CHAPTER 4

Optimization of Infrared Data Link Layer

The IrLAP performance evaluation presented in chapter 3 revealed that utilization significantly degrades if unsuitable values for the window and frame size parameters are implemented. If a high window size value is used in links with high BER, an error frame is followed by many frames in the same window transmission. As IrLAP utilizes a Go-Back-N retransmission scheme, all these frames will be eventually retransmitted. If a low window size value is utilized, the increased link turn around frequency may significantly affect performance. If a large frame size is used as related to link BER, the resulting high frame error probability degrades utilization because a single bit error causes the retransmission of the entire frame. If a small frame size is used, the constant frame overhead degrades performance.

This chapter employs the mathematical model developed in the previous chapter for IrLAP performance to derive optimum values for window and frame size parameters for maximum performance. To find the utilization maximum, the first derivative of the utilization equation versus window and frame size is set to zero to derive simple equations for optimum window and frame size values. However, the communicating stations can only estimate the link BER based on the number of error frames. An algorithm is developed for the transmitting station that estimates link BER and implements optimum values based on frame rejections by the receiver. The effectiveness of the proposed algorithm is explored using simulation techniques.

The outline of this chapter is as follows. Section 4.1 presents the importance of the F-timer time out period when optimum window and frame size values are implemented. It also proposes an S-frame improvement to IrLAP operation that eliminates delays arising from the F-timer expiration. Section 4.2 derives (a) optimum window size values for fixed frame size, (b) optimum frame size values for fixed window size and (c) simultaneously optimal window and frame size values. Section 4.3 presents the improvement in IrLAP performance when optimum window and/or frame size values are employed. Section 4.4 presents the effectiveness of the proposed (in section 4.1) S-frame improvement in IrLAP operation combined with optimum window and frame size employment. The implementation issues of optimum values are addressed in section 4.5

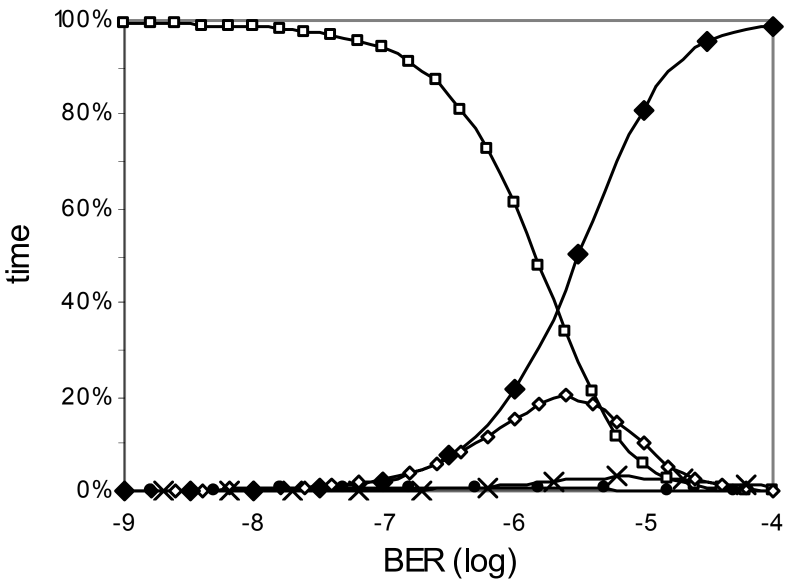
by developing a simple and effective algorithm for the transmitting station that estimates link BER and implements optimum window and frame size values.

4.1 Significance of F-timer time out period

Equation (3.5) shows that if the link BER p_b is increased, frame error probability p is significantly increased. In such a case, the time spent on the primary's F-timer expiration, represented in (3.9) by term pt_{Fout}, may significantly increase the average WTT resulting in utilization degradation. IrLAP specification [49] poses only an upper limit of 500ms for the t_{Fout} value and allows the implementation of smaller values. According to IrLAP specification [49], if the secondary has information ready for transmission, it sets the F-bit in the last I-frame it transmits. Otherwise, upon gaining transmission control, it immediately transmits an S-frame with the F-bit set, thus acknowledging correctly received I-frames and reversing link direction. Thus, the secondary station never holds transmission control without transmitting I-frames. As a result, the t_{Fout} value may be safely reduced from 500ms to the smaller time period required for the secondary to transmit a full window (N) of full payload (16Kbits) I-frames plus the time required to reverse the link direction twice, $t_{Fout} = Nt_{Imax} + 2t_{ta}$. This value assumes that the secondary has transmitted a full window of I-frames and the primary did not manage to correctly receive a single I-frame.

In the saturation case considered in this work, the secondary station never transmits I-frames to the primary and immediately acknowledges I-frames correctly received by means of an S-frame transmission. As a result, a smaller t_{Fout} value of $t_{Fout} = t_{Imax} + 2t_{ta}$ may be safely implemented in the current information exchange scenario. This value allows the secondary station to transmit an S-frame or an I-frame if it wishes to transmit data at the end of considered information transfer from the primary. This t_{Fout} value is valid since it corresponds to a maximum window size parameter of one for the primary station negotiated and agreed during link establishment.

The t_{Fout} value becomes of key importance for maximum utilization at high BER if optimum link layer parameter values are implemented by the primary station. Fig. 4.1 shows the time allocation of various IrLAP tasks versus BER when optimum window size N values are implemented for t_{Fout}=500ms. At high BER, a significant amount of time is spent on F-timer expiration causing serious utilization degradation. It can be



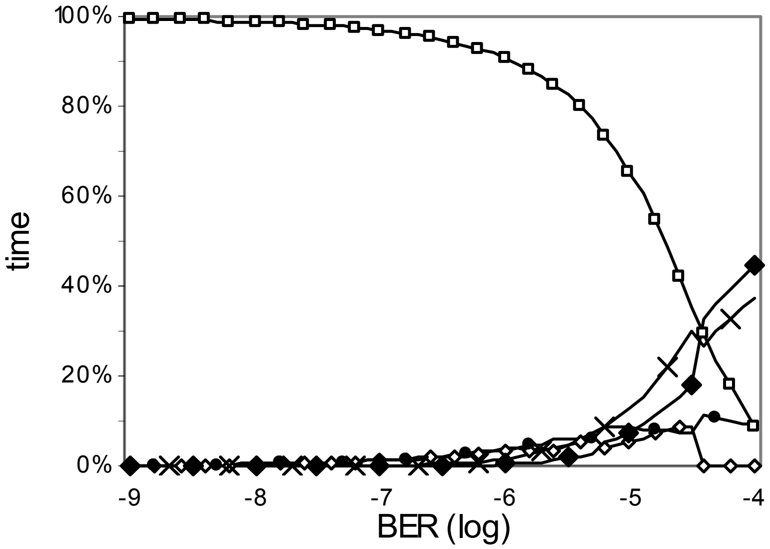
□ *useful data transmission (utilization)*
◇ *retransmission of correctly received out of sequence frames*
x *retransmission of error frames*
◆ *F-timer expiration*
● *reversing link direction (hardware latency)*

Figure 4.1 Time allocation of various IrLAP tasks against BER for N optimum, t_{Fout}=500ms, C=16Mbit/s, l=16Kbits, t_{ta}=0.1ms

easily observed that time portion utilized on F-timer expiration is much larger than the time portion utilized on other IrLAP tasks, such as retransmitting error frames, retransmitting correctly received out of sequence frames and reversing link direction. The situation is explained by considering that a single I-frame transmission error results in a significant 500ms delay if the lost I-frame contains the P-bit. For the saturation case considered, if the maximum window size allowed for the primary is agreed to be equal to one and $t_{Fout} = t_{Imax} + 2t_{ta}$, a much different behavior is shown in Fig. 4.2. A significant utilization improvement is observed over a wide BER range (10^{-7} to 10^{-4}) mainly by taking advantage of time otherwise wasted on F-timer expiration [98]. Unless otherwise specified, the t_{Fout} value implemented in this work is given by

$$t_{Fout} = t_{Imax} + 2t_{ta} \tag{4.1}$$

A different approach to address the significant delays arising from the F-timer expiration is to reduce the probability of P-bit loss rather than reducing the time wasted for every P-bit loss. According to the IrLAP specification state charts [49], the primary station sets the P-bit of the last I-frame in a window transmission. This decision



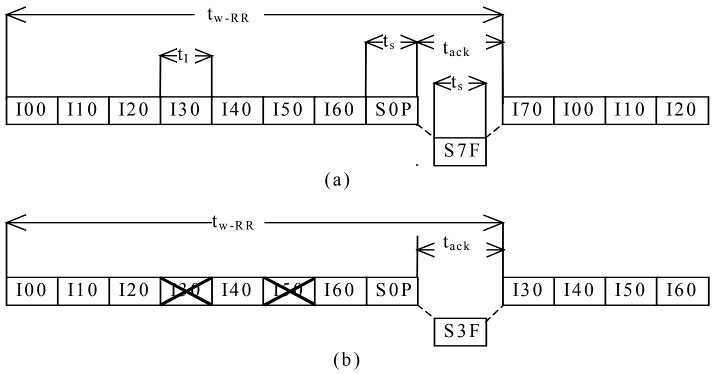
□ *useful data transmission (utilization)*
◇ *retransmission of correctly received out of sequence frames*
x *retransmission of error frames*
◆ *F-timer expiration*
● *reversing link direction (hardware latency)*

Figure 4.2 Time allocation of various IrLAP tasks against BER for N optimum, $t_{Fout}=t_{Imax}+2t_{ta}$*,* $C=16Mbit/s$*,* $l=16Kbits$*,* $t_{ta}=0.1ms$

assumes that link BER is very low and frame error probability p is very small. Thus, the P-bit is seldom lost and time spent on F-timer expiration is negligible. However, if link BER is relatively high, p is significantly increased as it usually refers to an I-frame with 16Kbits of user data. To reduce the probability of P-bit loss, an IrLAP modification is proposed. The primary should not set the P-bit in the last I-frame it transmits, but transmit the P-bit in a new Receive Ready (RR) S-frame that follows the last I-frame transmission. As S-frames are very small, they introduce negligible additional delays. As S-frames have very small frame error rates, delays on F-timer expiration are significantly reduced. The mathematical model presented in this work can be easily altered to calculate the utilization performance for the proposed IrLAP improvement. S-frame modification is presented in Fig. 4.3(a)(b) and WTT becomes

$$t_{w-RR} = Nt_I + t_s + t_{ack} \tag{4.2}$$

independent of the number of frame errors in the window transmission. The assumption that S-frames are always transmitted error free holds true because the S-frame error rate is well below 0.01 at the highest BER value considered in this work. Utilization is given



Ixy : *I-frame with* N_s=x *and* N_r=y
SxP : *S-frame with* N_r =x *and P-bit set*
SxF : *S-frame with* N_r =x *and F-bit set*
a) Window error free transmission (P-bit in S-frame)
b) Retransmitted frames due to error frame with N_s *=3 and* N_s *=5 (P-bit in S-frame)*

Figure 4.3 Determination of window transmission time $t_{w\text{-}RR}$

by

$$U_{RR} = \frac{l}{C}\cdot\frac{1-p}{p}\cdot\frac{1-(1-p)^N}{Nt_I + t_s + t_{ack}} \tag{4.3}$$

The following analysis for deriving optimum values for window and/or frame size parameters is derived for links not employing the S-frame modification and using small t_{Fout} values, such as the value given in (4.1). Identical formulae have been derived for the S-frame modification (which eliminates F-timer delays) by taking the first derivative of utilization equation (4.3). Hence the following results and conclusions apply to both cases.

4.2 Derivation of optimum values

4.2.1 Optimum window size for fixed frame size

Due to the half duplex nature of the IrLAP protocol, window size is a very important and easily adjustable parameter. If a small window size value is implemented, the increased link turn around frequency results in significant delays and decreases utilization. If a high window size value is implemented for high BERs, a large number of frames following an error frame may be transmitted. Even if these frames are correctly received, they are considered as out of sequence and are discarded by the receiver. These frame transmissions essentially delay reversing link direction, acknowledging correctly received frames and retransmitting the erred frame. Time needed for such frame transmissions is simply wasted.

To derive optimum window size values that result in maximum utilization, the first derivative of (3.15) against N must be set to zero. First considering the valid approximation for small p,

$$(1-p)^N \approx 1 - Np + \frac{N(N-1)}{2}p^2 \tag{4.4}$$

the derivative of (3.15) becomes

$$\frac{\partial U}{\partial N} = \frac{l(1-p)}{2C} \cdot \frac{\partial}{\partial N}\left\{\frac{2N - N(N-1)p}{Nt_I + 2pt_{ta} + pt_{Imax} + pt_s + t_{ack}}\right\} = 0 \tag{4.5}$$

After some algebra and assuming $2pt_{ta} + pt_{Imax} + pt_s + t_{ack} \approx t_{ack}$

$$(-pt_I)N^2 + (-2pt_{ack})N + 2t_{ack} + pt_{ack} = 0 \tag{4.6}$$

Assuming $pt_{ack} << 2t_{ack}$ and $-2pt_{ack} < -pt_I$, (4.6) becomes

$$(-pt_I)N^2 + 2t_{ack} = 0 \tag{4.7}$$

and

$$N_{opt} = \sqrt{\frac{2t_{ack}}{pt_I}} \tag{4.8}$$

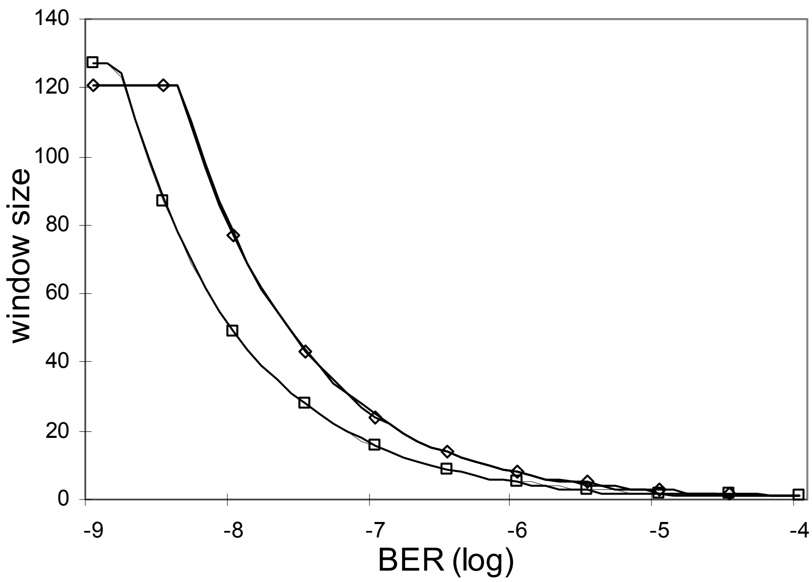
Considering the valid approximations for small p_b and $l >> l'$, $p \approx lp_b$ and $t_I \approx \frac{l}{C}$, optimum window size value is given by

$$N_{opt} = \sqrt{\frac{2t_{ack}C}{l^2 p_b}} \tag{4.9}$$

The optimum window size values versus BER for fixed frame size are shown in Fig. 4.4. Window size should be decreased with the increase of BER for maximum utilization. Note that at very low BER, the optimum window size values should be greater than the maximum window size value of 127 frames allowed by the IrLAP specification. Fig. 4.4 compares N_{opt} values derived from (4.9) with optimum window size values obtained using exact numerical methods in (3.15) for a 16Mbit/s link with t_{ta}=0.1ms and for a 4Mbit/s link with t_{ta} =1 ms. An exact match is observed validating the approximations used to derive (4.9).

4.2.2 Optimum frame size for fixed window size

A different approach for reducing the data transmitted in a window transmission is



– optimum N (analysis), C=16Mbit/s, t_{ta}*=0.1ms*
□ optimum N (numerical), C=16Mbit/s, t_{ta}*=0.1ms*
– optimum N (analysis), C=4Mbit/s, t_{ta}*=1ms*
◇ optimum N (numerical), C=4Mbit/s, t_{ta}*=1ms*

Figure 4.4 Optimum window size validation, l=16Kbits, $t_{Fout}=t_{Imax}+2t_{ta}$

by decreasing frame size. A small frame size reduces frame error probability and the necessity for retransmissions. However, as each frame transmission requires the transmission of flags, address field, control field and FCS, employing small frame sizes results in relative increase of overheads. Frame size adjustment may require buffer reorganisation if adjustment on frame retransmissions is implemented. Thus, optimum frame size implementation is more difficult than optimum window size implementation but it may also be employed for increasing utilization performance.

The following approximations are considered for small p_b

$$p = 1-(1-p_b)^{l+l'} \approx (l+l')p_b \tag{4.10}$$

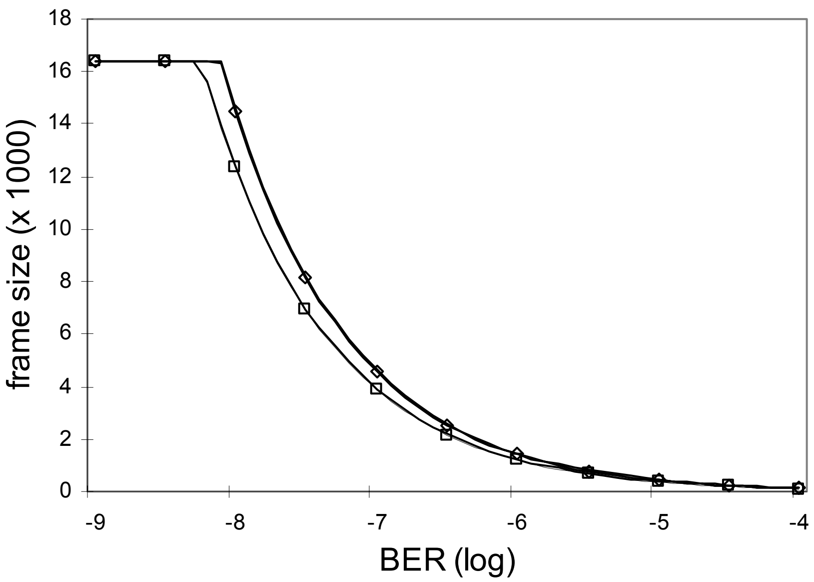
$$\frac{1-p}{p} = \frac{1}{p} - 1 \approx \frac{1}{p} \tag{4.11}$$

$$(l+l')p_b t_{Fout} = 0 \tag{4.12}$$

$$(l+l')p_b t_s = 0 \tag{4.13}$$

$$1-(1-(l+l')p_b)^N \approx N(l+l')p_b - \frac{N(N-1)}{2}(l+l')^2 p_b^2 \tag{4.14}$$

and U is given, to a good approximation, by



– optimum l (analysis), C=16Mbit/s, t_{ta}*=0.1ms*
□ optimum l (numerical), C=16Mbit/s, t_{ta}*=0.1ms*
– optimum l (analysis), C=4Mbit/s, t_{ta}*=1ms*
◇ optimum l (numerical), C=4Mbit/s, t_{ta}*=1ms*

Figure 4.5 Optimum frame size validation, N=127, $t_{Fout}=t_{Imax}+2t_{ta}$

$$U = \frac{l}{2Np_b} \cdot \frac{2Np_b - N(N-1)(l+l')p_b^2}{(l+l') + \frac{t_{ack}C}{N}} \tag{4.15}$$

The derivative against *l* is taken, set equal to zero and after some algebra, we derive that optimum frame size values are given to a good approximation by

$$l_{opt} = \sqrt{\frac{2(Nl' + t_{ack}C)}{N^2 p_b}} \tag{4.16}$$

The optimum frame size values versus BER for a fixed window size of 127 are shown in Fig. 4.5. As expected, frame size should be decreased for high BER in order to increase utilization. Note that at very low BER, the optimum frame size values should be greater than the maximum frame size value of 16Kbits allowed by the IrLAP specification. As in the case of optimum window size values, all approximations considered in deriving (4.16) are validated by comparing optimum values given from (4.16) with optimum values derived by employing numerical methods in (3.15) for a 16Mbit/s link with t_{ta}=0.1ms and for a 4Mbit/s link with t_{ta}=1 ms.

An important conclusion can be extracted by observing that (4.9) and (4.16) for optimum values can be rewritten as

$$Nlp_b \frac{Nl}{2} = t_{ack}C + Nl' \tag{4.17}$$

Equation (4.17) reveals that maximum utilization is achieved when the probability of a bit error in a window frame transmission ($\approx Nlp_b$), times the number of bits that have to be retransmitted due to the error occurred, which on average is half the window transmission $Nl/2$, is equal to the acknowledgement time in bits $t_{ack}C$ plus the number of overhead bits in the window transmission Nl'.

The term Nl' is missing from (4.9) because, if optimum window size values are implemented, optimum *N* becomes relatively small for high BER, so term Nl' can be safely neglected [92].

4.2.3 Simultaneous optimal window and frame sizes

If the window and frame size parameters can be simultaneously adjusted, maximum utilization performance can be achieved. Optimum *N* and *l* values are derived by taking $\frac{\partial U}{\partial N} = \frac{\partial U}{\partial l} = 0$ [98]. First, the derivative versus *N* can be taken following the analysis in section 4.2.1. Optimum *N* values derived by setting the derivative equal to zero can be substituted to utilization equation. Utilization *U* is now a function of frame size *l* for optimum *N* values. The derivative versus *l* can now be taken and set equal to zero to derive optimum *l* values. N_{opt} given by (4.8) should be used as the assumption *l>>l'* is no longer valid as optimum *l* values may be significantly small.

$$N_{opt} = \sqrt{\frac{2t_{ack}}{pt_I}} \approx \sqrt{\frac{2t_{ack}}{(l+l')p_b \frac{l+l'}{C}}} = \sqrt{\frac{2t_{ack}C}{(l+l')^2 p_b}} \tag{4.18}$$

and

$$N_{opt}(l+l') = \sqrt{\frac{2t_{ack}C}{p_b}} = c \tag{4.19}$$

Considering (3.5), utilization equation (3.15) can be rewritten as

$$U = \frac{l(1-p)}{pC} \cdot \frac{1-(1-p_b)^{N(l+l')}}{N\frac{l+l'}{C} + p(t_{Fout} + t_s) + t_{ack}} \tag{4.20}$$

Considering (4.19), (4.20) becomes

$$U=\frac{l(1-p)}{pC}\cdot\frac{\left(1-(1-p_b)^c\right)}{\left(\frac{c}{C}+p\left(t_{Fout}+t_s\right)+t_{ack}\right)} \qquad (4.21)$$

Assuming the valid approximation $p\approx(l+l')p_b$ then

$$U=\frac{\left(1-(1-p_b)^c\right)}{c}\cdot\frac{l\left(1-(l+l')p_b\right)}{(l+l')p_b\left(1+(l+l')p_b\frac{\left(t_{Fout}+t_s\right)C}{c}+\frac{t_{ack}C}{c}\right)} \qquad (4.22)$$

Denoting $s=\frac{\left(t_{Fout}+t_s\right)C}{c}$, taking the first derivative versus l and by setting it to zero

$$\left(-2lp_b-(l'p_b-1)\right)\left((l+l')^2p_b^2s+(l+l')p_b\left(1+\frac{t_{ack}C}{c}\right)\right)+\left(l^2p_b+l(l'p_b-1)\right)\left(2(l+l')p_b^2s+p_b\left(1+\frac{t_{ack}C}{c}\right)\right)=0 \quad (4.23)$$

Considering the valid approximation $l'p_b\approx 0$, we reach, after some algebra

$$-l^2p_b\left(s+2l'p_bs+1+\frac{t_{ack}C}{c}\right)+p_bl\left(-2l'^2p_bs-2l'\left(1+\frac{t_{ack}C}{c}\right)\right)+l'^2p_bs+l'\left(1+\frac{t_{ack}C}{c}\right)=0 \quad (4.24)$$

As $-2l'^2p_bs-2l'\left(1+\frac{t_{ack}C}{c}\right)\approx 0$

$$l_{opt}^2=\frac{l'\left(l'p_bs+1+\frac{t_{ack}C}{c}\right)}{p_b\left(s+2l'p_bs+1+\frac{t_{ack}C}{c}\right)} \qquad (4.25)$$

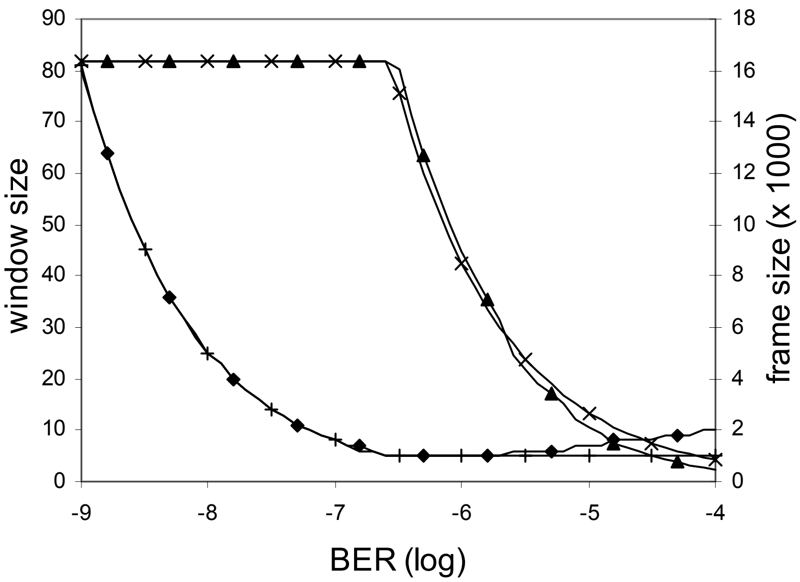
and, to a very good approximation,

$$l_{opt}\approx\sqrt{\frac{l'}{p_b}} \qquad (4.26)$$

By substituting (4.26) into (4.9), we obtain

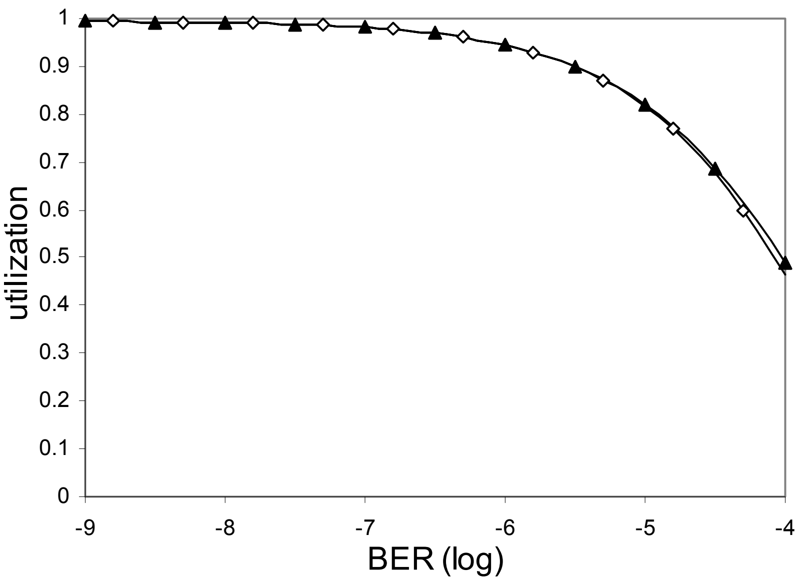
$$N_{opt}\approx\sqrt{\frac{2t_{ack}C}{l'}} \qquad (4.27)$$

Fig. 4.6 plots simultaneously optimal window and frame sizes for 4Mbit/s links with t_{ta}=0.1ms. It is observed that for a high range of BERs (less than $10^{-6.5}$), (4.26) suggests that frame size values greater than 16Kbits (the maximum allowed by IrLAP) should be employed. For this range, optimum N values are given by (4.9) instead of (4.27) since frame size values are constant (l=16Kbits) and not optimum. As a very good match between values given by (4.9)(4.26) and (4.27) and optimum values derived by using numerical methods in (3.15) is observed, approximations made to derive (4.26) and (4.27) are validated. Slight differences are observed mainly for high BER because



+ *optimum N (analysis)*
◆ *optimum N (numerical)*
x *optimum l (analysis)*
▲ *optimum l (numerical)*

Figure 4.6 Optimum window and frame size validation for C=4Mbit/s, t_{ta}*=0.1ms,* $t_{Fout}=t_{Imax}+2t_{ta}$



◇ *maximum utilization for optimum N and l values (analysis)*
▲ *maximum utilization for optimum N and l values (numerical)*

Figure 4.7 Utilization for simultaneous optimal N and l, C=4Mbit/s, t_{ta}*=0.1ms,* $t_{Fout}=t_{Imax}+2t_{ta}$

optimum N values given by the mathematical analysis and (4.27) are real values and have to be rounded as N can, of course, take only integer values. These differences result in negligible difference in maximum utilization as shown in Fig. 4.7.

An important conclusion can be extracted by observing that (4.9) and (4.26) for optimum values can be rewritten as

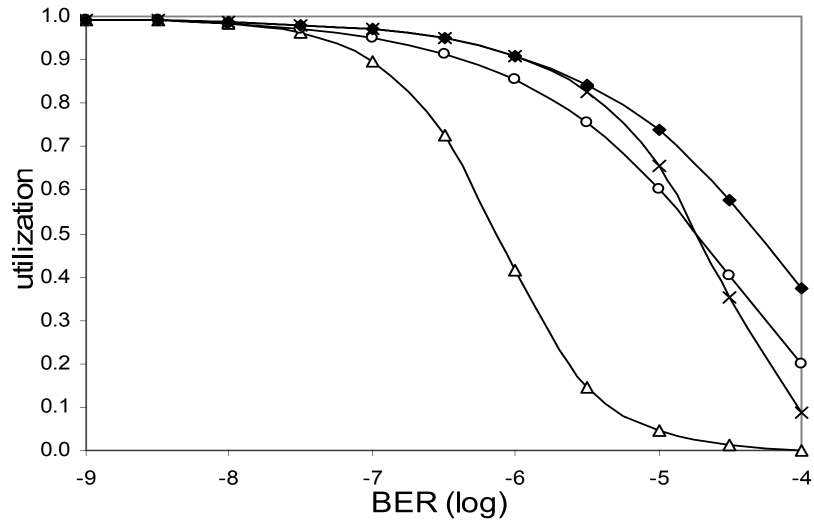
$$N_{opt} l_{opt} p_b \frac{N_{opt} l_{opt}}{2} = t_{ack} C \tag{4.28}$$

$$l_{opt} l_{opt} p_b = l' \tag{4.29}$$

Equation (4.29) reveals that maximum utilization is achieved when the probability of a bit error in the optimum frame length ($\approx l_{opt} p_b$), times the number of bits that have to be retransmitted due to this error ($\approx l_{opt}$) must be equal to the frame bit overhead *l'*. This equation shows that optimum frame size values should balance between time consumed on retransmitting error frames and time consumed on transmitting overheads. Equation (4.28) shows that maximum utilization is achieved when the probability of a bit error in the optimum window frame transmission ($\approx N_{opt} l_{opt} p_b$), times the number of bits that have to be retransmitted in the following frames due to this error, which on average is half the window transmission $N_{opt} l_{opt} / 2$, is equal to the acknowledgement time in bits $t_{ack} C$. In other words, the bits transmitted in the optimum window transmission, $N_{opt} l_{opt}$, should balance the time utilized in retransmitting out of sequence frames and the time utilized on acknowledgments.

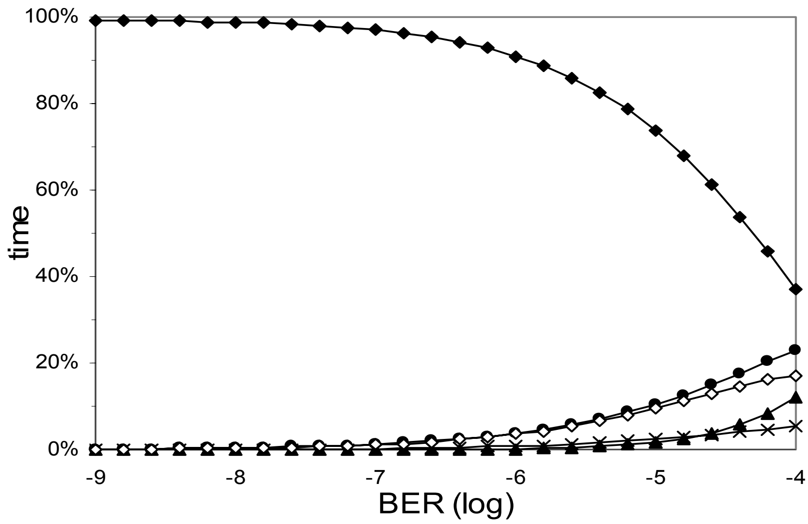
4.3 IrLAP Performance for optimum value implementation

Fig. 4.8 compares the utilization of a 16Mbit/s link with t_{ta}=0.1ms employing N=127 frames and l=16Kbits with the utilization achieved by implementing optimum window or frame size values given by (4.9) and (4.16) respectively. It shows that utilization is significantly improved for a wide range of BER (from 10^{-7} to 10^{-4}) if optimum window or frame size values are employed. For low BER, utilization for optimum N values is higher than utilization for optimum l values because as window size decreases, fewer frame overheads *l'* are utilized in a window transmission. The situation is reversed for high BER because the optimum window size implementation always utilizes large frame sizes (l=16Kbits), has a high frame error probability in high BER links and often the P-bit is lost. Fig. 4.8 also shows that applying optimum window and frame size values simultaneously (given by 4.9, 4.26 and 4.27) results in better performance overall. Fig. 4.9 shows the % time portion utilized on various IrLAP tasks for simultaneously optimal N and l values for the same link parameters. It reveals



△ *N=127, l=16Kbits* ○ *optimum l, N=127*
x *optimum N, l=16Kbits* ◆ *optimum N and optimum l*

Figure 4.8 Utilization against BER, C=16Mbit/s, t_{ta}=0.1ms, $t_{Fout}=t_{Imax}+2t_{ta}$



◆ *useful data transmission (utilization)*
◇ *retransmission of correctly received out of sequence frames*
x *retransmission of error frames*
▲ *F-timer expiration*
● *reversing link direction (hardware latency)*

Figure 4.9 Time allocation of various IrLAP tasks against BER for simultaneous optimal N and l, C=16Mbit/s, t_{ta}=0.1ms, $t_{Fout}=t_{Imax}+2t_{ta}$

that the retransmission of correctly received out of sequence frames is of no importance any more as optimum window and frame size employment reduced the probability of transmitting out of sequence frames. The main factor that results in utilization degradation is the hardware latency arising from the frequent link turn around.

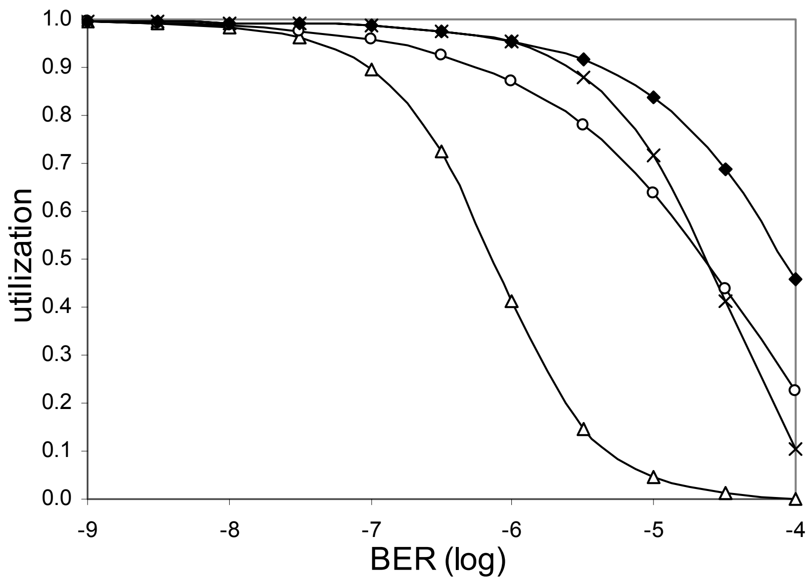
Figures 4.10 and 4.11 show the effect of reducing t_{ta} in 16Mbit/s links by plotting the same results as figures 4.8 and 4.9 for t_{ta}=0.01ms. Comparison of figures 4.8 and 4.10 shows that reducing t_{ta} significantly improves only the simultaneously optimal *N* and *l* implementation because the link has a high turn around frequency in this case. For high BER, Fig. 4.11 shows that the main detrimental factor to utilization in this case is the F-timer expiration; IrLAP utilizes 36% of the time on F-timer expiration and 46% of the time on transferring payload data (*U*=0.46) for BER=10^{-4}.

This analysis leads to the conclusion that the implementation of optimal window size (*N*) and frame size (*l*) values simultaneously results in significant utilization improvement. The minimum turn around time (t_{ta}) and F-timer time-out period (t_{Fout}) are the main detrimental factors to utilization if optimal *N* and *l* values are implemented. Reducing t_{ta} (a physical layer parameter) significantly improves utilization.

4.4 IrLAP S-frame modification combined with optimum values

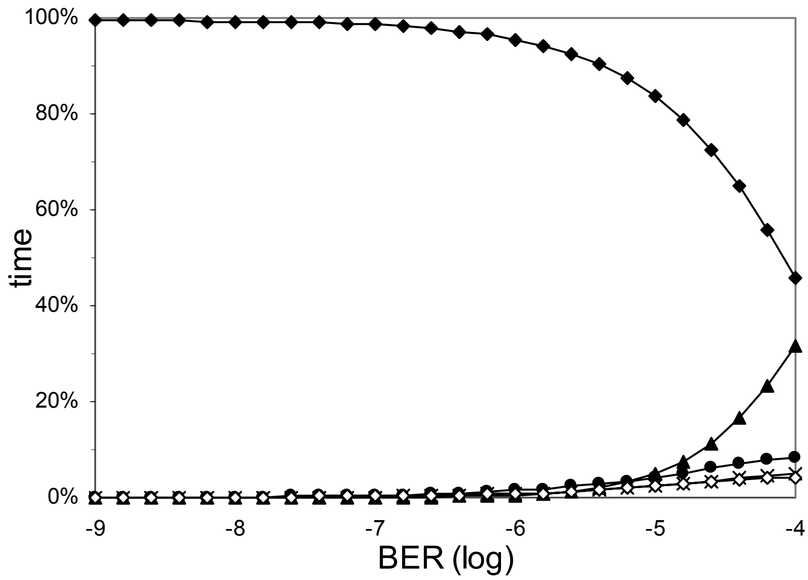
Analysis in the previous section revealed the importance of t_{ta} and t_{Fout} to IrLAP performance when optimal *N* and *l* values are employed. If t_{ta} is adequately decreased, time utilized on F-timer becomes of prime importance. This section discusses IrLAP performance when optimal *N* and/or *l* values are implemented for the S-frame modification (proposed in section 4.1) that minimizes delays on F-timer.

Fig. 4.12 compares the utilization of a 16Mbit/s link with t_{ta}=0.1ms employing *N*=127 frames and *l*=16Kbits with the utilization achieved by implementing optimum window or frame size values given by (4.9) and (4.16) respectively. Utilization for optimum *N* values is usually higher than utilization for optimum *l* values because the optimum window size implementation utilizes fewer frame overheads l' in a window transmission and delays from F-timer are minimized in the S-frame modification case. Simultaneous implementation of optimal window and frame size values always results in better performance. Fig. 4.13 shows the % time portion utilized on various IrLAP tasks for simultaneously optimal *N* and *l* values for the same link parameters. The main detrimental factor to utilization is again the hardware latency arising from the frequent link turn around.



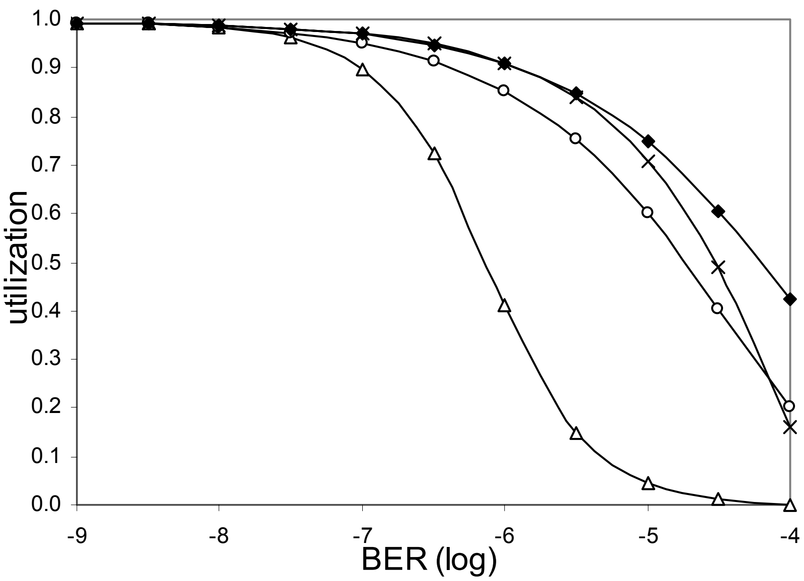
△ *N=127, l=16Kbits* ◦ *optimum l, N=127*
x *optimum N, l=16Kbits* ◆ *optimum N and optimum l*

Figure 4.10 Utilization against BER, C=16Mbit/s, t_{ta}*=0.01ms,* $t_{Fout}=t_{Imax}+2t_{ta}$



◆ *useful data transmission (utilization)*
◇ *retransmission of correctly received out of sequence frames*
x *retransmission of error frames*
▲ *F-timer expiration*
● *reversing link direction (hardware latency)*

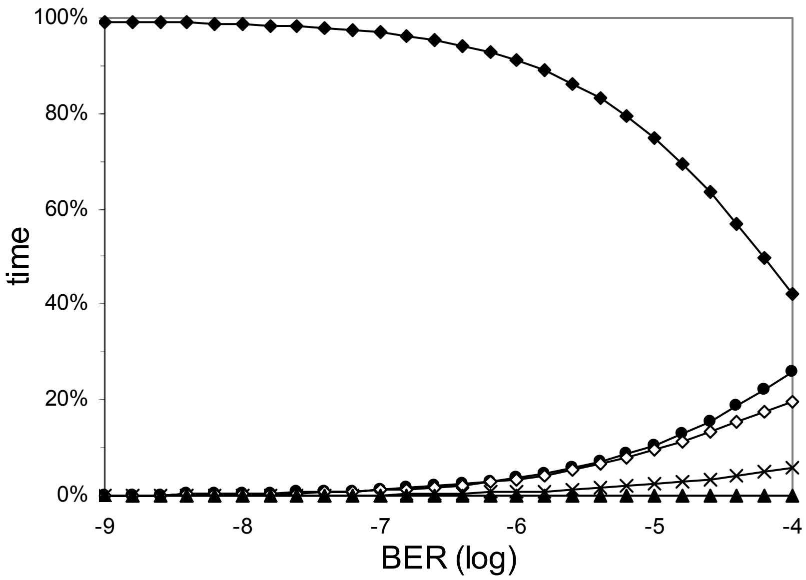
Figure 4.11 Time allocation of various IrLAP tasks against BER for simultaneous optimal N and l, C=16Mbit/s, t_{ta}*=0.01ms,* $t_{Fout}=t_{Imax}+2t_{ta}$



△ *N=127, l=16Kbits* ○ *optimum l, N=127*

x *optimum N, l=16Kbits* ◆ *optimum N and optimum l*

Figure 4.12 Utilization against BER, C=16Mbit/s, t_{ta}*=0.1ms, P-bit in S-frame*



◆ *useful data transmission (utilization)*

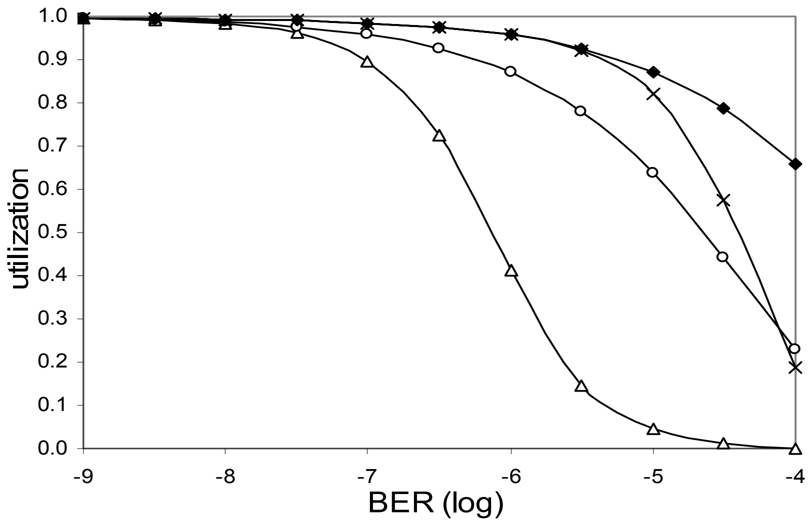
◇ *retransmission of correctly received out of sequence frames*

x *retransmission of error frames*

▲ *F-timer expiration*

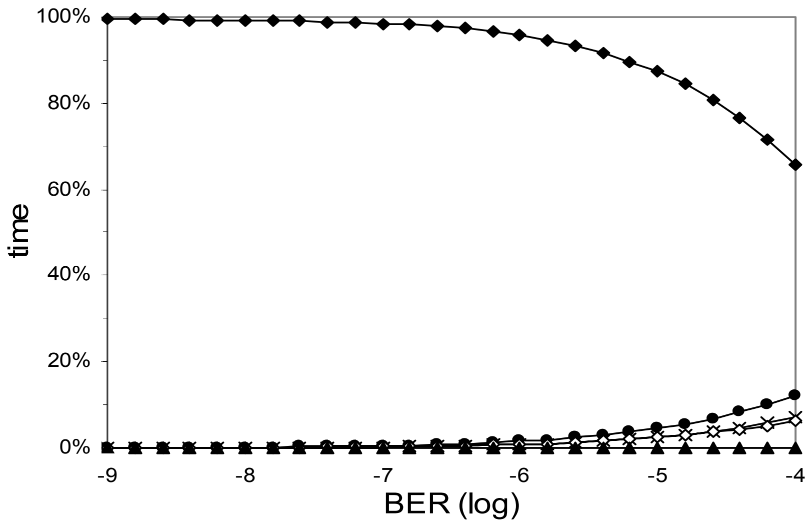
● *reversing link direction (hardware latency)*

Figure 4.13 Time allocation of various IrLAP tasks against BER for simultaneous optimal N and l, C=16Mbit/s, t_{ta}*=0.1ms, P-bit in S-frame*



△ *N=127, l=16Kbits* ○ *optimum l, N=127*
x *optimum N, l=16Kbits* ◆ *optimum N and optimum l*

Figure 4.14 Utilization against BER, C=16Mbit/s, t_{ta}=0.01ms, P-bit in S-frame



◆ *useful data transmission (utilization)*
◇ *retransmission of correctly received out of sequence frames*
x *retransmission of error frames*
▲ *F-timer expiration*
● *reversing link direction (hardware latency)*

Figure 4.15 Time allocation of various IrLAP tasks against BER for simultaneous optimal N and l, C=16Mbit/s, t_{ta}=0.01ms, P-bit in S-frame

Figures 4.14 and 4.15 show the same results when reducing t_{ta} to 0.01ms. Fig. 4.14 shows that the t_{ta} reduction significantly improves the utilization for the optimum *N* and the simultaneous optimal *N* and *l* cases. Fig. 4.15 shows that all IrLAP tasks affecting utilization are kept to minimum. As a result, 16 Mbit/s links employing a small t_{ta} of

0.01ms and the proposed S-frame modification achieve a utilization of 0.66 (U_{RR}=0.66) even for a 10^{-4} BER by employing optimum window and frame size values.

This analysis concludes that the implementation of simultaneous optimal window and frame size values, combined with the S-frame modification and a small minimum turn around time results in significant utilization figures in high BER links.

4.5 Practical implementation of optimum values

This section examines the practical utilization improvement that can be achieved if the transmitter implements the optimum values for window and/or frame size parameters derived in the previous section. The OPNET simulator presented in section 3.5.1 is altered to implement window and frame size adaptivity to link BER. The transmitter can estimate the link BER based on the frame acknowledgments provided by the receiving station [100]. Based on this estimation, the transmitter calculates the window and frame size values it implements using equations (4.9)(4.16)(4.26) and (4.27) for optimum values.

According to the IrLAP analysis presented in section 4.3, maximum window and frame size values should be implemented at link BERs less than 10^{-9}. The analysis also shows that if the link BER is higher that 10^{-4}, the low link quality at the physical layer renders the link unoperational and optimum value implementation is unprofitable. Thus, only the BER range [10^{-9}, 10^{-4}] is considered. Simulation results are obtained by varying link BER using a step of 0.1 in the logarithmic scale in the above range. Simulations run for 15 sec after a 'warm-up' period of 1 sec.

An algorithm is presented in [68] for optimizing frame size for full duplex "optimal" ARQ protocols, i.e. protocols that retransmit only error frames. The presented algorithm estimates optimum frame size based on the number of frame retransmission requests *R* out of the last *M* frame transmissions. Analysis presented in [68] concludes that an accurate estimate of the link BER is not necessary in order to choose the optimum frame size for nearly maximum performance; an approximate estimate is usually sufficient. In the IrLAP information transfer procedure, as the receiver rejects frames not received correctly, the transmitter receives information about bit errors occurring on its transmission. Despite the fact that the bit error position in an error frame is not known, an approximate bit error evaluation can be made by the transmitter, as it knows the frame containing the error bit. This section proposes a model in which

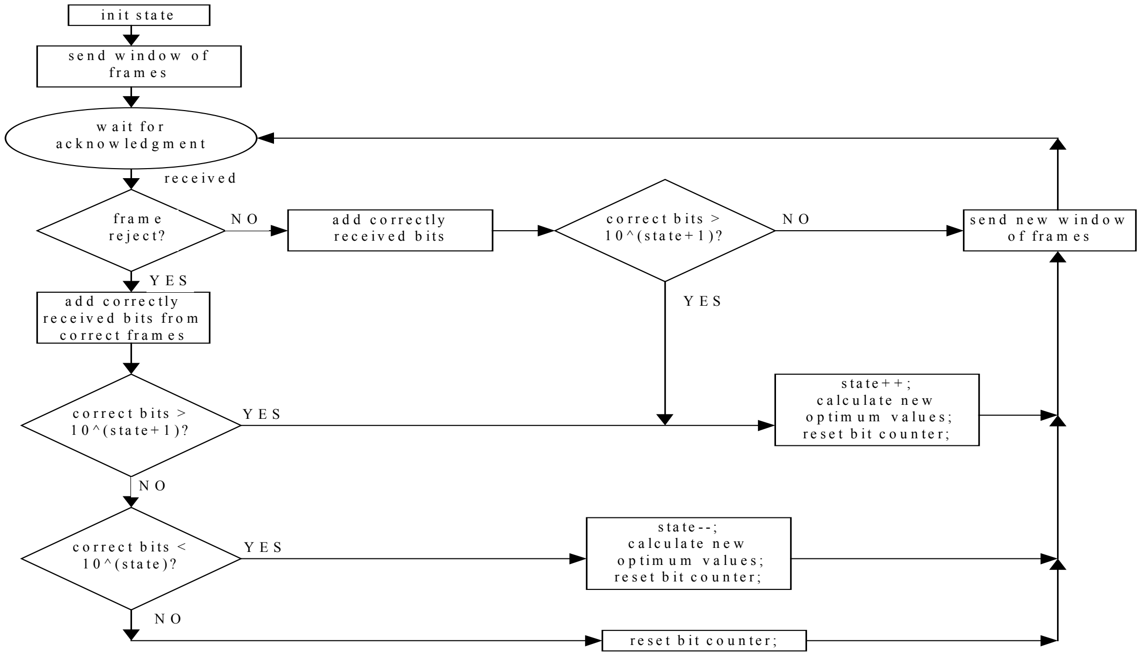


Figure 4.16 Adaptive window and/or frame size scheme based on link BER evaluation

the transmitter approximately estimates link BER by counting correct frame transmissions before a frame is rejected. Based on this estimation of the number of correctly transmitted bits between two error bits, the transmitter adjusts window and/or frame size, according to eq. (4.9)(4.16)(4.26) and (4.27).

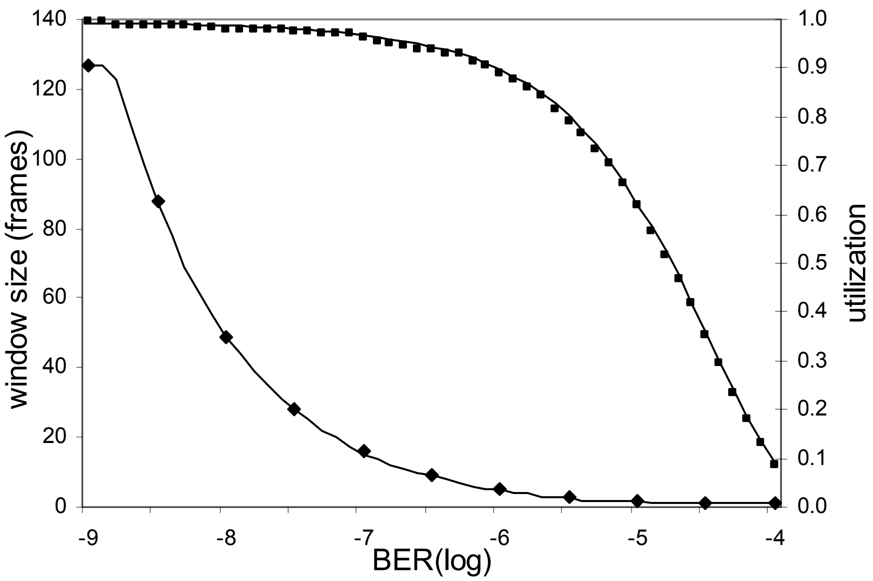
This model assumes that retransmitting buffered copies of error frames using different frame and window sizes does not result in significant processing delays. The transmitter's decisions are based on instant evaluations of link BER. This model may enforce different window and/or frame size values after a bit error assuming that the old values are not suitable. In the proposed adaptive model, the BER range $[10^{-9},10^{-4}]$ is divided to a small number of sub-ranges and optimum values suitable for each subrange are calculated and implemented. Implementation of this model is simple as the transmitter only needs to hold information about its current evaluation of link BER and of the number of sub-ranges implemented in the above BER range.

The transmitter's adaptive model for implementing optimum values is shown in Fig. 4.16. The following example assumes that the BER range $[10^{-9}, 10^{-4}]$ is divided into five subranges, the transmitter's current evaluation of link BER is 10^{-6} (state=6) and that optimum values from eq. (4.9)(4.16)(4.26)(4.27) have been calculated and implemented for $p_b=10^{-6}$. It is also assumed that these values are suitable for the third BER subrange of $[10^{-7},10^{-6}]$. The transmitter then counts the frames acknowledged correctly by the receiver and multiplies the number of frames correctly received with the frame size it implements. The product represents the number of correctly transmitted bits. If 10,000,000 (10^7) bits are correctly transmitted before an error occurs, the transmitter assumes that link BER is less that 10^{-7}, it changes its current BER evaluation to 10^{-7} (state=7) and calculates new window and/or frame size values from eq. (4.9)(4.16)(4.26)(4.27) for $p_b=10^{-7}$. The transmitter implements these values in future transmissions and resets counters. If a bit error occurs before 10,000,000 (10^7) but after 1,000,000 (10^6) correctly transmitted bits, the transmitter assumes that its current BER evaluation of 10^{-6} is correct, it continues to implement current optimum values and resets counters. If a bit error occurs before 1,000,000 (10^6) correct bits, the transmitter assumes that link BER is now higher that 10^{-6}. It changes its current BER evaluation to 10^{-5} (state=5), calculates and implements new window and/or frame size values suitable for $p_b=10^{-5}$ and resets counters.

The above set of rules for BER estimation and optimum value adjustment were chosen due to their simplicity. As IrLAP procedures are implemented at low level, simple and easily implemented at run time adaptive rules are needed. Simulation results presented in this section always divide the BER range [10^{-9},10^{-4}] into ten subranges, thus employing eleven different window and/or frame size values.

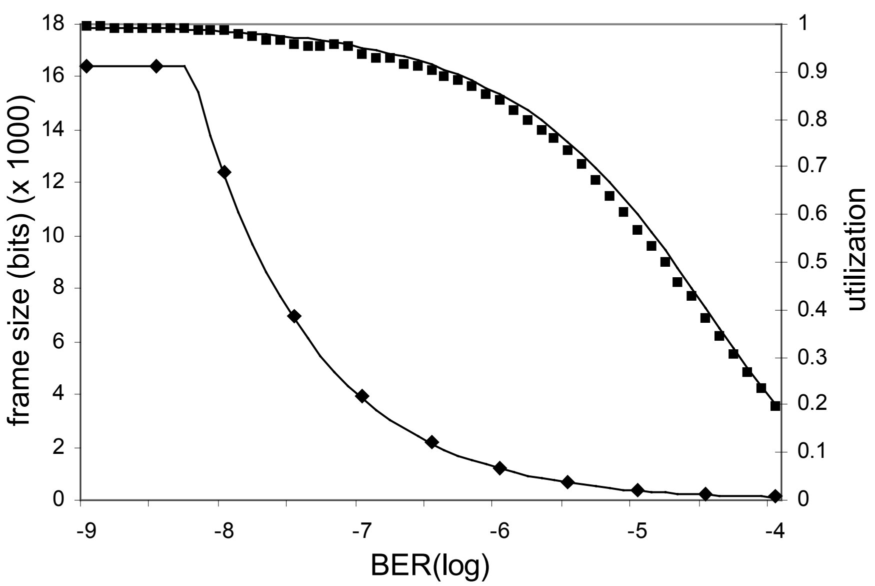
Fig. 4.17 plots the optimum window size values and the corresponding utilization versus link BER derived by applying numerical methods to eq.(3.15) for a 16Mbps link with t_{ta}=0.1ms and l=16Kbits. It also plots the implemented window sizes in simulation and the resulting utilization. An almost exact match between simulation and maximum utilization is observed. Results show that the implementation of exact optimum window size values for link BER is not necessary. The implementation of window size values close to the optimum value based on estimations of link BER result in a utilization figure very close to the maximum for the specific BER.

Fig. 4.18 plots optimum l values for fixed N=127 frames and the corresponding maximum utilization versus BER by employing numerical methods to eq. (3.15) for a 16Mbps link with t_{ta}=0.1ms. It also plots the implemented frame sizes by the simulator and the resulting utilization. A very close match between simulation and maximum utilization is observed. As a conclusion, an almost optimum IrLAP performance is achieved by implementing ten subranges.



— N optimum (numerical)
◆ N values implemented by primary station in simulation
— optimum utilization (numerical)
■ simulation utilization

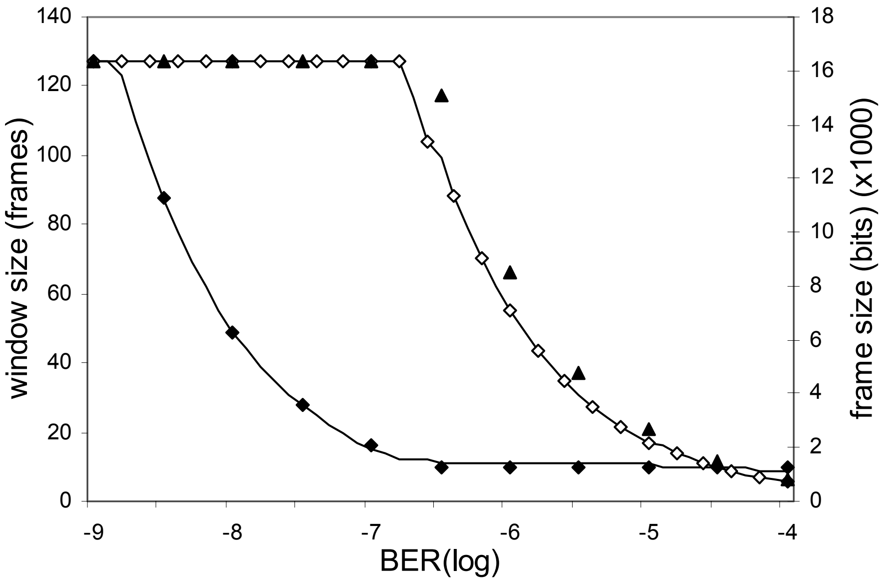
Figure 4.17 Utilization comparison for implementing 11 window size values, C=16Mbit/s, t_{ta}=0.1ms, l=16Kbits, $t_{Fout}=t_{Imax}+2t_{ta}$



— l optimum (numerical)
◆ l values implemented by primary station in simulation
— optimum utilization (numerical)
■ simulation utilization

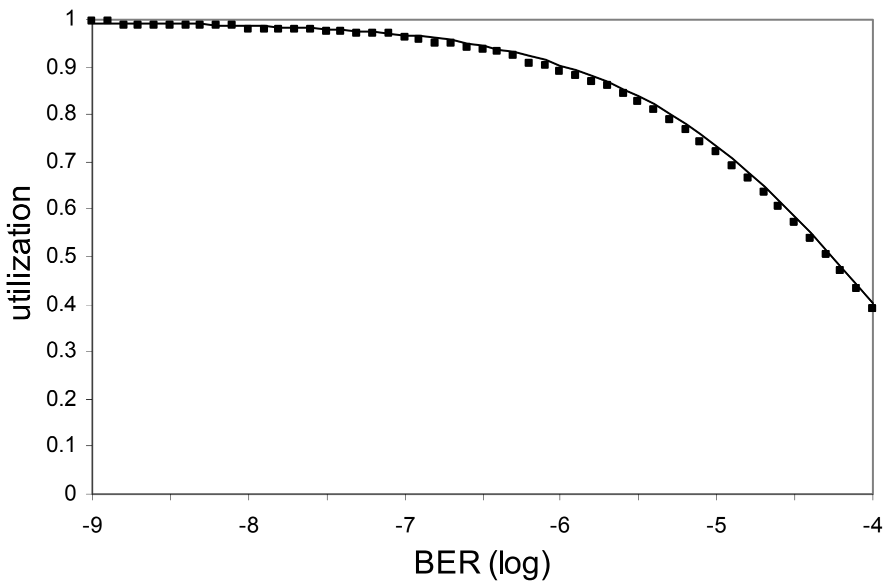
Figure 4.18 Utilization comparison for implementing 11 frame size values, C=16Mit/s, t_{ta}=0.1ms, N=127, $t_{Fout}=t_{Imax}+2t_{ta}$

Fig. 4.19 plots simultaneous optimum window and frame size values derived numerically from eq. (3.15) for maximum utilization for a 16Mbps link with t_{ta}=0.1ms. It also plots the optimum values implemented in simulations and derived from eq. (4.9)(4.26)(4.27) for the same link parameters. The simulation utilization is very close to the maximum utilization as presented in Fig. 4.20. As a conclusion, the proposed simple model for BER estimation and implementation of optimum values is very effective. If the primary station implements (a) only eleven different sets for both optimum window and frame size values, (b) simple rules for estimating BER and (c) both optimum window and frame size values, a significant IrLAP increase can be achieved.



◇ *l optimum (numerical)*
▲ *l values implemented by primary station in simulation*
— *N optimum (numerical)*
◆ *N values implemented by primary station in simulation*

Figure 4.19 Optimum value comparison for implementing 11 window and frame size values, C=16Mbit/s, $t_{ta}=0.1ms$, $t_{Fout}=t_{Imax}+2t_{ta}$



— maximum utilization (numerical)

■ *simulation utilization*

Figure 4.20 Utilization comparison for implementing 11 window and frame size values, C=16Mbit/s, t_{ta}*=0.1ms,* $t_{Fout}=t_{Imax}+2t_{ta}$