

Window and frame size adaptivity for maximum throughput in IrDA links

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Abstract. Performance results are presented for the implementation of optimum link parameter values for infrared IrDA links. Optimum link layer parameter values may be employed to cope with increase of line Bit Error Rate (BER). The adaptivity is based on the transmitting station estimating line BER based on frame acknowledgements provided by the receiving station. A simple model, which adjusts window and frame size values based on the number of correctly received bits between two error bits is developed. A simulator following this simple model is implemented. The simulation results present the effectiveness of this simple model and prove that significant throughput increase at high BER can be practically achieved by optimum window and frame size employment. Throughput performance achieved is very close to its theoretical maximum for any BER.

I. Introduction

A large number of portable devices on market today use an infrared port for their wireless communication needs [1]. These devices range from mobile phones and digital cameras to portable computers and inkjet printers [2]. Infrared spectrum is very suitable for short range wireless information transfer between portable devices as it employs low cost and low power consumption components, uses an unregulated spectrum and can achieve high transfer rates.

Infrared Data Association (IrDA) was established in 1993 by major IT companies to develop and promote infrared standards for mobile appliances. IrDA introduced the IrDA 1.x layered platform architecture [2][3] for indoor point to point infrared links. Computer manufacturers adopted the IrDA standard [1] to the extent that IrDA ports are a commonplace.

IrDA ports provide a significant alternative for indoor information transfer.

IrPHY [4], the IrDA 1.x physical layer specification, supports short range half duplex wireless links from zero to at least 1m and a maximum angle of ± 15 degrees. Due to hardware tolerance, adequate link operation at angles up to 30 degrees is observed [3]. Data rates range from 9600bps and 115.200 bps using standard serial hardware to 16Mbps with high speed extension. IrPHY requires that all IrDA compliant links operate at a Bit Error Rate (BER) less than 10^{-8} . Due to strict range and angle restrictions, IrDA links may operate at a higher BER in real life.

IrLAP [5], the IrDA link layer (OSI layer 2), is an HDLC derivative. IrLAP throughput performance is examined in [6] [7] and [8]. A mathematical model using the concept of a frame's 'virtual transmission time' is presented in [6] and a mathematical model using the concept of 'window transmission time' leading to a simple equation for IrLAP throughput is presented in [7]. By differentiating this equation, optimum values for window size and frame size that should be implemented by the transmitting station for maximizing link throughput are presented in [8]. These equations give optimum window size values for fixed frame size, optimum frame size values for fixed window size and optimum values for window and frame size for a specific BER. To implement these optimum values, the transmitting station must estimate line BER based on frame acknowledgments and rejections provided by the receiving station. A simulator implementing optimum values based on the number of correctly transmitted bits between two error bits is implemented. Simulation throughput results indicate that throughput is significantly

increased by implementing optimum values based on line BER estimations.

II. Brief description of IrLAP protocol and parameter definitions

IrLAP is based on HDLC operating in Normal Response Mode (NRM). During link establishment, IrLAP assigns primary and secondary roles to communicating stations. Any station may claim to become the primary station but only one station is finally assigned the primary role. A number of parameters, such as data rate, maximum frame size, maximum window size and minimum turn around time, are negotiated and agreed during link establishment. Current analysis assumes the saturation case, when the primary station always has information ready for transmission. As secondary does not wish to transmit any information, it transmits only supervisory frames (S-frames), acknowledging frames correctly received. The parameters used in current model are shown in Table 1.

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_l	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}	Acknowledgment time	sec
T_{max}	Maximum turn-around time	sec
t_{Fout}	F-timer time-out period	sec
D_f	Frame throughput	frms/sec
D_b	Data throughput	bits/sec

Table 1: IrLAP Parameters

IrLAP frame structure is shown in Figure 1. Link direction is reversed by setting the Poll/Final (P/F) bit of a transmitted frame. If it is set by the primary, it is called the Poll bit (P-bit). If it is set by the secondary, it is called the Final bit (F-bit). The primary station transmits a number of Information frames (I-frames) that

contain user data. The number of I-frames transmitted is determined by the window size parameter. Maximum window size is 7 frames if an 8-bit control field is implemented, as shown in Figure 1. However, IrLAP 16Mbps extension [9] optionally extended control field to 16 bits to accommodate 7-bit Ns and Nr values for 4Mbps and 16Mbps data rates. Thus, if an extended control field is used, maximum window size may take values up to 127 frames.

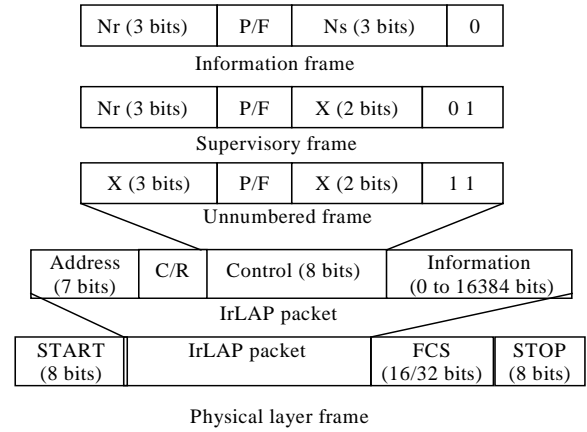


Figure 1: IrDA frame structure

The values for t_s , t_l , t_{ack} , p and D_b are given by:

$$t_s = \frac{l'}{C} \quad (1)$$

$$t_l = \frac{l + l'}{C} \quad (2)$$

$$t_{ack} = 2t_{ta} + t_s \quad (3)$$

$$p = 1 - (1 - p_b)^{l+l'} \quad (4)$$

$$D_b = lD_f \quad (5)$$

According to [7], effective window size N is given by

$$N = \min \left\{ W_{max}, \text{floor} \left(\frac{T_{max}}{t_l} \right) \right\} \quad (6)$$

where \min is 'the lesser of' and floor is 'the largest integer not exceeding'. IrLAP throughput [7][8] is given by

$$D_b = l \frac{1-p}{p} \frac{(1-(1-p)^N)}{Nt_l + p(t_{Fout} + t_s) + t_{ack}} \quad (7)$$

To achieve maximum throughput, optimum window size values for fixed frame size [8] is given by

$$N_{opt} = \sqrt{\frac{2t_{ack}C}{l^2 p_b}} \quad (8)$$

Optimum frame size values for fixed window size [8] is given by

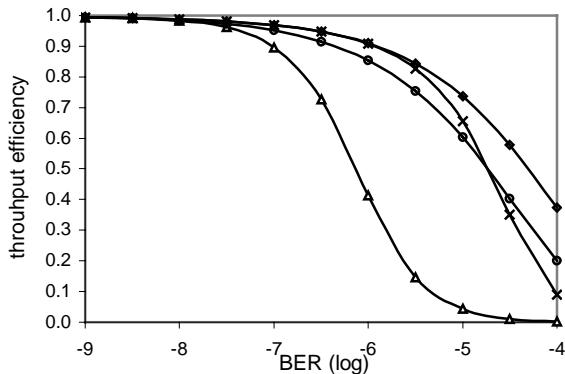
$$l_{opt} = \sqrt{\frac{2(Nl'+t_{ack}C)}{N^2 p_b}} \quad (9)$$

If window and frame size can be altered simultaneously, optimum window and frame size values are given by

$$l_{opt} = \sqrt{\frac{l'}{p_b}} \quad (10)$$

$$N_{opt} = \sqrt{\frac{2t_{ack}C}{l'}} \quad (11)$$

IrLAP specification poses an upper limit of 127 frames for the window size parameter and an upper limit of 16Kbits for the frame size parameter. However, equations (10) and (11) may propose larger values than IrLAP limits. If eq. (10) suggests implementation of frames longer than 16Kbits, transmission of 16Kbits I-frames is enforced and optimum window size values are given by eq. (8) instead of eq. (11) because a constant instead of an optimum frame length is enforced.



- Δ $N=127, l=16Kbits$
- \times optimum $N, l=16Kbits$
- \circ optimum $l, N=127$
- \diamond optimum N and optimum l

Figure 2. Throughput against BER for 16Mbit/s link, $t_{ia}=0.1ms$

For a 16Mbps link with $t_{ia}=0.1ms$, Fig. 2 compares throughput efficiency for fixed $l=16Kbits$, $N=127$ frames and for optimum window and/or frame size values. A significant improvement is observed if optimum values for window size or frame size are implemented.

Further throughput efficiency improvement is observed when optimum window and frame size values are employed simultaneously.

III. Simulation Results

In current work, the IrDA OPNETTM[10] simulator developed in [11] was altered to employ window and frame size adaptivity by the primary station. According to IrLAP performance evaluation [6][8], maximum window and frame size values should be implemented for line BER less than 10^{-9} . Fig. 2 reveals that if line BER is higher than 10^{-4} , link becomes unoperational at the physical level and link layer optimum value implementation is worthless. Current work implements adaptive simulation model for line BERs in range [10^{-9} , 10^{-4}]. Simulation results are obtained by varying line 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 [12] for optimizing frame size for full duplex ‘optimal’ ARQ protocols, i.e. protocols that retransmit only errored frames. The algorithm estimates optimum frame size based on the number of frame retransmission requests R out of the last M frame transmissions. Analysis presented in [12] concludes that an accurate estimate of the channel error rate is not necessary in order to choose a ‘good’ frame size for nearly optimum performance. In IrLAP, as the secondary station rejects frames not received correctly, the primary station 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 primary by knowing the frame the error occurred. In the current model, the primary actually counts correct frame transmissions before a frame is rejected. Based on this evaluation of the number of correctly transmitted bits between two error bits, it adjusts window and/or frame size, according to eq. (8)(9)(10)(11).

The current work assumes that bit errors occur following a random distribution. The primary’s decisions are based on instant evaluations of line BER. It is assumed that retransmitting buffered copies of error frames using different frame and window sizes does not result in significant delays. The proposed model may enforce

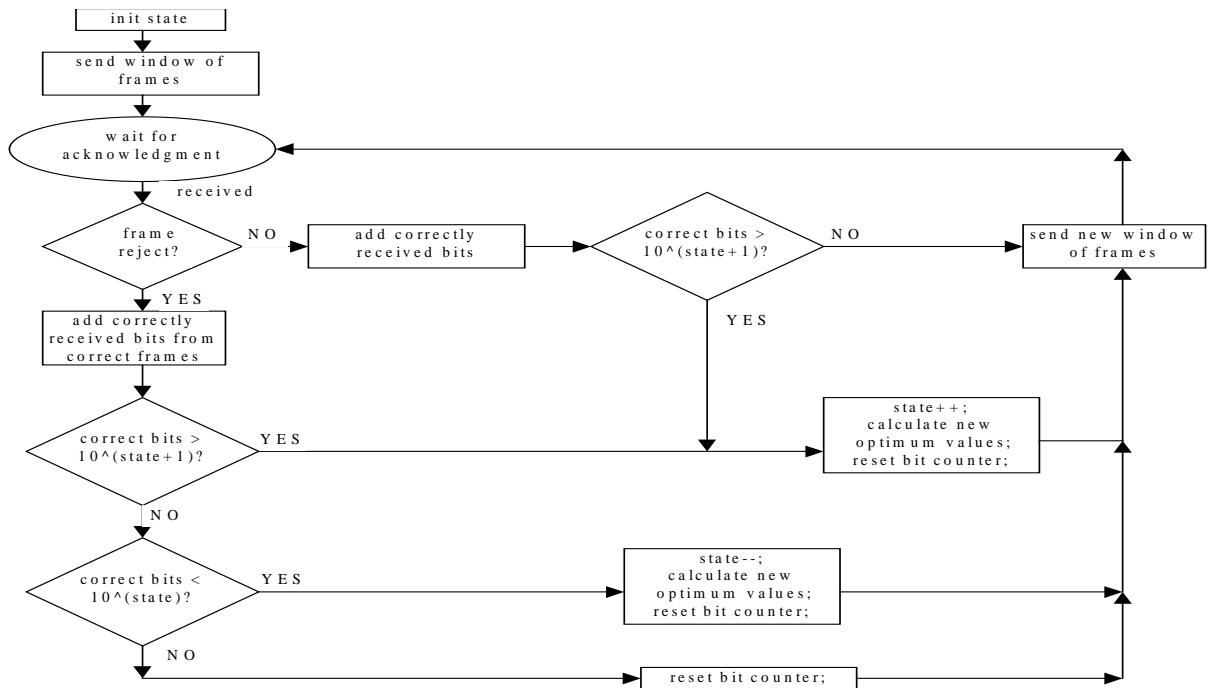


Figure 3. Adaptive window and/or frame size scheme based on line BER evaluation.

different window and/or frame size values after a bit error occurrence implying that the old values are not suitable. In the current adaptive simulation 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 the current model is simple as the primary only needs to hold information about its current evaluation of line BER and of the number of sub-ranges implemented in the above BER range.

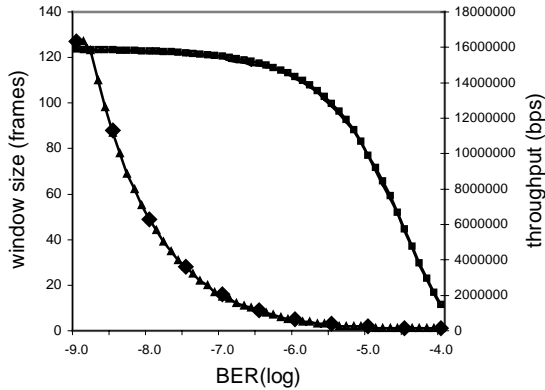
Our adaptive simulation model implements optimum values in a manner shown in Fig. 3. The following explanation assumes that the useful BER range is divided into five subranges. For an instance that the primary's current evaluation of line BER is 10^{-6} (state=6), optimum values from eq. (8)(9)(10)(11) are calculated and implemented for $p_b=10^{-6}$. These values are assumed to be suitable for the third BER subrange of $[10^{-7}, 10^{-6}]$. The primary then counts frames acknowledged by the secondary 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, primary assumes that line BER is less than 10^{-7} , it changes its current BER evaluation to 10^{-7}

(state=7) and calculates new window and/or frame size values from eq (8)(9)(10)(11) for $p_b=10^{-7}$. The primary 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 primary assumes that its current evaluation of BER 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) error free bits, the primary assumes that line BER is now higher than 10^{-6} , it changes its current BER evaluation to 10^{-5} (state=5), calculates and implements window and/or frame size values suitable for $p_b=10^{-5}$ and resets counters.

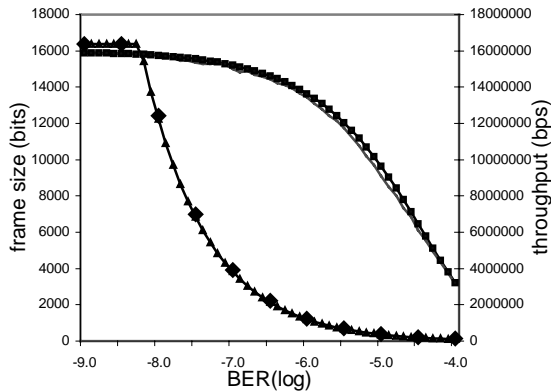
The above set of rules for BER evaluation and optimum value adjustment were chosen due to their simplicity. As IrLAP procedures are implemented at low level, simple and easily implemented at run time adaptive rules should be investigated. Simulation results presented in current work always divide the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

Figure 4 plots the optimum window size values and the corresponding throughput versus line BER derived by applying numerical methods to eq.(7) for a 16Mbps link with $t_{ca}=0.1ms$ and $l=16Kbits$. It also plots simulation results for

optimum window size values and throughput achieved. An almost exact match for simulation is achievable and maximum throughput is observed. Results show that implementation of exactly optimum values is not necessary. If window size values close to the optimum values are implemented, throughput performance very close to the maximum possible can be achieved.



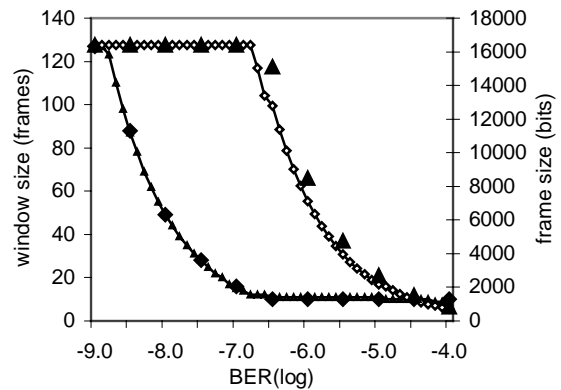
Δ N optimum (numerical)
 \blacklozenge N values implemented by primary station in simulation
 \blacksquare optimum throughput (numerical)
 — simulation throughput
 $C=16\text{Mbps}$, $t_{ia}=0.1\text{ms}$, $l=16\text{Kbits}$
 Figure 4. Throughput comparison for implementing 11 window size values



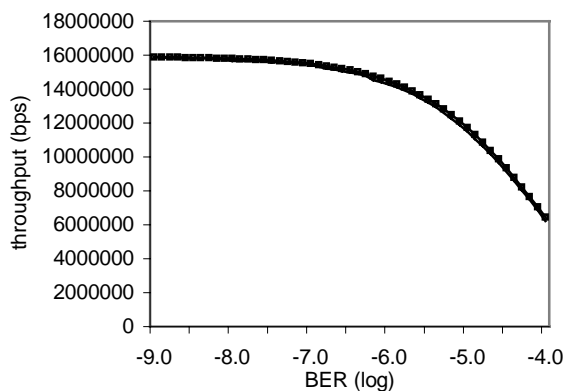
Δ l optimum (numerical)
 \blacklozenge l values implemented by primary station in simulation
 \blacksquare optimum throughput (numerical)
 — simulation throughput
 $C=16\text{Mbps}$, $t_{ia}=0.1\text{ms}$, $l=16\text{Kbits}$
 Figure 5. Throughput comparison for implementing 11 frame size values

Figure 5 plots optimum l values and the corresponding maximum throughput versus BER by employing numerical methods to eq. (7) for fixed $N=127$ frames for a 16Mbps link with $t_{ia}=0.1\text{ms}$. Simulation results also plotted in Figure 5 show that an almost optimum throughput performance is achieved by implementing ten subranges.

Figure 6 plots simultaneous optimum window and frame size values derived numerically from eq. (7) for maximum throughput. It also plots the optimum values implemented in simulations and derived from eq. (8)(10)(11) for the same link. The simulation achievable throughput is very close to the mathematically optimum throughput as presented in Fig 7. It is shown that when 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 value enforcement, a significant throughput performance increase can be achieved.



Δ l optimum (numerical)
 \blacklozenge l values implemented by primary station in simulation
 \diamond N optimum (numerical)
 \blacktriangle N values implemented by primary station in simulation
 $C=16\text{Mbps}$, $t_{ia}=0.1\text{ms}$, $l=16\text{Kbits}$
 Figure 6. Optimum value comparison for implementing 11 window and frame size values



■ optimum throughput (numerical)
 — simulation throughput
 $C=16\text{Mbps}$, $t_{ia}=0.1\text{ms}$, $l=16\text{Kbits}$
 Figure 7. Throughput comparison for implementing 11 window and frame size values

IV. Conclusions

We have shown by simulation that if the estimated optimum link parameter values for IrDA links are implemented, a significant and very close to the theoretically maximum achievable throughput performance increase can be achieved. Simple rules for primary's line BER evaluation and for optimum value adjustment are presented. We show that implementation of these rules is quite effective resulting in significant throughput increase. A simulator using the OPNET modeller is developed and employed to prove the effectiveness of optimum link parameter values implementation.

References

- [1] A. C. Boucouvalas, Z. Ghassemlooy, Editorial, Special Issue on Optical Wireless Communications, *IEE Proceedings J, Optoelectronics*, **147**, 279, (2000).
- [2] Williams S., 'IrDA: Past, Present and Future', *IEEE Personal Communications*, **7**(1), 11-19 (2000)
- [3] I. Millar, M. Beale, B. J. Donoghue, K. W. Lindstrom, & S. Williams, 'The IrDA Standard for High-Speed Infrared Communications'. *The Hewlett-Packard Journal* 1998; 49(1):10-26.
- [4] IrDA, Serial Infrared Physical Layer Specification – Version 1.3, *Infrared Data Association*, (1998)
- [5] IrDA: Serial Infrared Link Access Protocol (IrLAP) – Version 1.1, *Infrared Data Association*, (1996).
- [6] Barker P., Boucouvalas A.C. & Vitsas V., "Performance Modelling of the IrDA Infrared Wireless Communications Protocol", *International Journal of Communication Systems* 2000, **13**:589-604.
- [7] Vitsas V. & A. Boucouvalas, 'Throughput Analysis of the IrDA IrLAP Optical Wireless Link Access Protocol', *3rd Conference on Telecommunications, ConfTele 2001*, pp. 225-229, April 23-24, 2001, Figueira da Foz, Portugal.
- [8] AC Boucouvalas & V. Vitsas, "Optimum window and frame size for IrDA links", *Electronics Letters* 2001, **37**(3):194-196.
- [9] IrDA: Serial Infrared Link Access Protocol Specification for 16Mb/s Addition (VFIR) – Errata to version 1.1, *Infrared Data Association*, (1999).
- [10] OPNET™ modeller, MIL3 Inc., 3400 International Drive NW, Washington DC 20008, USA.
- [11] Barker P. and Boucouvalas A.C, "A simulation model of the IrDA infrared communication protocol", *First Int. Symposium on Comm. Systems & Digital Signal Processing*, 6-8 April 1998, pp 2-5, Sheffield, UK.
- [12] Modiano E., "An adaptive algorithm for optimizing the packet size used in wireless ARQ protocols", *Wireless Networks 1999*, **5**:279-286.

