THE MEDITERRANEAN JOURNAL OF COMPUTERS AND NETWORKS

Gbit/s Data Rate IrDA Protocol Performance Evaluation

A.C. Boucouvalas and Pi Huang
Multimedia Communications Research Group
School of Design, Engineering and Computing
Bournemouth University, Fern Barrow, Poole, BH12 5BB, U.K.
Email: { tboucouv, phuang }@bournemouth.ac.uk

Abstract

Indoor infrared links are anticipated to reach Gbit/s or even higher data rates in the near future. The aim of this paper is to examine how the existing IrDA IrLAP protocol performs at very high data rates. The contribution of this work is to assess backwards compatibility of future development with existing products and give design guidelines for performance at very high speed. This contribution is achieved by modelling the link layer protocol and including in the model the effects of link minimum turnaround time and propagation delay. A comprehensive analytic model for throughput is derived by using the concept of "window transmission time". We present equations to optimize the link layer parameters for maximum throughput for any line BER. Furthermore, based on the analytically derived equations, we produce numerical results offering guideline parameter values for optimum throughput for any BER.

Index Terms

Optical wireless, IrDA, propagation delay, performance evaluation.

1. INTRODUCTION

IrDA ports are manufactured in millions every year and installed in products such as laptops, printers, mobile phones, and digital cameras. IrDA links currently offer very short range fast data links with data rates up to 16Mbit/s, [1]. The 'point and shoot' nature of the

IrDA user model, unlike the diffuse infrared user model, [2], requires line of sight link alignment, and as a result short data transfer times are important. As the trend of using larger files combined with the desire for high transmission speed continues to become more important, there will be a greater need for much faster short range wireless links [3]. The wireless channel and point and shot nature of the IrDA links implies that there is a variation in signal to noise ratio within and between various data transfers resulting in varying BER and as a result throughput. As existing IrDA links are examined for future evolution to 100Mbit/s [4] and beyond to Gbit/s data rates, backwards compatibility with previous generation products is of interest and design for high performance in view of the varying channel BER is very important [5]. The existing IrDA Link Access Protocol (IrLAP) [6] runs on top of the physical layer of the devices. The important parameters expected to affect the performance of IrLAP are the minimum turnaround time, bit error rate and the propagation time at high speeds. It is worth examining first how well such a protocol performs at higher data rates for backwards compatibility and also what the link layer parameters for high performance at the link layer for any BER should be.

In the following section we proceed by deriving the link layer throughput equation based on a mathematical analysis using the “window transmission time” model. The link throughput is maximised by suitably adapting the optimum window and frame size depending on the link BER and other link layer parameters.

2. IRLAP MODELLING INCLUDING PROPAGATION TIME

IrLAP facilitates the interconnection of devices using a directed half duplex serial infrared link as defined in IrDA physical layer [7]. One device assumes primary and the other secondary role during link establishment. The primary initiates the transfer, manages the link and controls the information flow. The secondary cannot send any data until the Poll (P) bit is set to 1 in the incoming frame from the primary. Once the P bit is set, the secondary is allowed to transfer data after the minimum turnaround time (t_{ta}). Since the receiver is saturated by the infrared generated from the adjacent transmitter in the same transceiver, a minimum turnaround time is needed for the receiver to recover from the temporary saturation. The duration of t_{ta} is dependent on the IrDA transceiver design. When the secondary finishes data transfer, it sets P bit to 0 which implies the end of secondary transmission. IrLAP transmits data in the form of frames and organizes the transmission in a manner of go-back-N (GBN) error recovery. Therefore, IrLAP can send maximum N frames (known as a window) without receiving any acknowledgement. Referring to the IrDA standard, [6] [7] and [8], the frame size and window size set by the standard range from 512-16384bit and 1-127 respectively. By assuming the primary has a very large file to send, the IrLAP transmission model is illustrated in Fig.1. Fig.1(a) illustrates a 7 frames window, according to [6], and data transmission with no errors. Fig.1(b) illustrates when there is an error in frame #12 and Fig.1(c) shows an error in frame #12 but also an error in frame #16 where the P bit is set and lost.

In the following section, we derive the mathematical models for the IrDA IrLAP half duplex infrared channel. Since we are interested in very high speeds, we incorporate the propagation time in the analysis. For the purposes of this analysis, we assume there is always an IrLAP window ready to transmit. The relevant parameters and symbols used in the analysis are shown in Table 1. Values for t_s, t_I, t_{ack}, t_p, p and t_{Fout} are given by:

$$t_s = \frac{l'}{C} \quad , \quad t_I = \frac{l+l'}{C} \quad , \quad t_{ack} = 2t_{ta} + t_s \quad , \quad t_p = \frac{d}{c} \quad , \quad p = 1-(1-p_b)^{l+l'} \quad \text{and}$$

$t_{Fout} = t_{\mathrm{Im}ax} + 2t_{ta}$ according to the IrDA standard [6].

In the following, we apply the concept of “window transmission time” (WTT) [9] to the development of the mathematical model. WTT is used to denote the average time needed for a complete window transmission. It 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 period frame transmissions and acknowledgements, delays for reversing the link, transmission time and timer timeouts.

The average number of correctly transmitted frames in an *N*-frame window p_{all} is given in (1), where *P* is the frame error rate.

$$p_{all} = \sum_{i=1}^{N-1} i(1-p)^i p + N(1-p)^N = \frac{(1-p)(1-(1-p)^N)}{p} \qquad (1)$$

According to Fig.1, the average transmission time for one IrLAP window t_w is,

$$t_w = t_1 + t_2 + t_3 \qquad (2)$$

Where $t_1 = Nt_I + t_p$, $t_2 = t_{ack} + t_p$, and $t_3 = p(t_{Fout} + t_s + 2t_p)$.

From (1) and (2), the throughput D_b defined as the number of information bits transmitted per second is derived as:

$$\boxed{D_b = l\,\frac{1-p}{p}\,\frac{(1-(1-p)^N)}{t_w}} \qquad (3)$$

In the special case of an error free channel $p_b = 0$, we can easily get the frame error rate $p = 1-(1-p_b)^{l+l'} = 0$. In this case D_b becomes:

$$D_b = \frac{lN}{Nt_I + t_{ack} + 2t_p} \qquad (4)$$

The throughput efficiency is given in (5), where *C* is the link data rate

$$TPE = D_b / C \qquad (5)$$

The relative time consumed in each of the protocol tasks affecting IrLAP performance is given next.

The percentage of transmission time taken due to acknowledgements (T_{ack}), P bit frame loss (T_{Fout}) and propagation time (T_{tp}), are given by

$$T_{ack} = \frac{t_{ack}}{t_w} \qquad (6)$$

$$T_{Fout} = \frac{p(t_{Fout} + t_s)}{t_w} \qquad (7)$$

$$T_{tp} = \frac{2t_p(1+p)}{t_w} \tag{8}$$

In comparison to the overall time, the time percentage consumed on transmitting frame overheads ($T_{l'}$), error frames in a window transmission (T_{error}) and out of sequence but correctly received frames (T_{corr}) are given in (9), (10) and (11)

$$T_{l'} = \frac{Nl'/C}{t_w} \tag{9}$$

$$T_{error} = \frac{Npl/C}{t_w} \tag{10}$$

$$T_{corr} = \frac{(N - \frac{1-p}{p}(1-(1-p)^N) - Np)\frac{l}{C}}{t_w} \tag{11}$$

3. OPTIMUM LINK PARAMETER VALUES

Equation (3) is a function of both window size *N* and frame size *l*. It can be optimized by varying *N* and *l* for different BER for maximum D_b [11]. If it is often convenient to optimize only one variable, either *N* or *l*, we can obtain maximum throughput by fixing either *N* or *l* and optimizing the other. However the best throughput can be achieved when both *N* and *l* are simultaneously optimized with BER.

3.1. Optimum window or frame size for maximum throughput

By taking $\frac{\partial D_b}{\partial N} = 0$ for the equation (3), the optimum value of *N* for any fixed *l* is derived. Also, for fixed *N*, optimum *l* value is derived by taking the derivative of D_b, $\frac{\partial D_b}{\partial l} = 0$. After some calculus and good approximations, N_{opt} and l_{opt} are derived

$$\boxed{N_{opt} = \sqrt{\frac{2(t_{ack} + 2t_p)C}{l^2 p_b}}} \tag{12}$$

and

$$\boxed{l_{opt} = \sqrt{\frac{2(nl' + (t_{ack} + 2t_p)C)}{N^2 p_b}}} \tag{13}$$

3.2. Simultaneously optimization of window and frame size for maximum throughput

In this case, both window and frame size can be simultaneously adjusted. The maximum possible throughput can be achieved. To optimize both *N* and *l*, the first step is to take $\frac{\partial D_b}{\partial N} = 0$ for the equation (3) to derive the optimum *N* for fixed *l*. The optimum *N* equation for fixed *l* is then substituted into (3). Throughput D_b becomes a function of frame size *l* for optimum *N*. Next, the derivative of $\frac{\partial D_b}{\partial l} = 0$ is taken and the optimum *l* equation for optimum *N* is derived. After that, the derived optimum *l* equation for optimum *N* is substituted into (3). This time, throughput D_b becomes a function of *N* for optimum *l*. Finally, $\frac{\partial D_b}{\partial N} = 0$ is taken and the optimum *N* equation for optimum *l* is derived. This essentially derives $\frac{\partial D_b}{\partial N} = \frac{\partial D_b}{\partial l} = 0$. The simultaneous N_{opt} and l_{opt} are given in (14) and (15):

$$\boxed{l_{opt} = \sqrt{\frac{l'}{p_b}}} \tag{14}$$

and

$$\boxed{N_{opt} = \sqrt{\frac{2(t_{ack} + 2t_p)C}{l'}}} \tag{15}$$

Equations (14) and (15) reveal that N_{opt} is essentially independent of BER, and l_{opt} becomes very large and takes values larger than 16Kbits (the maximum allowed by the specification [6]) for low bit error rates ($BER < 2.6 \times 10^{-7}$ from equation (14) using $l' = 72$, and $l_{opt} = 16Kbit$).

In order to comply with IrDA specification, for the simultaneous N and l optimization, when l_{opt} is required to be greater than 16Kbits ($BER < 2.6 \times 10^{-7}$), we fix l_{opt} at 16Kbits and use (12) for optimum N. When $BER > 2.6 \times 10^{-7}$, however, we can use (14) and (15) for the optimum N and l values.

4. PROPAGATION DELAY IN HIGH SPEED TRANSMISSION

Using equation (3) and (4), the effect of propagation delay (t_p) on the throughput as a function of data rates is examined in this section. Numerical results have been produced in two cases, using non-optimum and optimum values for IrLAP window and frame size respectively. In order to highlight the effect of t_p in performance, the results with and without t_p are compared. In order to examine the biggest possible impact from t_p, the maximum allowed by the standard link distance of d=2m (t_p=6.7ns) is considered in this paper. The IrDA standard recommends the BER should be less than 10^{-8}. However, due to the ad hoc nature of infrared link, many factors can increase the BER to higher than 10^{-8}, e.g. careless aligning, high ambient noise (close to fluorescent light source), and partial blockage. Given the fact that the link protocol faces much bigger challenge under higher bit error rate, we therefore also examine BER>10^{-8} in this paper.

4.1. Use of non-optimum window and frame size

Using minimum turnaround time t_{ta} as a parameter, and taking values of 10^{-6}s, 10^{-7}s and 10^{-8}s, IrLAP throughput efficiency is plotted against data rate using arbitrary values for window size N of 7 and frame size l of 1024. BER (p_b) of 10^{-4} and 10^{-8} are used in Fig.2 and 3 respectively.

For non-optimum N and l, the effect of t_p becomes significant for t_{ta} of 10^{-8}s and data rate greater than 10Gbit/s. However, the effect is insensitive to BER (by comparing respective curves in Fig.2 and 3).

4.2. Use optimum window and frame size

Fig.4 and 5 are the results of throughput efficiency versus data rate using simultaneously optimum window and frame size where possible. The optimum N and l are restricted between 1-127 and 512-16384bits respectively by [6]. t_{ta} with values of 10^{-6}s, 10^{-7}s and 10^{-8}s are used for both figures. Fig.4 is for BER (p_b), of 10^{-4} and Fig.5 corresponds to BER (p_b), of 10^{-8}.

For optimum N and l, throughput efficiency is higher than non-optimum N and l. When BER=10^{-4}, propagation delay shows significant effect on the link throughput for a small value of t_{ta}. When BER=10^{-8}, the optimum values of N and l reduce the detriment of t_p on the link throughput drastically, t_p only has a minor effect, Fig.5.

As shown in Fig.2, 3 and 4, the effect of t_p is more pronounced when the value of t_{ta} is less than 10^{-7}s. As the value of t_{ta} decreases approaching t_p ($t_p = 6.7ns = 6.7\times10^{-9}s$), propagation delay affects the link throughput considerably. The effect of propagation delay on throughput is swamped by the loss of throughput when large t_{ta} values are used.

The results also show that when the optimum values of window and frame size are used, Fig.4 and 5, the effect of t_p is significant while BER is high, but much less while BER is low. In the non-optimum N and l cases, because of the fixed N and l values, t_p shows the same effect on throughput for both high and low BER. For both optimum and non-optimum cases, t_p has more significant effect when the data rate is high.

The effect of t_p on throughput at different data rates varies as a function of the minimum turnaround time, window and frame size. It is significant when t_{ta} has small values ($t_{ta} \le 10^7 s$) at high data rates ($C \ge 10^{10} bit/s = 10Gbit/s$).

5. MINIMUM TURNAROUND TIME EFFECT ON 10GBIT/S IRLAP THROUGHPUT

In this section, we examine the effect of minimum turnaround time (t_{ta}) on the link throughput, and search for suitable value of minimum turnaround time for the system at the link data rate of 10Gbit/s. In a similar manner as in the previous section, figures are produced using non-optimum and optimum N and l values respectively. The result also includes the propagation delay t_p.

5.1. Use of non-optimum window and frame size

Throughput Efficiency is plotted against t_{ta} in the range from 10^{-7}s to 10^{-9}s in Fig.6. BER (p_b) of 10^{-7}, 10^{-6}, 10^{-5} and 10^{-4}, window size N=7, frame size l=16384 are used in the calculation.

From Fig.6, we can see that t_{ta} has significant effect on link throughput when t_{ta} is greater than 10^{-8}s. However, the t_{ta} effect is negligible when $t_{ta}<10^{-8}$s.

5.2. Use of optimum window and frame size

Throughput Efficiency versus t_{ta} results are shown in Fig.7 for BER (p_b) of 10^{-7}, 10^{-6}, 10^{-5} and 10^{-4}, and using optimum N and l values. N and l values are restricted between 1-127 and 512-16384 respectively.

By comparing Fig.7 and Fig.6, much better throughput efficiencies are achieved by using the optimum N and l values. The results from Fig.6 and 7 reveal that the minimum turnaround time has additional significant effect only when it takes the values $t_{ta} > 10^{-8} s$. Therefore, t_{ta} of 10^{-8}s should be used when the link data rate is 10Gbit/s.

6. PROPAGATION DELAY AND MINIMUM TURNAROUND TIME EFFECTS ON THE 10GBIT/S LINK THROUGHPUT USING OPTIMUM *N* AND *L* VALUES

The significance of different factors that affect the IrLAP throughput is studied in this section. The percentages of the transmission time consumed by various protocol tasks, are examined using equations (6), (7), (8), (9), (10) and (11) derived in section 2.

In Fig.8 to 11, results are plotted against p_b from high BER to low BER in the range of 10^{-4} to 10^{-7}. The optimum window and frame sizes are used. In order to examine the effect of t_{ta} and t_p on throughput efficiency, t_{ta} values of 10^{-6}s (Fig.8 and 9) and 10^{-8}s (Fig.10 and 11) are used respectively. The results are displayed in figure pairs: the first shows the different factors that affect the throughput in comparison to the overall time, while the second is the corresponding optimum link parameters (N and l) for the first figure. Note that, in order to make the figure more readable, we do not show all the time percentages. If the time percentage is less than 3% of the overall time, it is not shown in the figures.

When t_{ta}=10^{-6}s, Fig.8, the throughput efficiency is very low for high BER. The effects of t_{ack} (6), and correctly transmitted but out of sequence frames (CTOSF) (11) combined occupy a huge portion (>0.5) of the overall time for BER<10^{-5}. The percentage of throughput efficiency wasted due to t_{ack}, is even bigger than the throughput efficiency itself when $\mathrm{BER} > 0.5 \times 10^{-4}$. Due to the small optimum values of window size (N) used for high BER as shown in Fig.9, acknowledgement packets are frequently transmitted. Therefore, t_{ack} is dominating the overall time for high BER. Because small optimum N value but relatively large optimum frame size (l) are used for high BER, CTOSF time percentage is also high. t_{ack} and CTOSF are the two main reasons resulting low link performance.

When t_{ta}=10^{-8}s, Fig.10, the protocol offers very good throughput efficiency even at high BER. In this case, the effect of t_{ack} has been reduced significantly because of the small value of t_{ta}. As a result the propagation time t_p (8), CTOSF (11) and frame overhead (9) become the three major factors affecting the throughput instead of t_{ack}. Because t_p has the same order of magnitude as t_{ta} ($t_p = 6.7 \times 10^{-9}$ comparing to $t_{ta} = 10^{-8}$), propagation time detriment is playing a much more significant role than in the case of t_{ta}=10^{-6}s. Nevertheless, the link performance is benefited by the small value of t_{ta} and remains high.

For 10Gbit/s links, if the minimum turnaround time is as small as 10^{-8}s, even at BER as high as 10^{-4}, a throughput efficiency of 0.65 can still be achieved by using the optimum link parameters, Fig.10.

7. CONCLUSIONS

This article examines the performance of IrDA IrLAP protocol operating at Gbit/s data rates. A systematic analysis of IrLAP protocol has been carried out by including the effect of link propagation time and derivation of the optimum values of the window and frame size. We derived BER dependent equations for window and frame sizes for maximum link layer throughput. The effect on throughput of propagation time and minimum turnaround time at different data rate has been studied by using both optimum and non-optimum link parameters for comparison. Furthermore, to also have specific understanding of the protocol performance, different parameter values for IrLAP have been studied and recommended at the specific data rate of 10Gbit/s.

The performance results indicate that propagation delay (even by considering the maximum distance of 2m) does not significantly detriment throughput until the data rate reaches 10Gbit/s for IrDA indoor short distance links. When optimum link parameters are used, even in high BER environments, a minimum turnaround time of less than 10^{-8}s can give excellent throughput efficiency at the high speed of 10Gbit/s.

From the results, we conclude overall that the IrLAP protocol is not a limitation even for the data rates as high as 10Gbit/s if a small enough minimum turnaround time ($t_{ta} \le 10^{-8} s$) is used. For short distance (indoor links), the propagation delay has significant effect on the throughput efficiency only when the data rate exceeds 10Gbit/s. Furthermore, the link performance is increased remarkably by using the optimum N and l values especially in the high BER channels.

REFERENCES

[1] W. Hirt, M. Hassner, N. Heise, “IrDA-VFIR (16Mb/s): Modulation Code and System Design,” *IEEE Personal Communications*, pp. 58-71, February 2001.

[2] G. Marsh and J. Kahn, “Performance evaluation of experimental 50-Mb/s diffuse infrared wireless link using on-off keying with decision-feedback equalization,” *IEEE Transaction on Communications*, Vol. 44, No. 11, pp.1496-1504, 1996.

[3] D. Heatley, D. Wisely, I. Neild and P. Cochrane, “Optical wireless: the story so far,” *IEEE communications magazine*, Vol. 36, No.12, pp.72-82, 1998.

[4] A. C. Boucouvalas and V. Vitsas “100 Mbit/s IrDA Optical Wireless Throughput Performance Analysis” *IEE Proceedings Optoelectronics*, Vol. 150, No. 5, October 2003, pp. 465-472

[5] Williams S., “IrDA: Past, Present, and Future,” *IEEE Personal Communications*, vol. 7, No.1, pp11-19, Feb. 2000.

[6] IrDA, Serial Infrared Link Access Protocol (IrLAP), Version 1.1 (Infrared Data Association, 1996)

[7] IrDA, Serial Infrared Physical Layer Specification – Version 1.1, (Infrared Data Association, 1995)

[8] IrDA, Serial Infrared Physical Layer Specification for 16Mb/s Addition (VFIR)–Errata to version 1.3, Infrared Data Association, (1999)

[9] Bux W., Kummerle K. & Truong H.L., “Balanced HDLC procedures: A performance Analysis” *IEEE Trans. Comm*, 1980, com-28, pp.1889-1898.

[10] P. Chatzimisios and A. C. Boucouvalas **“**IrLAP IrDA Protocol Throughput Dependence on Processor Speed,” *International Symposium on CSNDSP 2002*, Staffordshire University, July 15-17, pp. 272-275.

[11] V. Vitsas and A. C. Boucouvalas, “Window and frame size adaptivity for maximum throughput in IrDA links,” *Proceedings of the 3rd Electronic Circuits and Systems Conference*, Slovak University of Technology in Bratislava, Bratislava, Slovakia on September 5-7, 2001, pp.147-152.

[12] V. Vitsas and A.C. Boucouvalas “Optimisation of IrDA IrLAP Link Access protocol” *IEEE Transactions on Wireless Communications*, Vol. 2, No. 5, pp.926-938, September 2003

TABLE 1:

PARAMETERS USED IN MODELLING IRLAP THROUGHPUT

Symbol	Parameter Description	Unit
c	Speed of light	m/sec
C	Link data rate	bits/sec
d	Distance between transmitter and receiver	m
p_b	Link bit error rate	-
p	Frame error rate	-
N	Number of frames in one window	-
l	I-frame message data length	bits
l'	S-frame length/ I-frame overhead	bits
t_I	Transmission time of an Information (I)-frame	sec
t_{Imax}	Transmission time of a 16Kbits frame	sec
t_s	Transmission time of a Supervision (s)-frame	sec
t_{ta}	Minimum turn-around time	sec
t_{ack}	Acknowledgement time	sec
t_{Fout}	F-timer time-out period	sec
t_p	Propagation time	sec
D_b	Data throughput	bit/sec

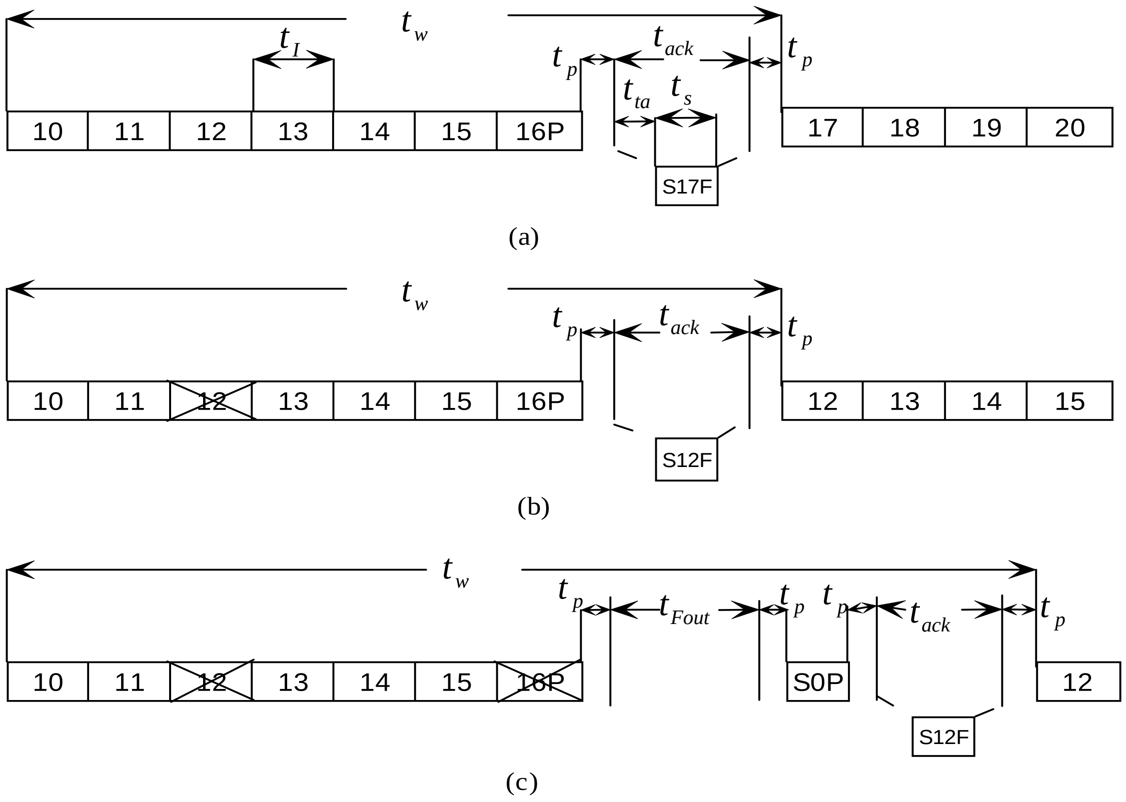

Fig. 1. (a) Error free transmission of a window (b) Retransmission frames due to error frame at I=3 (c) Retransmitted frames and F-timer delay due frame error at I=3 and I=7.

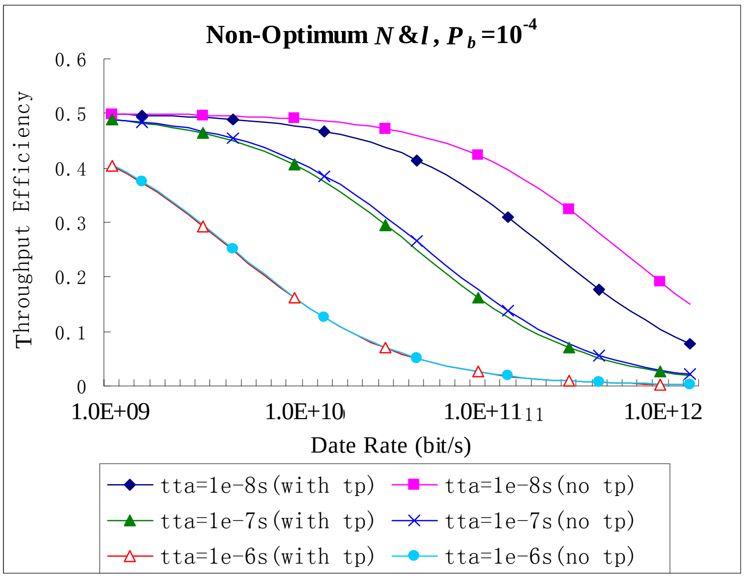

Fig. 2. Effects of t_p with N=7, l=1024 and p_b=10^{-4}

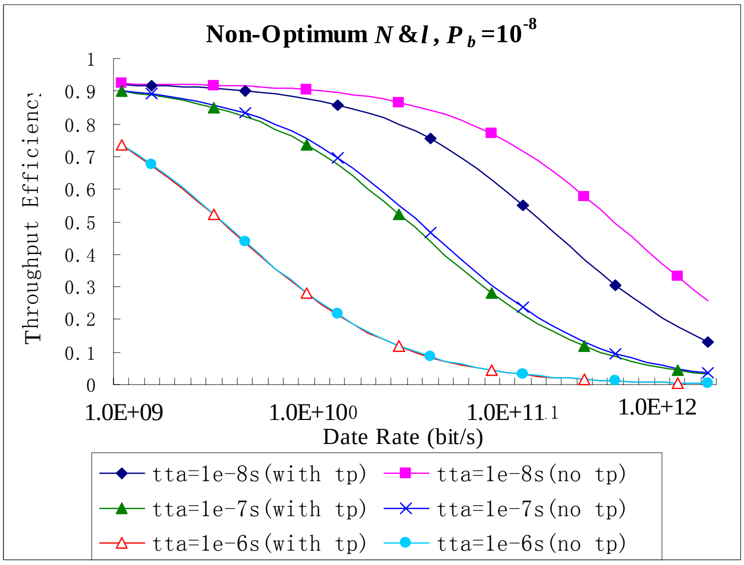

Fig. 3. Effects of t_p with N=7, l=1024 and p_b=10^{-8}

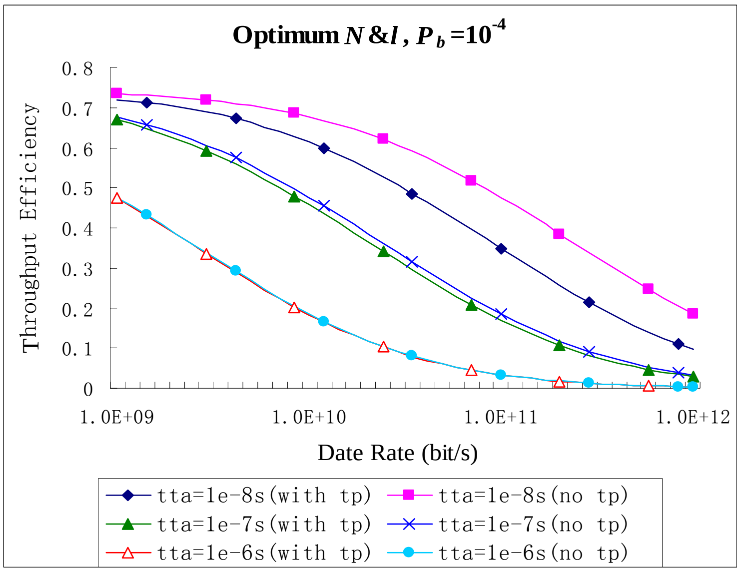

Fig. 4. Effects of t_p with optimum N &l and p_b=10^{-4}

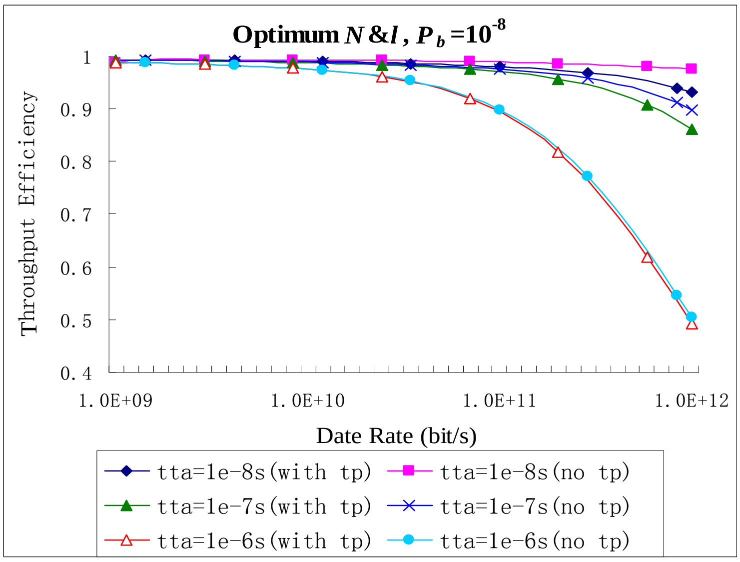

Fig. 5. Effects of t_p with optimum N &l and p_b=10^{-8}

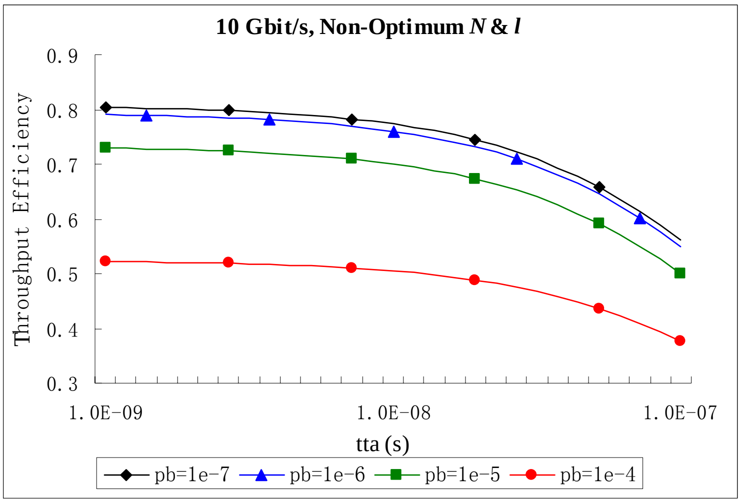

Fig. 6. Effect of t_{ta} with N=7 and l=16384

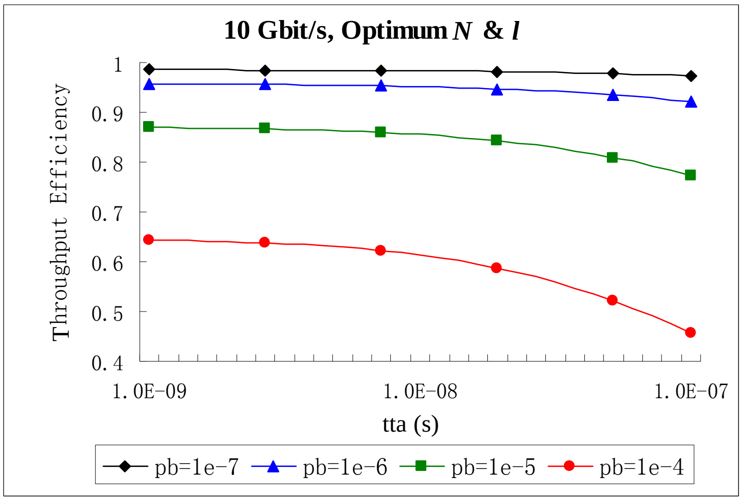

Fig. 7. Effect of t_{ta} with optimum N and l

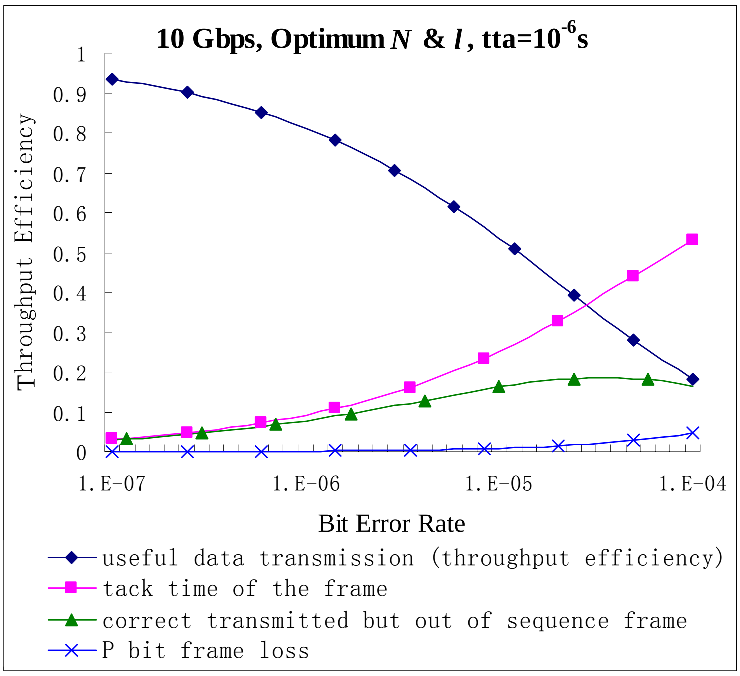

Fig. 8. Relative percentages of transmission time, t_{ta}=1e^{-6}s.

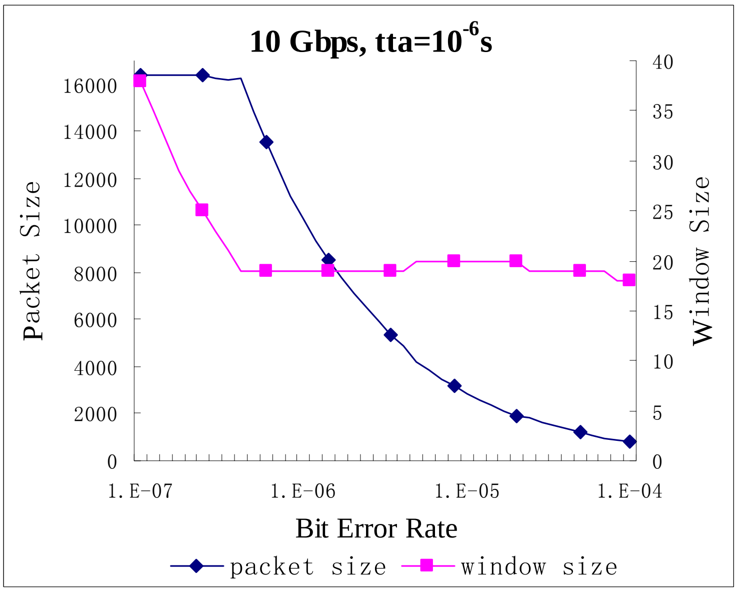

Fig. 9. Optimum values of *N* & *l* corresponding to Fig.8.

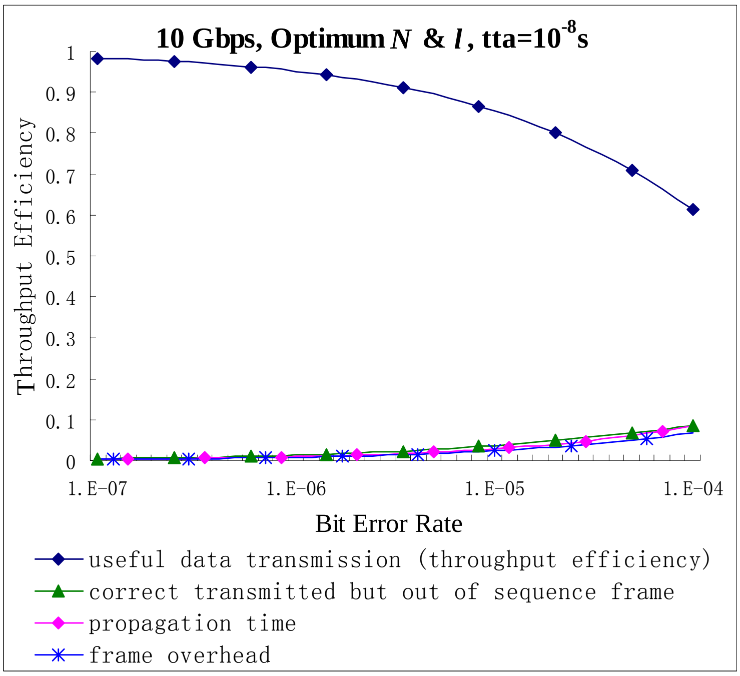

Fig. 10. Relative percentages of transmission time, t_{ta}=1e^{-8}s.

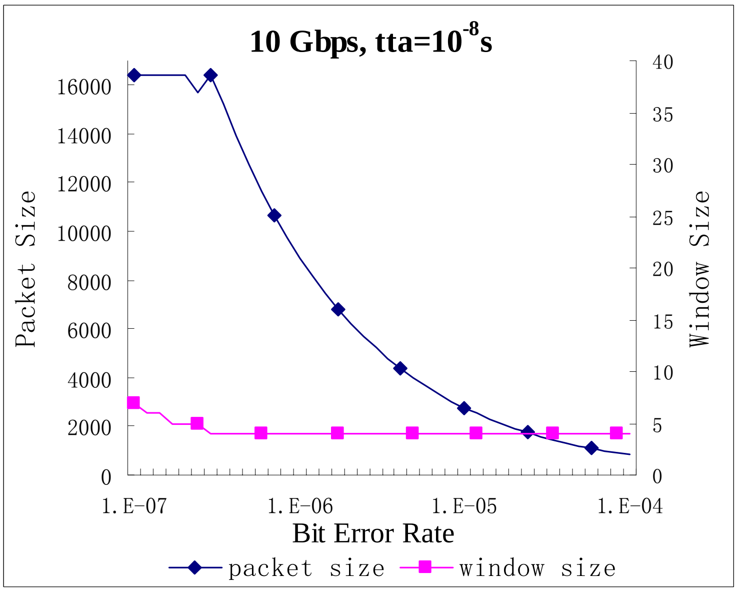

Fig. 11. Optimum values of *N* & *l* corresponding to Fig. 10.