + \frac{(2 \times 10^3) \times 033}{7174} + \frac{1031 \times 032}{7174}
\end{equation}

\begin{equation}
02' / IM = \frac{(2 \times 10^3) \times 02}{7174} + \frac{1031 \times 022}{7174}
\end{equation}

\begin{equation}
01' / IM = \frac{1031 \times 01}{7174}
\end{equation}

(51) optimum block size = \frac{351407}{(e \times 10^8)} \quad (57)

**[\log(351407/102901)]/3**

where e is the bit error rate; and, as before, the double asterisks denote exponentiation. This empirically derived equation is accurate to within less than 10% error for bit error rates between 10^{-8} and 10^{-5}, inclusive. The error could be made essentially negligible at the expense of a more complex equation. Figure 11 illustrates optimum block size as a function of bit error rate utilizing equation (57).

RESULTS

Tables 3 and 4 illustrate various analytical results for both 3- and 7-frame SDLC modulo 8 transmission of a 10 megabyte message over a 56 KB Comsat channel. The results of the last 5 columns may be modified by the appropriate ratio to determine values for other message sizes.

After completing the original analysis, making runs, and plotting results, it was observed by examination of Figure 7 that a simple equation could be expressed to closely represent the optimum block size in bytes as a function of bit error rate for the example variables assumed, namely:

\begin{center}
Table 3: Three-Frame SDLC Block Detailed Example
\end{center}

<table>
<thead>
<tr>
<th>FRAME #5 IN BLOCK</th>
<th>BLOCK SIZE (BYTES)</th>
<th>BYTES XMITTED PER BLOCK</th>
<th>OUTPUT MESSAGE CONTENT (BYTES) PER BLOCK</th>
<th>BLOCKS XMITTED PER 10 MEG MESSAGE</th>
<th>WAIT (1) TIME (SEC)</th>
<th>MSG (2) TIME (SEC)</th>
<th>TOTAL TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>3050</td>
<td>3377.13</td>
<td>2760.21</td>
<td>1156731</td>
<td>3792.70</td>
<td>1638.49</td>
<td>4430.05</td>
</tr>
<tr>
<td>2-3</td>
<td>2662</td>
<td>179.33</td>
<td>155.72</td>
<td>621290</td>
<td>301.30</td>
<td>201.04</td>
<td>502.34</td>
</tr>
<tr>
<td>3</td>
<td>1031</td>
<td>89.62</td>
<td>81.07</td>
<td>310645</td>
<td>301.30</td>
<td>44.85</td>
<td>346.15</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5308.32</td>
</tr>
</tbody>
</table>

EFFICIENCY = 28.22%
CHANNEL RATE = 56 KB
BIT ERROR RATE = 10^{-8}
PROBABILITY OF TIMEOUT = 0.01

\begin{center}
Table 4: Seven-Frame SDLC Block Detailed Example
\end{center}

<table>
<thead>
<tr>
<th>FRAME #5 IN BLOCK</th>
<th>BLOCK SIZE (BYTES)</th>
<th>BYTES XMITTED PER BLOCK</th>
<th>OUTPUT MESSAGE CONTENT (BYTES) PER BLOCK</th>
<th>BLOCKS XMITTED PER 10 MEG MESSAGE</th>
<th>WAIT (1) TIME (SEC)</th>
<th>MSG (2) TIME (SEC)</th>
<th>TOTAL TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>7174</td>
<td>7849.38</td>
<td>5662.26</td>
<td>11558304</td>
<td>1611.14</td>
<td>1373.01</td>
<td>2984.15</td>
</tr>
<tr>
<td>2-7</td>
<td>6156</td>
<td>537.70</td>
<td>395.73</td>
<td>791772</td>
<td>127.99</td>
<td>126.40</td>
<td>254.39</td>
</tr>
<tr>
<td>3-7</td>
<td>5155</td>
<td>446.08</td>
<td>346.05</td>
<td>659010</td>
<td>127.99</td>
<td>102.40</td>
<td>229.39</td>
</tr>
<tr>
<td>4-7</td>
<td>4124</td>
<td>358.47</td>
<td>287.76</td>
<td>527848</td>
<td>127.99</td>
<td>102.40</td>
<td>229.39</td>
</tr>
<tr>
<td>5-7</td>
<td>3093</td>
<td>268.85</td>
<td>224.96</td>
<td>396886</td>
<td>127.99</td>
<td>102.40</td>
<td>229.39</td>
</tr>
<tr>
<td>6-7</td>
<td>2062</td>
<td>179.32</td>
<td>155.72</td>
<td>263924</td>
<td>127.99</td>
<td>102.40</td>
<td>229.39</td>
</tr>
<tr>
<td>7</td>
<td>1031</td>
<td>89.62</td>
<td>81.07</td>
<td>131962</td>
<td>127.99</td>
<td>102.40</td>
<td>229.39</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3954.09</td>
</tr>
</tbody>
</table>

EFFICIENCY = 37.88%
CHANNEL RATE = 56 KB
BIT ERROR RATE = 10^{-8}
PROBABILITY OF TIMEOUT = 0.01
example, equals the sum of the frame 2 and 3 message plus overhead bytes of Table 2, 2 frames per block, "GOOD BLOCK" data divided by 31252256. Observe that the Retransmission factor R2 is not used in this determination. Alternatively, the 2-frame block value, for example, may be determined by multiplying the total input to the 2 frames per block model by the two block retransmission factor, R2.

Column 4 contains the number of received message bytes per block. These values may be derived by using equations (38) to (41), and (49) to (56), after first replacing all occurrences of 986 and 1031 with 977 and 1024, respectively, to obtain message content without overhead. Observe that the column 4 total figure in both tables equals the original block message content. The difference between these values and the complete block size of column 2, row 1 represents overhead bytes of 11 bytes for the first frame and 7 bytes for additional frames in the block.

Column 5 contains the total bytes per block required to be transmitted in order for the complete 10 megabyte message received to exactly equal the message sent. These values are obtained by dividing the message size of 10 megabytes by the message content block size of 3025 bytes, and multiplying the results by the bytes transmitted per block values of column 3.

Column 6 contains the blocks transmitted per 10 megabyte message, and is obtained by dividing column 5 by column 2.

Column 7 contains the wait time, and is obtained by multiplying the column 6 values of blocks per message by the wait time per block. The wait time per block in these examples is 800 milliseconds, consisting of round-trip propagation delay plus mean service time.

Column 8 contains message (including ACKs and NAKs) transmission time determined by adding the total ACK/NAK frame bytes of 11 times column 6 values to the transmitted message and overhead bytes of column 5, multiplying these values by 8 to convert bytes to bits, and dividing the results by the channel rate of 56000 bits per second.

Column 9 values are obtained by adding column 8 and column 7 values. The result is total time including propagation delay, service time, plus message transmission and retransmission for each of the 1 to 3-frame block configurations of these examples.

Columns 4 through 9 are summed individually to produce total results for these columns. Efficiency is determined by dividing the time required to transmit the 10 megabyte message as one error free block without overhead by the estimated time determined, then multiplying by 100 to convert to percent.

![Figure 7: Expected Time Versus Block Size for a 56 Kbps SDLC Comsat Link](image7.png)

![Figure 8: Efficiency Versus Frames Per Block for e = 10^{-6}](image8.png)

![Figure 9: Efficiency Versus Frames Per Block for e = 10^{-6}](image9.png)