

IrDA IrLAP Throughput Optimisation with Physical Layer Consideration

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Abstract

This paper presents results for simultaneous optimisation of data packet size and transmission window size providing optimum throughput at the IrDA IrLAP data link layer. By linking a throughput model with optimisation to an IrDA physical layer model it is shown how optimisation increases the physical range performance. We also show how optimisation can be achieved through variation of data packet size alone.

1. Introduction

Data transfer with an IrDA 1.x based IR wireless link involves the transmission of a window of data frames at the IrLAP data link layer and a retransmission of lost or consequently out-of-sequence frames following acknowledgement of the window from the receiving station. At link initiation, a set of parameters including data packet size, transmission window size, minimum turn-around delay, and maximum turn-around (transmission) time are negotiated for the required data rate of the link. These then remain fixed for the duration of the link. We have provided elsewhere [1] [2] models for calculation of IrLAP throughput in relation to the data rate, BER and link parameters and demonstrated that optimisation of throughput for a particular BER can be achieved through simultaneous variation of data packet size and transmission window size [3]. In this paper we demonstrate that by linking the throughput and optimisation model to a physical layer model providing link BER in relation to link distance and physical layer parameters, optimisation provides a more gradual fall-off of throughput with link distance than is achieved with fixed IrLAP parameters only. We also demonstrate that provided the minimum turn-around delay is made sufficiently small, optimisation can be achieved through variation of the data packet size only.

2. IrLAP layer operation

The IrLAP layer is the data link layer of the IrDA 1.x protocol, and is closely based on the HDLC-NRM (High-level Data Link Control – Normal Response Mode) data link standard. As such it provides reliable data exchange between a Primary / Secondary device pair using data carrying I-frames and control S-frames. A ‘window’ of I-frames is transmitted during a maximum transmission period of 500 ms and has a maximum size 7 frames, or 127 frames in high-speed extension mode. I-frames can have a data packet size up to 2Kbytes (16384 bits). On transferring from a transmission to a reception state, each device must implement a minimum turn-around delay of up to 10 ms to cover for receiver hardware latency.

The use of the send sequence number N_s , receive sequence number N_r and P/F (Poll / Final) bit in the I-frame control field (N_r and P/F bit only with an S-frame) control the flow and error correction of data. The returned N_r value in an acknowledgement indicates correctly received frames number up to $N_r - 1$. If N_r is not as expected, unacknowledged frames beginning at N_r are retransmitted. The P/F bit is set in the last frame in the window and passes permission to transmit to the receiving device. An F-timer is used at the Primary to force a re-poll of the Secondary after a time-out period if the P/F bit frame or returning acknowledgement is lost [4].

3. IrLAP throughput model

An IrLAP throughput model has been produced [5] providing saturation throughput in relation to the link data rate, BER and link parameter settings. The model uses the probability of frame error and a Markov model of the frame retransmission process to provide the average successful window transmission time. In the model we assume a saturation condition, where data frames are continually waiting transmission. We also assume that I-frames are transmitted from the Primary to the Secondary only (i.e. Secondary only returns S-frames) and that S-frames from either station are small enough to be considered error free. From this model, the throughput efficiency U is given by:

$$U = \frac{l}{C} \cdot \frac{(1-p)}{p} \cdot \frac{1-(1-p)^N}{Nt_I + p(t_{Fout} + t_s) + t_{ack}} \quad (1)$$

where l is the data packet size (bits), C is the link data rate (bits/s), N is the transmission window size (frames), t_I is the I-frame transmission time (sec), t_s is the S-frame transmission time, t_{Fout} is the F-timer period (sec), and t_{ack} is the acknowledgement delay. p is the frame error probability, which is related to the bit-error-rate (BER) p_e by:

$$p = 1 - (1 - p_e)^{l+l_{oh}} \quad (2)$$

where l_{oh} is the frame overhead size (bits). The I-frame and S-frame transmission times are given by:

$$t_I = \frac{l+l_{oh}}{C} \quad t_s = \frac{l_{oh}}{C} \quad (3)$$

The acknowledgement time consists of 2 minimum turn-around delay times t_{ta} (sec) and the returning S-frame transmission time.

$$t_{ack} = 2t_{ta} + t_s \quad (4)$$

4. Throughput optimisation

Increasing the data packet size (assuming other parameters remaining constant) will reduce the relative frame overhead and reduce the frequency of required link turn-around following transmission of the window, thus tending to increase throughput. However increasing the data packet size also increases the probability of frame error from a given link BER, therefore increasing the average number of required frame retransmissions in a window and so decreasing throughput. There is therefore an optimum data packet size for a particular data rate, BER and parameter set that will maximise throughput. Similarly, increasing the transmission window size reduces the frequency of link turn-around, tending to increase throughput. However increasing the window size also increases the average retransmission window, reducing throughput. There is therefore an optimum transmission window size that will maximise throughput for a given BER. The optimum data packet size and window size can then be found by equating the first order derivative of the throughput with respect l and N to zero. It has been shown that, using suitable approximations, the optimum window size N_{opt} (frames) and optimum data packet size l_{opt} (bits), when simultaneously optimised, are given by [6]:

$$N_{opt} \approx \sqrt{\frac{2t_{ack} C}{l_{oh}}} \quad (5)$$

$$l_{opt} \approx \sqrt{\frac{l_{oh}}{P_e}} \quad (6)$$

It can be seen that the optimum window size is effectively independent of the link BER and that the optimum data packet size is independent of the link data rate and minimum turn-around delay. Figure 1 shows the optimum data packet size (simultaneously optimised with window size) Vs BER and Figure 2 shows the optimum window size (simultaneously optimised with data packet size) for the 16 Mbits/s data rate. These results were produced numerically from the throughput model [7]. This demonstrates the independence of the optimum packet size from the minimum turn-around delay and that the window size is independent of BER if the minimum turn-around delay is made sufficiently small. It can also be seen that performance at low BER values can benefit from a data packet size in excess of the 2Kbyte maximum specification. Figure 3 shows throughput efficiency Vs BER using the maximum, independently optimised and simultaneously optimised data packet and window sizes for the 16 Mbits/s link with a minimum turn-around delay of 0.1 ms. It can be seen that optimisation provides an improvement in throughput for a given BER value over that for fixed parameters. At a BER of 10^{-5} , the increase is approximately 65%. It is also seen that the more significant effect is from optimisation of the data packet size.

5. Physical Layer Considerations

At the IrDA physical Layer (IrPHY), there are different encoding / modulation schemes for different data rate ranges. IrDA SIR (Serial Infrared) up to 115,200 uses a 3/16 bit period RZI (Return to Zero Inverted) modulation with 0.576 and 1.152 Mbits/s using ¼ bit period RZI modulation. The 4 Mbits/s FIR (Fast Infrared)

physical layer uses 4 PPM (Pulse Position Modulation) while the high speed 16 Mbits/s VFIR (Very Fast Infrared) uses the dedicated HHH encoding, a rate 2/3 (1|13,5) RLL (Run Length Limited) scheme [8]. As such each mode has a different formula relating the BER to the signal-to-noise ratio (SNR).

Data Rate	Encoding	BER	Bandwidth
9600 – 115,200 bits/s	3/16 RZI	$Q(\sqrt{SNR} / 2)$	250 KHz
0.576 & 1.152 Mbits/s	1/4 RZI	$Q(\sqrt{SNR} / 2)$	2.48 MHz
4 Mbits/s	4 PPM	$1 - (1 - Q(\sqrt{SNR} / 2))^2$	6.1 MHz
16 Mbits/s	HHH	$1 - (1 - Q(\sqrt{SNR} / 2))^{3/2}$	14.5 MHz

Table 1: BER formulae and recommended bandwidth for the IrPHY

Assuming an LED transmitter and PIN photodiode detector with ambient light induced shot noise (white Gaussian) dominant, the peak electrical line-of-sight (LOS) signal to noise ratio (SNR) is given by [9]:

$$SNR_{LOS} = \frac{RAI_0^2}{2d^4 qE_B B} \quad (7)$$

where R is the detector responsivity (A/W), A is the detector area (m^2), I_0 is the transmitter axial radiant intensity (W/Sr), d is the link distance, E_B is the background ambient irradiance (W/m^2), and the B is the receiver bandwidth (Hz), with q the electron charge ($\sim 1.6 \times 10^{-19}$ C).

Parameter	Value
Detector Area	0.16 cm^2
Detector Responsivity	7 $\mu A/mW$
Transmitter Radiant Intensity	109 mW/Sr
Ambient Irradiance	490 $\mu W/cm^2$

Table 2: IrDA specified physical layer parameters

Using the parameters in Table 2 with the formula given in (4) for the SNR and substituting into the relevant formula given Table 1, provides the BER in relation to the link distance d and for the given physical layer parameters. This then provides a mechanism using the formula in (1) to relate throughput to the link LOS distance d . Figure 4 presents throughput efficiency Vs link LOS distance with maximum, independently optimised and simultaneously optimised data packet size and window size for a 16 Mbits/s link. It can be seen that optimisation produces a more gradual ‘fall-off’ in throughput with link distance than using the maximum or independently optimised values. In practice this would result in a link not suddenly failing beyond a critical distance but more gradually reducing performance.

6. Conclusions

We have shown in this paper that through simultaneous optimisation of the IrLAP data packet size and transmission window size parameters that throughput can be improved for a given link BER. By linking the throughput to a LOS physical layer model, the effect of optimisation on throughput with link distance has been examined. We have also shown that if the minimum turn-around delay is made small, the window size can be kept small and constant, with optimisation provided through variation of the data packet size only.

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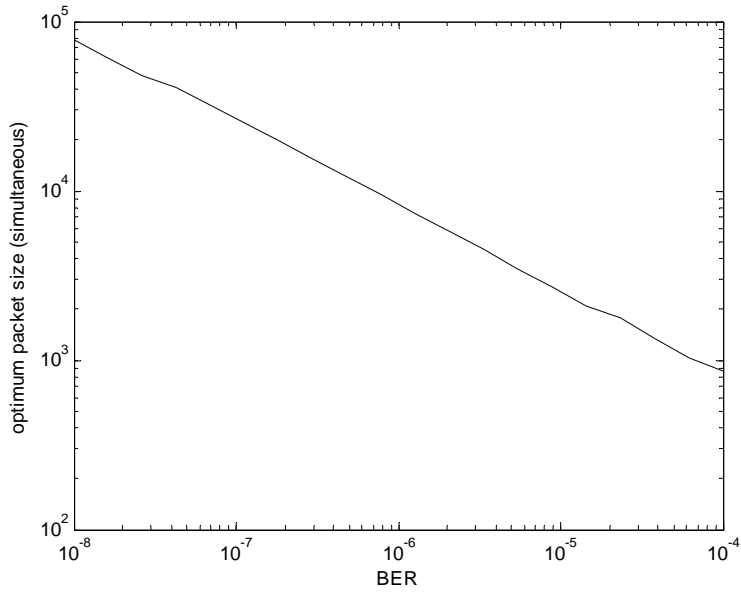


Figure 1: Optimum packet size Vs BER for 16 Mbits/s link

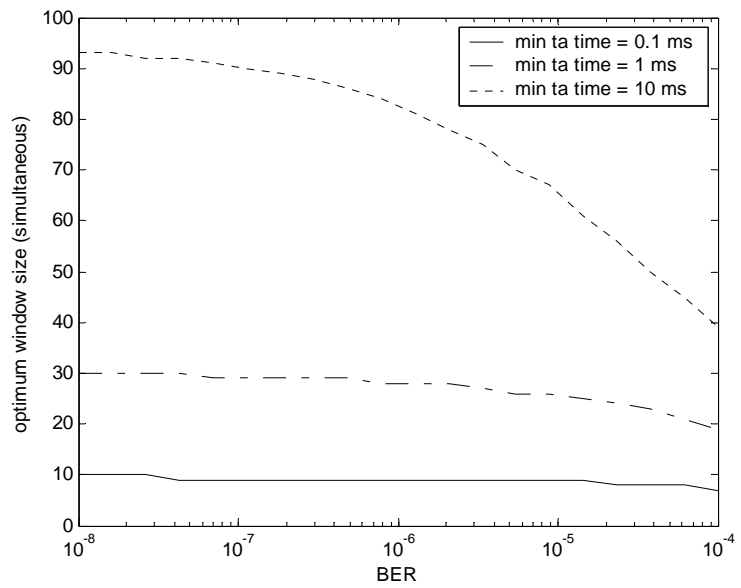


Figure 2: Optimum window size Vs BER for 16 Mbits/s link

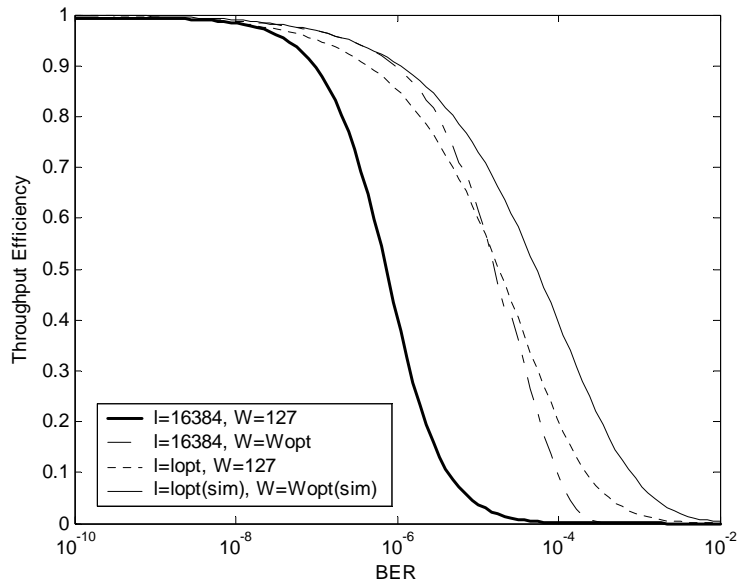


Figure 4: Throughput Efficiency Vs BER with maximum, optimum and simultaneously optimised packet and window sizes

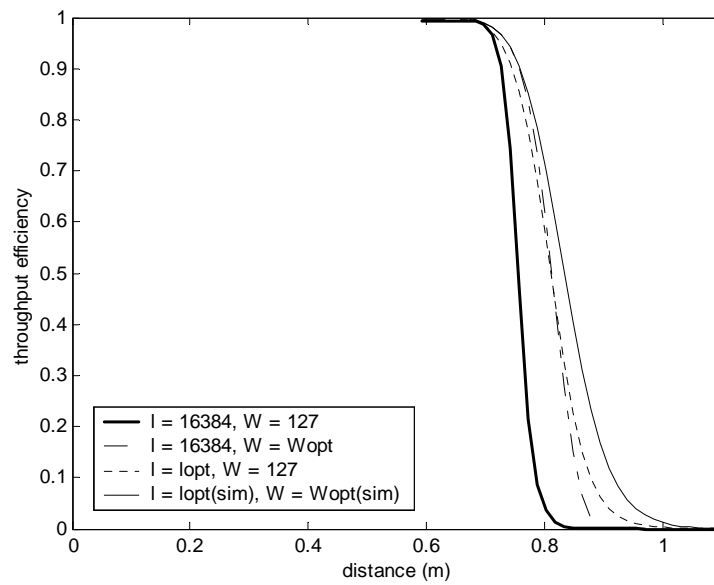


Figure 5: Throughput Efficiency Vs LOS link distance with maximum, optimum and simultaneously optimised packet and window sizes