IrDA IrLAP PROTOCOL THROUGHPUT PERFORMANCE ANALYSIS FOR OPTICAL WIRELESS LINKS

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Abstract

Infrared ports are employed in a wide variety of devices ranging from personal computers, printers to mobile phones. Infrared ports comply to specifications defined by Infrared Data Association (IrDA). The performance of IrDA links may be measured at IrLAP data link layer, which controls IrDA hardware. In this work a simple equation to calculate the throughput from different link parameters is derived by employing a mathematical model making use the concept of "window transmission time". Simple equations, for the optimum values for window size and packet length can be derived, for different BER values. Optimum values for window and packet sizes for 16Mbps are calculated, which result in maximum throughput and make the link less vulnerable to BER.

1. Introduction

The development of IrDA optical wireless links as an industry standard has led to a plethora of IrDA infrared ports in computers of all sizes and in peripherals. Personal computers, personal digital assistants (PDAs), digital cameras, mobile phones and printers are examples of devises utilising IrDA links. Over 40 million devices with infrared ports are manufactured each year following standards defined by IrDA[1]. Digital representation of information is expanding to new devices such as video and cameras. New devices have "computer like" capabilities for storing and retrieving information such as cell phones and PDAs. Optical wireless and the IrDA standard offer a means for all these devices to communicate with each other in a wireless manner. IrDA specifications for infrared communications play an important role in short-range communications. IrDA devices replace communication cables and ease user connectivity.

The IrDA physical layer is controlled by a link layer protocol, IrLAP [2]. The performance of IrDA optical wireless links may be measured by the throughput, which can be drawn at the IrLAP layer. Performance analysis of IrLAP using the concept of virtual transmission time is given in [6] following a HDLC performance analysis model given in [7]. However, there has been no simple closed form formula available to date, which allows us to have an intuitive understanding of the performance of such links. Such equation relating all the important variables linking to throughput at the IrLAP layer would be very valuable for designers and implementers of such links.

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2. Description of IrLAP Protocol and parameter definitions

IrLAP is the data link layer in IrDA protocol stack. It facilitates the interconnection of devices using a directed half duplex serial infrared link as defined in IrDA physical layer [3]. It assigns primary and secondary roles to devices during link establishment. IrLAP supports one primary and one or more secondary stations to facilitate communication between multiple stations. All information traffic passes through the primary station. The present work is limited to the interconnection of two devices, a primary and a secondary node.

IrLAP packets consist of an 8-bit address field, an 8-bit control field and a variable length, information field [2]. The control field contains an identifier, which determines the frame type. Unnumbered frames (U-frames) are used in establishing and disconnecting links and in reporting procedural errors. Supervisory frames (S-frames) assist in the transfer of information although S-frames never carry information data. S-frames are used to acknowledge correctly received frames, report frame sequencing errors and convey ready or busy conditions. Information frames (I-frames) carry information data across the link. Depending on frame type, the control field may contain a send sequence number, Ns, used to number the frames sent. It may also contain a receive sequence number, Nr, used to number frames correctly received. Valid Ns and Nr values are from 0 to 7. The control field size is extended to 16-bit for 16Mbps link data rate to accommodate send and receive sequence numbers from 0 to 127. The control field also contains the P/F bit, which is used to transfer transmission control. When it is used by the primary, it is the poll (P) bit, which is used to solicit a response or a sequence of responses from the secondary. When used from the secondary station it is the final (F) bit, which indicates the last frame transmitted, as a response to the previous poll command.

The performance model we employ examines data transfer from primary to secondary nodes. We assume the saturation case, where the primary always has information ready for transmission. I-frames carry data from primary to secondary station. Since the secondary does not transmit information to primary, it responds only with S-frames with the F bit set, acknowledging frames received correctly and reversing link direction.

Only receive ready, (RR) and reject (REJ) S-frame responses are considered. The I-frame contains a send sequence number Ns, which circles through values 0 to 7 for 4Mbps and values 0 to 127 for 4Mbps and 16Mbps links. S-frame RR responses contain a receive sequence number Nr which acknowledges the correct reception of frames up to Nr-1, thus indicating that Nr is the next frame expected. S-frame REJ responses contain a receive sequence number Nr which rejects frame Nr and thus acknowledges the correct reception of frames up to Nr-1, thus indicating that Nr is the next (retransmitted) frame expected.

The parameters used in mathematical analysis are shown in Table 1.

The values for t_S, t_I, t_{ack}, p and D_b are given by:

$$t_S = \frac{l'}{C} \qquad t_I = \frac{l+l'}{C} \qquad t_{ack} = 2t_{ta} + t_S \qquad p = 1-(1-p_b)^{l+l'} \tag{1}$$

$$D_b = lD_f \tag{2}$$

Symbol	Parameter Description	Unit
C	Link data baud rate	bits /sec
p_b	Link bit error rate	-
p	Frame error probability	-
l	I-frame message data length	bits
l'	S-frame length / I-frame overhead	bits
t_I	Transmission time of an I-frame	sec
t_S	Transmission time of an S-frame	sec
t_{ta}	Minimum turn-around time	sec
t_{ack}	Acknowledgement time	sec
T_{max}	Maximum turn-around time	sec
t_{Fout}	F-timer Time-out period	sec
D_f	Frame throughput	frames/sec
D_b	Data throughput	bits/sec

Table 1: Parameters used in modelling IrLAP throughput

Window size N is the maximum number of unacknowledged frames that the transmitter can transmit. Its maximum value is 7 for link rates up to 4Mbps and 127 for the 4Mbps and 16Mbps links. Maximum window size parameter $W_{\max}$, is negotiated and agreed between the two stations during link establishment. However, the maximum time a station can hold the link, $T_{\max}$, combined with data rate and packet size may limit the number of consecutive frames a station can transmit as it has higher priority over the agreed window size and packet size [2]. Thus, N is given by

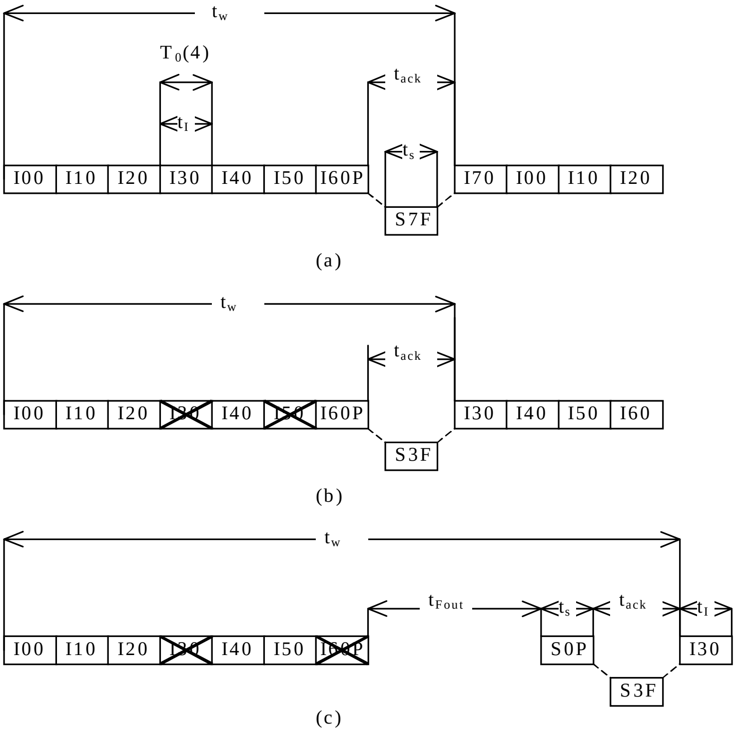
$$N = min\left\{W_{\max}, floor\left(\frac{T_{\max}}{t_I}\right)\right\} \tag{3}$$

where *min* is 'the lesser of', and *floor* is 'the largest integer not exceeding'.

In the case considered here, the transmitter always has a data packet ready for transmission. As a result, a window of N frames will be transmitted before the link direction is reversed. The last data packet in the window has the P bit set forcing the receiving station to respond. The receiver waits a specific amount of time t_{ta}, to cope with hardware latency and transmits a RR or REJ response indicating the next data frame expected or the frame received in error, respectively. The transmitter then determines the number of consecutive frames successfully received before any error(s) occurred and repeats the erred frame and the frames following it, in the next window, followed by new frames to form a complete N frame transmission. If the last frame in a window is not correctly received, the receiver does not respond, since the P bit is lost. The transmitter waits for F-timer expiration and sends a RR forcing the receiver to respond. RR and REJ frames are considered small enough to be error free.

3. Mathematical modelling of IrLAP Protocol

Our model uses the concept of the "window transmission time" (WTT) to denote the average time needed for a complete window transmission. WTT denotes the average time taken from the beginning of the window's first frame transmission to the beginning of next window's first frame transmission. WTT incorporates time needed for frame transmissions and acknowledgements, delays for reversing the link and timer time outs.



(a) Window error free transmission
(b) Retransmitted frames due to error frame at $w = 4$
(c) Retransmitted frames and F-timer delay due frame error at $w = 4$ and $w = 1$

Figure 1.

As shown in Fig 1.(a) and 1.(b), if the last frame in a window transmission is correctly received and regardless of the number of frames in this particular window received in error, WTT t_w, is given by

$$t_w = Nt_I + t_{ack} \tag{4}$$

If the last frame in sequence is not correctly received, the P bit is lost and the receiver does not respond as it is unaware of link reversion. The primary waits for an F-timer expiration and sends a RR S-frame forcing the receiver to respond as shown in Fig. 1.(c). This situation incorporates an additional delay of $t_{Fout} + t_s$ and WTT is given by

$$t_w = Nt_I + t_{Fout} + t_s + t_{ack} \tag{5}$$

As the last frame in sequence is lost with probability p, the average window transmission time is given by

$$t_w = Nt_I + p\left(t_{Fout} + t_s\right) + t_{ack} \tag{6}$$

Since correct frame transmissions following an erroneous frame transmission in the same window are considered out of sequence and have to be retransmitted, the probability $p_c(w)$ of successive w correct frame transmissions followed by an error at the beginning of a window transmission is given by

$$p_c(w) = (1-p)^w p\,,\ w=1,2,\ldots,N-1 \tag{7}$$

The probability that all frames in a window are correctly transmitted is

$$p_c(N) = (1-p)^N \tag{8}$$

The number of frames correctly transmitted in one window transmission p_{all} is

$$p_{all} = \sum_{w=1}^{N} wp_c(w), w=1,2,\ldots,N \tag{9}$$

The frame trougthput D_f can now be calculated by dividing the number of frames correctly transmitted in one window transmission p_{all} by the average time needed for this window transmission t_w.

$$D_f = \frac{\sum_{w=1}^{N} wp_c(w)}{Nt_I + p(t_{Fout} + t_s) + t_{ack}} \tag{10}$$

Finally

$$\boxed{D_f = \frac{1-p}{p} \frac{\left(1-(1-p)^N\right)}{Nt_I + p(t_{Fout} + t_s) + t_{ack}}} \tag{11}$$

For the rest of this paper, t_{Fout} is assumed to be

$$t_{Fout} = Nt_I + t_{ta} \tag{12}$$

This value means that the primary assumes that the frame contained the P-bit is lost if a reply has not received from the secondary for the time needed to reverse the link direction and to send a full window of I-frames. IrLAP specification [2] poses only an upper limit of 500ms for t_{Fout} timer. A much smaller value may be agreed between the two stations for data rates higher that 115.2 kbit/s. According to the secondary station state transmission diagram [2], the station immediately reverses the link direction upon reception of an I-frame with P-bit set, provided the upper layer has not placed a data unit to be sent over the connection. Otherwise, a series of I-frames (maximum N) will carry secondary data over the connection. The link direction is reversed when the F-bit is set in the last I-frame transmitted. The secondary station reverses the link direction within $N*t_I$ time plus the time needed due to hardware latency. The above discussion validates the assumptions made.

For the rest of this paper a maximum window size value of 127 frames for 4Mbps and 16Mbps links is assumed. The large window size validates the approximations, which will follow in the rest of this paper in order to derive simple equations.

4. Optimum window size

In order to derive the optimum values for different link parameters, (11) is differentiated. The most important and easily altered parameter that may seriously degrade throughput is the window size. Should a relatively large window size is selected in high link BERs, many frames following an error frame may be transmitted out of sequence until link direction is reversed. These frames must be retransmitted. Transmitting out of sequence frames becomes inefficient and may seriously affect throughput. For small p, we approximate $(1-p)^N \approx 1 - Np + \frac{N(N-1)}{2}p^2$. We differentiate (11) and in order to find the optimum values of N, the derivative must be set to zero.

By taking $d = (pt_{ta} + pt_s + t_{ack})/(p+1)$, we derive

$$(-pt_I)N^2 + (-2pd)N + 2d + pd = 0 \tag{13}$$

Assuming $pd << 2d$, $-2pd < -pt_I$, $-2pd < 2d$, $d \approx t_{ack}$, and considering that for $l >> l'$, $p \approx lp_b$ and $t_I \approx \frac{l}{C}$ we derive

$$\boxed{N_{opt} = \sqrt{\frac{2t_{ack}C}{l^2 p_b}}} \tag{14}$$

Fig. 2, shows the optimum window size for fixed frame size and for various BER. As the BER increases, the optimum window for best throughput decreases. Comparing the results obtained from (14) with results obtained using exact numerical methods for a link with t_{ta}=0.1ms and l=16Kbits, a perfect match is observed in Fig. 2.(a), for a 16Mbps link and in Fig2.(b) for a 4Mbps link. The results validate the approximations used to derive (14).

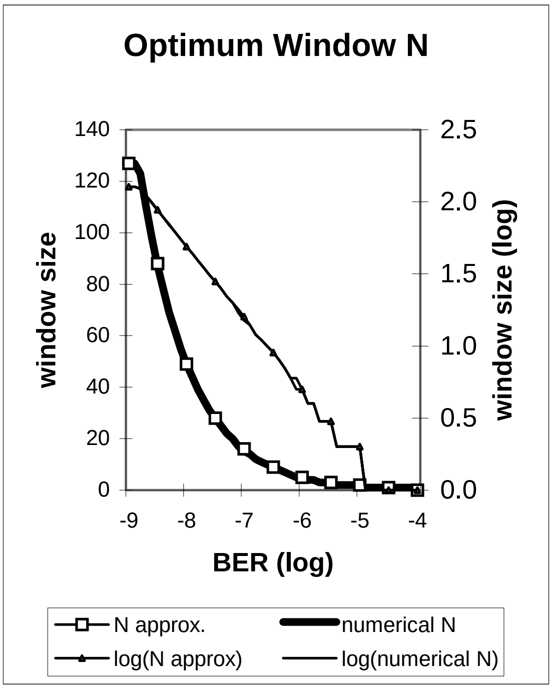


Figure 2 (a)
C=16Mbps,t_{ta}=0.1ms,l=16Kbits

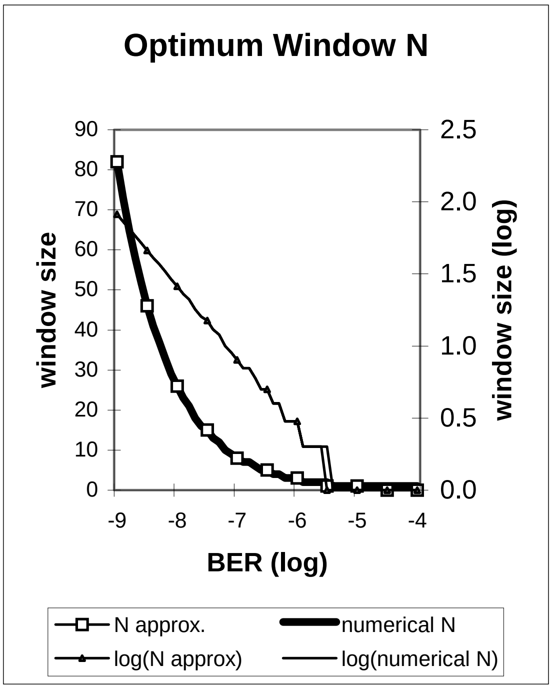


Figure 2 (b)
C=4Mbps,t_{ta}=0.1ms,l=16Kbits

5. Optimum packet size

Considering that a single bit transmission error causes the whole packet to be discarded by the receiver, reducing packet size decreases the discarding of correctly received information for every bit error occurrence. The price we pay for that is that each packet transmission requires transmission of flags, control field, FCS etc.

The use of smaller packet size makes the link perform well at high line BER. Optimum value of packet size has to balance between the time needed to transmit packet overheads and the time needed to retransmit correctly transmitted data in packets containing error bits.

To calculate the optimum l, the derivative of D_b versus l is required. Certain approximations have to be considered. In particular, for small p,

$$\begin{gathered} p = 1-(1-p_b)^{l+l'} \approx 1-\left(1-(l+l')p_b\right) = (l+l')p_b \\ (l+l')p_b t_{Fout} \approx 0 \qquad (15) \\ (l+l')p_b t_s \approx 0 \end{gathered}$$

Considering the following approximation

$$1-\left(1-(l+l')p_b\right)^N \approx N(l+l')p_b - \frac{N(N-1)}{2}(l+l')^2 p_b^2 \qquad (16)$$

Setting the derivative equal to zero to obtain optimum values of l, and considering $N \approx N-1$, after some algebra we obtain

$$\boxed{l_{opt} = \sqrt{\frac{2\left(Nl'+t_{ack}C\right)}{N^{2}p_{b}}}} \tag{17}$$

Fig. 3.(a) compares optimum packet size values obtained from (17) with values obtained using numerical methods for a 16Mbps link. Fig 3.(b) shows the same comparison for a 4Mbps IrDA link. As with window size *N*, a perfect match is observed and all approximations are validated.

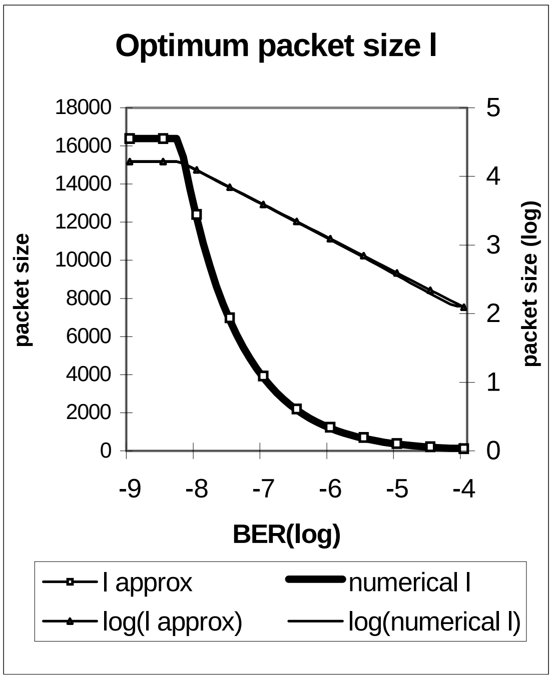


Figure 3 (a)
C=16Mbps,t_{ta}=0.1ms,N=127

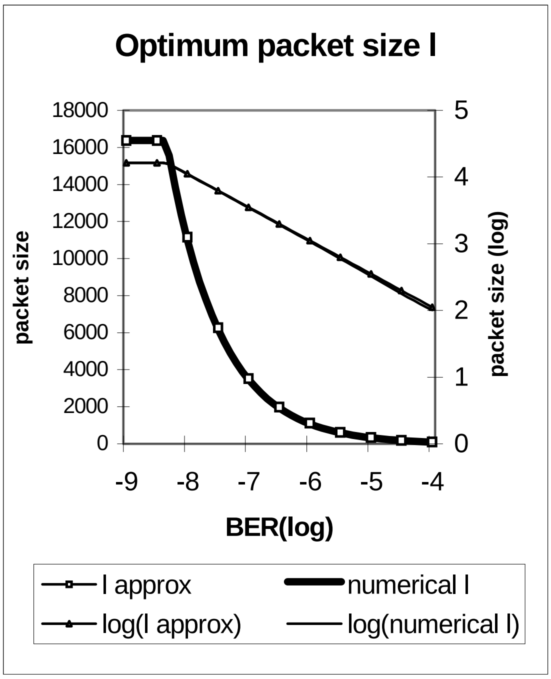


Figure 3 (b)
C=4Mbps,t_{ta}=0.1ms,N=127

6. Throughput analysis

Fig. 4 shows plots of normalised throughput versus BER for various minimum turnaround times and verifies the correctness of reducing the maximum value from 10ms to 0.1ms for the minimum turnaround time for the 16Mbps link [4]. The plots show that further reducing t_{ta} to values lower than the maximum allowed does not significantly increase throughput. These comments can also be verified by observing (11) and considering that for the maximum packet size of 16Kbits, t_I is approximately equal to 1ms. Normalised throughput against BER for different values of packet and window sizes is shown in Figure 5. It is observed that increasing the maximum window size from 7 to 127 frames for the 16Mbps link [5] slightly increases throughput for low BER and makes performance more vulnerable to high BER. Thus the practical effectiveness of maximum window increase becomes questionable for higher BER. It is shown that reducing window size from 127 to 7 frames or packet size from 16Kbits to 2Kbits makes link throughput more resistant to the increase of BER. By implementing optimum values for window size *N* given by (14) and for packet size *l* given by (17), a better performance for all possible BER is achieved.

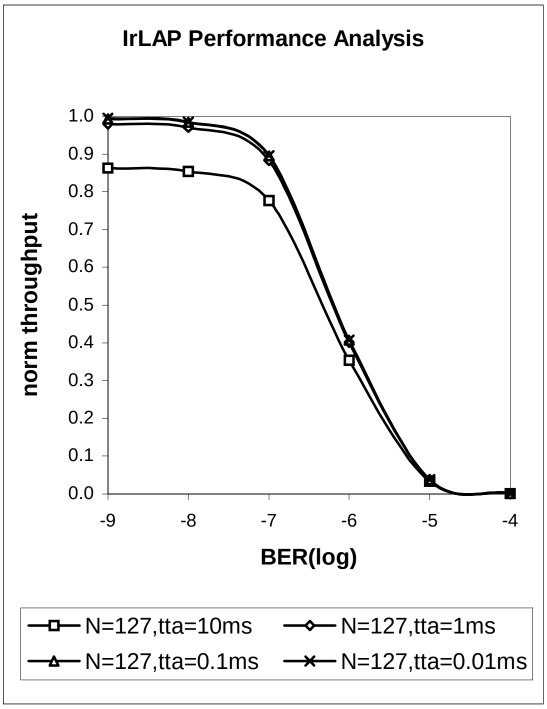


Figure 4.
C=16Mbps, *l*=16Kbits

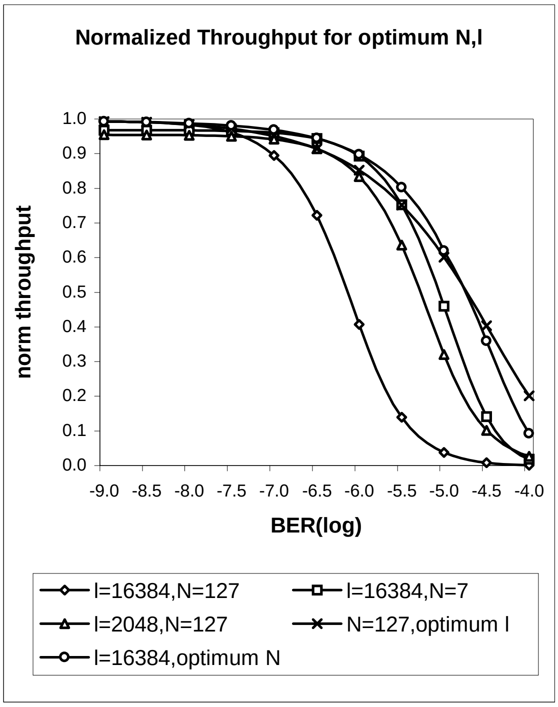


Figure 5.
C=16Mbps,t_{ta}=0.1ms

7. Conclusions

The mathematical analysis presented shows that the concept of “window transmission time” can be used to derive a simple equation for calculating the throughput at the IrLAP layer of IrDA links. By differentiation we obtain simple equations for optimum values for window and packet size for different BER. Similar analysis may be applied to other HDLC derivative protocols. Link turnaround delay may limit IrDA performance but if an adequately small value is selected, excellent performance is achieved. Implementing extended control field and extended maximum window size from 7 to 127 frames is questionable as it slightly increases performance for low BER at the expense of making throughput more vulnerable to high BER for the 16Mbps link.

References

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