IrDA Infrared Wireless Communications: Protocol Throughput Optimization

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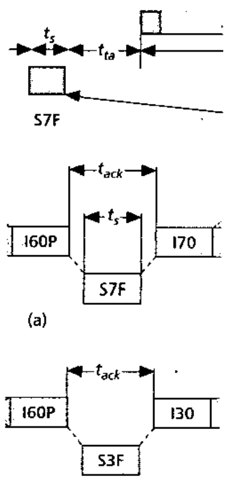

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Abstract

The delivery of the maximum data rate to users from IrDA IR wireless links depends not only on the physical layer, but also on higher-layer protocols being optimized. This article reviews the IrDA link layer protocol, IrLAP, and examines how to maximize its throughput performance. Simple equations yield to simple rules for the optimization of IrLAP. The analysis presented can also be employed in studying the physical layer requirements of the predicted future data rate increases (40 Mb/s and 100 Mb/s) of the IrDA 1.x standard. The model gives insights for the optimum control of the infrared connection for high performance. Simple formulas are derived for the optimum values of the window and frame size link layer parameters that maximize throughput. Results show that, for the proposed 16 Mb/s extension, significant throughput increase is observed if optimum link layer parameter values are employed. At high error rates, the significance of the minimum turnaround time (a physical layer parameter) and of the transmission control passing mechanism is studied. When the links are adapted to using the optimum window and frame size, combined with low minimum turnaround values and an efficient transmission control passing scheme, we observe performance improvements even at high error rates.

Introduction

The deployment of laptop and palmtop computers, and the expanding digital representation of music and images in portable digital appliances (e.g., MP3 players, digital cameras) have led to increasing demand for fast wireless information transfers. The infrared (IR) spectrum offers advantages over radio in short-range indoor communications [1]. Indoor IR links are low cost with low-power-consumption components for handheld devices. Since IR radiation does not penetrate walls, the IR spectrum is unregulated worldwide. IR room confinement and a line of sight (LOS) requirement simplify security issues and render IR an efficient and cost-effective choice.

In order to encourage the development of interoperable multivendor infrared link designs, the Infrared Data Association (IrDA) was established in 1993 by major IT companies [2]. IrDA first developed the IrDA 1.x protocol stack [3] for short-range low-cost half-duplex narrow beam point-to-point connections. IrDA 1.x links aim to replace cables between devices such as laptop computers, personal digital assistants (PDAs), digital still and video cameras, mobile phones, and printers. Computer manufacturers have widely adopted the IrDA 1.x standard, and popular operating systems fully support the IrDA 1.x specification. More than 40 million devices are shipped every year equipped with IrDA 1.x ports, and IrDA 1.x technology has achieved widespread deployment in a wide range of devices in a short period of time [2].

IrDA-based IR wireless links therefore provide an attractive alternative to radio: low cost, small size, low power consumption, low error rate, very fast short range, and LOS links. Applications include end-to-end digital payment systems, where there is recent interest in the IrDA financial messaging standard, IrFM, which utilizes existing financial services infrastructures (e.g., credit cards, mobile phones) to process wireless payment transactions at the point of sale.

IrDA Link Access Protocol (IrLAP) [4] is the IrDA 1.x data link layer, which drives the IR hardware. IrLAP design is based on the existing High-Level Data Link Control (HDLC) protocol. The performance of IrDA 1.x links may be measured by throughput, which can be drawn at the IrLAP layer. Link layer throughput takes into account all significant factors that affect performance, such as:

- Physical layer delays (e.g., hardware latency)
- The transmission control passing scheme
- Transmission errors introduced by the wireless medium
- Acknowledgment delays

IrDA links should operate under wide dynamic range conditions and are likely to be used under varying noise/interference indoor environments. Rooms are normally illuminated with fluorescent tube or tungsten lights, emitting light noise/interference in the passband of the IR links. Furthermore, handheld devices may not align perfectly, and alignment sway [5] may cause variation in the signal leading to bit error rate (BER) variation. Robust links should main-

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tain throughput performance under varying BER channel conditions.

This article describes the IrDA 1.x protocol stack, focusing on the physical and IrLAP layers. We also present a simple analytical model for IrLAP throughput. This model allows the derivation of optimum values for the window size and frame length parameters for maximum throughput at high BERs. We demonstrate the improvements in link throughput performance obtained when we adapt the window and frame sizes simultaneously to easily calculated optimum values.

IrDA Protocol Stack

The IrDA 1.x protocol stack (Fig. 1) consists of three mandatory components: the IrDA physical layer (IrPHY), the IrLAP data link layer, and the IrDA link management (IrLMP) layer. The latter consists of two subcomponents: an application channel multiplexer (LM-MUX) and a supported services database (information access services, LM-IAS). The LM-MUX allows multiple applications in an IrDA device to communicate independently and simultaneously over a single IrLAP connection. LM-IAS facilitates the discovery of available services between the communicating devices. An IrDA service first claims an LM-MUX port and then advertises itself to the communicating device by placing its service information and all the necessary parameters in a database.

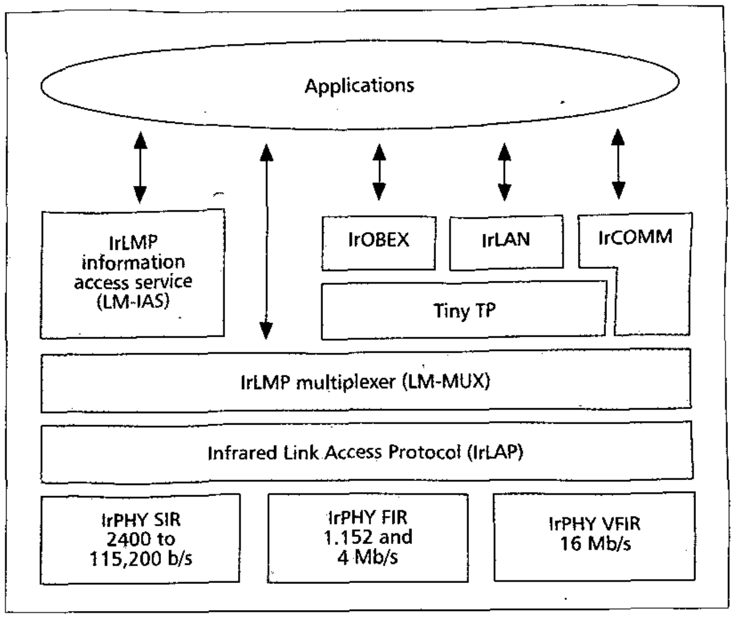
Optional IrDA components include Tiny TP, a credit-based application-level flow control protocol. IrCOMM is a serial and parallel port link emulator that enables all applications designed to operate over serial or parallel cables to operate unchanged over the IR medium. IrCOMM supports both data terminal equipment (DTE)–DTE (null modem) and DTE–data communications equipment (DCE) connections. IrLAN allows station LAN access over an IrDA link, and IrOBEX facilitates simple data object (e.g., business card) exchange [2, 3].

The IrDA Physical Layer

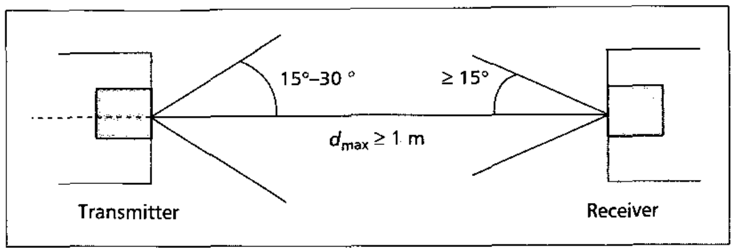
The IrPHY layer provides the optical, optoelectronic, and electronic components for transmission and reception of serial data over the IR wireless medium. The physical layer also includes frame construction and error detection functions using cyclic redundancy check (CRC), although these functions are often implemented as software components. Received frames that fail the CRC are simply discarded and not passed to the upper IrLAP layer.

The IR transmitter is an LED operating in the 800–900 nm wavelength range. Output intensities are limited by eye safety regulations to 500 mW/Sr but are typically less than 100 mW/Sr. The transmitter is fitted with a lens such that the optical half angle is ±15° to ±30°. The optical detector is a PIN photodiode with a receiver half-angle field of view (FOV) of at least 15° (Fig. 2). The IrPHY standard specifies that a minimum link range of 1 m with a BER no worse than 10^{-8} must be achieved.

The IrDA serial IR (SIR) physical layer specification is designed to utilize the standard UART serial port chips of a device, and therefore has a data rate range of 9.6–115.2 kb/s. The modulation used with IrDA SIR is return to zero inverse (RZI) with a 3/16 bit period duration. The IrDA fast IR (FIR) specification is a high-speed extension providing data rates of 576 kb/s, 1.152 Mb/s, and 4 Mb/s using a dedicated communications controller connected to the data bus [6]. The 4 Mb/s data rate uses four pulse position modulation (4-PPM) encoding. A recent addition to the physical layer specification is the very fast IR (VFIR) extension to 16 Mb/s. This uses a dedicated (1, 13|5) run length limited (RRL) encoding scheme. This eliminates the possibility of neighboring pulses (possible with PPM encoding) that could cause intersymbol interference at high data rate links with multipath propagation [7].



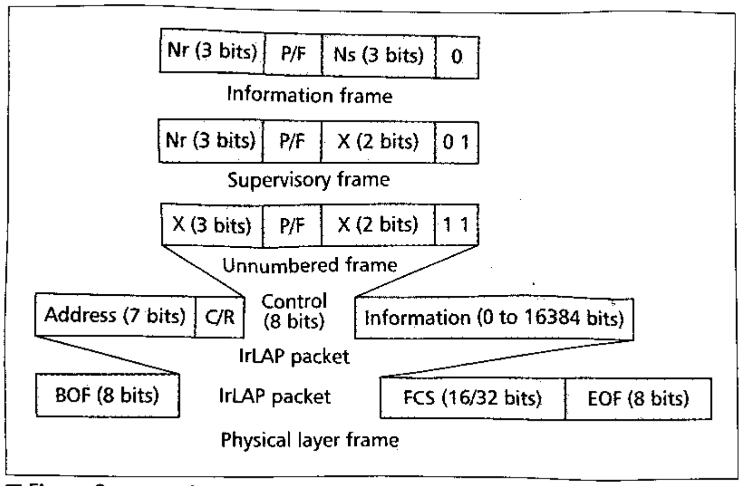
■ Figure 1. *The IrDA 1.x protocol stack.*



■ Figure 2. *IrPHY optical interface specification.*

The IrLAP Data Link Layer

The IrLAP layer is an unbalanced data link control protocol closely based on the HDLC — Normal Response Mode (HDLC-NRM) protocol. IrLAP uses primary and secondary device roles with frame sequencing and poll/final (P/F) bit checkpointing. Three frame types are used: unnumbered frames (U-frames), supervisory frames (S-frames), and information frames (I-frames). U-frames are employed for link management, device discovery, connection



■ Figure 3. *IrLAP frame structure.*

establishment procedures, and unreliable data transfer outside of a connection. S-frames' contribution is in the information exchange procedure, although they never carry information data themselves. S-frames are short control frames used to report frame sequencing errors, acknowledge correctly received frames, and request acknowledgments. I-frames contain the user data to be transferred during the connection period with data size up to 2048 bytes (16,384 bits).

The IrLAP frame structure is as shown in Fig. 3. I-frames contain send number (Ns) and Receive Number (Nr) sequence fields. These are 3 bits long and thus hold sequence numbers from 0 to 7. The P/F (poll from primary/final from secondary) bit is used to indicate the last frame in a transmission and pass transmission control. S-frames contain an Nr field used to acknowledge correctly received frames. U-frames contain no sequencing information (and hence are unnumbered) [4].

During connection establishment, several protocol parameters are negotiated and agreed on between the communicating devices. These are data rate (C), maximum data size (l), maximum turnaround time (maximum window transmission duration, maximum 500 ms), minimum turnaround time (t_{ta}, delay when moving from receive to transmit state to cover receiver latency, maximum 10 ms), and maximum window size (N, maximum 7). The maximum turnaround time must always be obeyed and has priority over the maximum window size. As a result, the maximum turnaround time combined with the data rate and frame data size may limit the window size applied to below that requested.

IrLAP Extension to 16 Mb/s (VFIR)

The extension of the physical layer to support the 16 Mb/s data rate requires an extension to the IrLAP layer to improve the performance of devices implementing the higher data rate [7]. The standard requires the maximum window size to be extended from 7 to 127 frames in order to reduce the increased link turnaround frequency arising from the higher data rate. Increasing the maximum window size value requires an enlargement of the IrLAP frame control field from 1 to 2 bytes to accommodate 7-bit Ns and Nr subfields now holding values from 0 to 127 [8]. The modulus of increment is also changed from 8 to 128. Increasing window size improves performance at low error rates but results in performance degradation at high error rates due to out-of-sequence frame transmissions [9].

Physical Layer Considerations

In this section we relate the link BER to physical layer properties of link distance and geometry, transceiver characteristics, ambient light power, and, finally, highlight the major factors affecting link performance. A basic two-dimensional model of the physical layer assuming no multipath propagation gives the signal-to-noise ratio (SNR) as

$$SNR = \frac{[P_t AR(n+1)\cos^n \theta \cos^m \phi]^2}{4\pi^2 d^4 N_0 B}, \quad (1)$$

where P_t is the average transmitted power (in watts), A is the receiver effective area (in square meters), R is the receiver responsivity (in amperes per watt), θ is the transmitter alignment angle to the LOS path between transmitter and receiver, ϕ the receiver alignment angle, and d the link separation [10]. The transmitter and receiver are modeled using the general Lambert cosine law where n and m are the transmitter and receiver lens lobe index numbers, respectively. N_0 is the double-sided noise power spectral density (in square amperes per hertz) and B the receiver bandwidth (in hertz). The receiver bandwidth B must be large enough to effectively detect a transmitted pulse, but a very large value will decrease the SNR. The detector area A cannot be made arbitrarily large as increasing the area increases the capacitance of the detector, which reduces the bandwidth B. For non-return to zero on-off keying (NRZ OOK) modulation, the bandwidth B should be equal to the data rate C [11, 12]. The design of a transmitter and suitable lenses for a directed LOS link should provide a reasonable level of device mobility without wasting optical power in a large diffuse beam.

The dominant source of noise in an IR wireless link is background ambient light. Typical light sources present in an office or home environment are sunlight (direct and indirect) and lamps (incandescent and fluorescent). Sunlight has by far the strongest power level. Optical filters are often used to reduce the level of ambient light in the spectral ranges outside of the intended IR signal, but ambient sources can still have a strong spectral presence in the IR region. Filters can also reduce the incident power of the IR signal [13]. Ambient light causes shot noise in the receiver from the random fluctuation of the detector photon current, which is a white Gaussian noise whose power is proportional to the received optical power level. Shot noise is produced from both the IR signal and ambient light, but is dominated by that from ambient light. The noise power spectral density N_0 due to the instantaneous current $i_s(t)$ can then be given as

$$N_0 = \langle i_s(t)^2 \rangle = qRAE_B, \quad (2)$$

where q is the electron charge ($\sim 1.6 \times 10^{-19}$ C) and E_B is the background ambient light irradiance (in watts per square meter). IrDA specifies an ambient irradiance no greater than 490 $\mu W/cm^2$ for normal link operation.

For NRZ OOK modulation with data rate C, where a data signal binary 1 is converted to a pulse of duration $T = 1/C$ and a 0 to an empty slot of the same duration, the BER is given as

$$p_b = Q\left(\sqrt{SNR}\right) = \frac{1}{2} erfc\left(\sqrt{SNR/2}\right), \qquad (3)$$

where $Q(z)$ is the Gaussian tail integral function. From this, the frame error probability p for a frame of length l (bits) and link BER p_b is given by

$$p = 1 - (1 - p_b)^l. \qquad (4)$$

The 16 Mb/s VFIR physical layer uses the HHH rate 2/3 (1, 13 | 5) encoding [7]. This is an RLL (d, k | ε) code with d being the minimum pulse separation (by nonpulse slots), k the maximum pulse separation, and ε the limit of consecutive pulses separated by d slots [6]. This gives an average duty cycle of 0.258 and requires a receiver upper cutoff frequency of 14.5 MHz [7]. For this encoding we will use the term *chip* to denote an encoded channel pulse slot and distinguish from the encoded data bit. The HHH uses a 3/2 coding rate, producing 3 encoded chips for every 2 data bits. The final encoding also uses a scrambling and descrambling function on the encoded bitstream.

Because of the complexity of the encoding, it is difficult to determine an effective probability of chip error. It is also likely that pulse and nonpulse slots have unequal error probabilities. However, if we assume one chip error with a probability p_c will cause an unsuccessful frame capture, we can describe the frame error probability, p, as

$$p = 1 - (1 - p_c)^{3l/2}, \qquad (5)$$

and link BER p_b is given by

$$p_b = 1 - (1 - p_c)^{3/2}. \qquad (6)$$

IrLAP Throughput Performance

Based on the link BER evaluated in the previous section, this section evaluates the throughput performance as a function of BER when a large amount of information data is transmitted. The saturation scenario is considered, in which the transmitter always has information data ready for transmission. Typical practical scenarios are:

- Picture downloading from a digital photo camera to a laptop computer for processing
- Downloading of data from a portable information gathering appliance to a host computer
- Transferring of a phone list from a mobile phone to a computer or another mobile phone
- Printing from a laptop to a (usually inkjet) printer

It is assumed that the transmitter claimed and was granted the primary role during the link setup procedure. It is also assumed that transmission errors follow a random distribution. As IrLAP allows the transmission of a window of frames before soliciting an acknowledgment and implements a Go-Back-N retransmission scheme, the primary station retransmits the correctly received frames that follow an error frame in a window transmission.

IrLAP Data Exchange Procedure

Each device holds sequence variables Vr and Vs and a window variable indicating the number of remaining frames in the transmission window. Before transmitting a data frame, a buffer copy of the data is made with index Vs. The data is then transmitted in an I-frame with the current Vs and Vr values copied to the Ns and Nr fields of the frame. Following frame transmission, the Vs variable is incremented (with modulus 8 or 128), and the window variable is reduced by 1. If the window variable is 1, the transmitted frame has the P/F bit set, and the window variable is set to its maximum value after the frame transmission. The device then moves to a receive state to await an S-frame acknowledgment or I-frame transmissions from the other device. On receiving an I-frame transmission, the Ns value of the frame should be equal to the current Vr value. If so, the data frame is accepted and the Vr variable is incremented (with modulus 8 or 128). If not, the Vr variable remains unchanged and the data frame is rejected. On receiving an S-frame or I-frame with the P/F bit set, the received Nr value should be equal to the current Vs value. If so, all previously transmitted I-frames were received correctly and the device can transmit new I-frames. If not, a number of I-frames are lost. The device then retransmits I-frames (using the buffered data frames) from the indicated Nr value to the current Vs value. If space remains in the transmission window following the I-frame retransmissions, new I-frames are transmitted to fill the window.

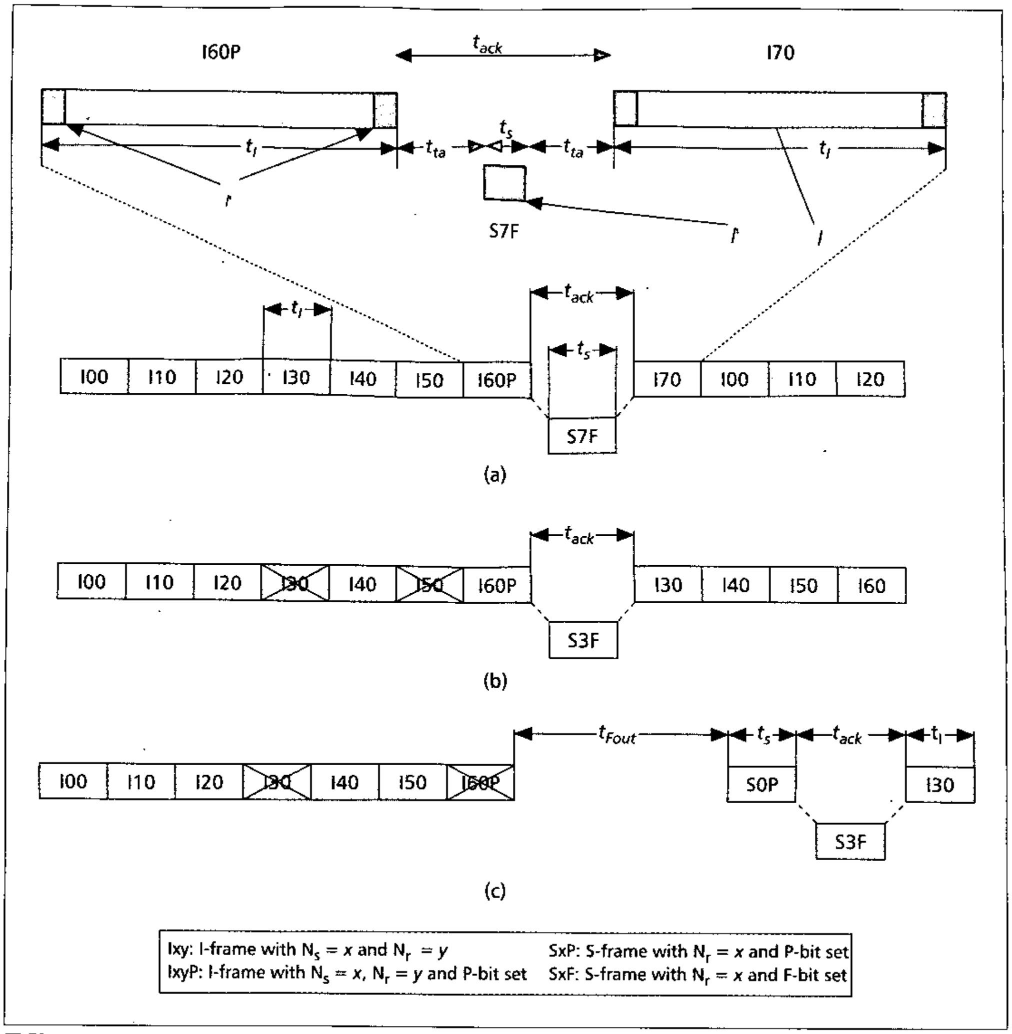
The principle difference between the primary and secondary device is in the use of the F-timer and P-timer held by the primary but not by the secondary. The F-timer is started on transmission of a frame with the P-bit set and is used to limit the time waiting for an F-bit frame return from the secondary. The timer will expire if either the P-bit frame from the primary or the returned F-bit frame from the secondary is lost due to transmission errors. On expiration of the F-timer, an S-frame with the P-bit set is sent from the primary to re-poll the secondary device. The P-timer is used to set a limit on the duration the primary holds transmission control when there is limited or sporadic data available for transmission. On expiration of the P-timer, an S-frame with the P-bit set is sent from the primary to poll the secondary. The secondary device does not hold transmission control waiting for new data transfer requests, but only transmits data immediately available for transmission. If no user data is currently available, the secondary transmits an S-frame with the F-bit set to pass transmission control and switches to receive mode [14].

Throughput Evaluation

Figure 4 presents a window frame transmission for the considered information transfer scenario for $N = 7$. If no frames are lost (Fig. 4a), the

As IrLAP allows the transmission of a window of frames before soliciting an Acknowledgment and implements a Go-Back-N retransmission scheme, the primary station retransmits the correctly received frames that follow an error frame in a window transmission.

If optimum window and/or frame size values are implemented at high BER, the main detrimental factors to throughput are the hardware latency and the time utilized on the primary's F-timer expiration when the P-bit is lost.



■ **Figure 4.** *Saturation window transmission: a) window error-free transmission; b) retransmitted frames due to error frame with $N_s = 3$ and $N_s = 5$; c) retransmitted frames and F-timer delay due to frame error at $N_s = 3$ and $N_s = 6$.*

primary proceeds with the transmission of new I-frames. If one or more I-frames are not correctly received (Fig. 4b–c)), the secondary indicates the frame loss using an S-frame, and the primary retransmits I-frames from the indicated position. If the P-bit is lost (Fig. 4c), an additional delay for the F-timer expiration is incorporated.

The analytical model evaluates that the IrDA 1.x saturation throughput is given by

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

where l is the frame data length, C is the data rate, p is the frame error probability, N is the window size, t_l is the transmission time of a data frame, t_s is the transmission time of a supervisory frame, t_{ack} is the acknowledgment time, and t_{Fout} is the F-timer timeout period. Delay t_{ack} is given by (Fig. 4)

$$t_{ack} = 2t_{ta} + t_s, \quad (8)$$

where t_{ta} is the hardware latency.

Due to the half duplex operation of the IrLAP protocol, the size of the transmission window must be reduced at high error rates. The window size parameter (N) is very important and can easily be adjusted to improve performance. Utilizing a small window size value results in an increased link turnaround frequency that significantly degrades throughput. Implementing a high window size value at high error rates results in the transmission of a significant number of frames that follow an error frame in a window transmission. These frames are considered as out of sequence and are discarded by the receiver even when they are correctly received. Time utilized in transmitting out-of-sequence frame transmissions is simply wasted. The analytical model calculates that the optimum window size values for fixed frame size are given, to a good approximation, by

$$N_{opt} = \sqrt{\frac{2t_{ack}C}{l^2 p_b}}, \quad (9)$$

where p_b is the link BER.

An alternative approach to reducing the size of a window transmission is decreasing the data frame size. A smaller frame size reduces frame error probability, frame retransmissions, and out-of-sequence frame transmissions. However, as each frame transmission requires the transmission of flags, address field, control field, and FCS, reducing the size of the information field results in a relative increase of overheads. In addition, optimum frame size implementation requires buffer reorganization if size adjustment on frame retransmissions is implemented. The analytical model calculates that the optimum frame size values for fixed window size are given by

$$l_{opt} = \sqrt{\frac{2(Nl' + t_{ack}C)}{N^2 p_b}}, \quad (10)$$

where l' is the I-frame overhead. An intuitive understanding of optimum values can be extracted by rewriting Eqs. 9 and 10 as

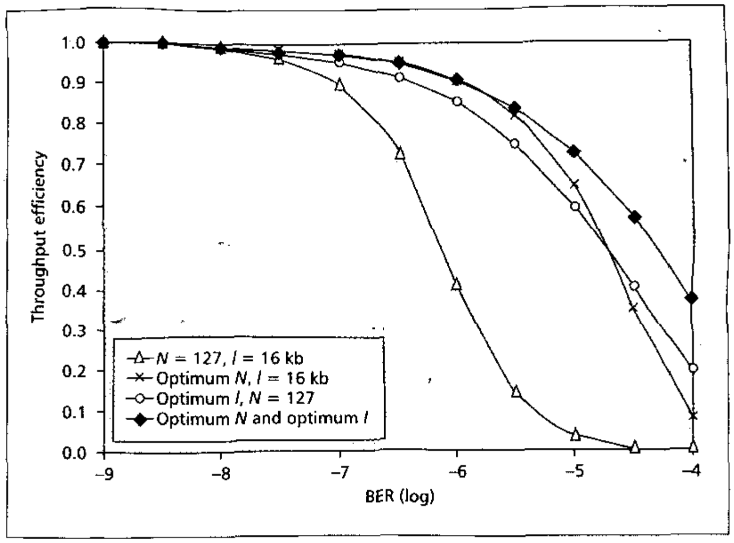
$$Nlp_b \cdot \frac{Nl}{2} = t_{ack}C + Nl'. \quad (11)$$

Equation 11 shows that maximum performance is reached 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 that occurred, which on average is half the window transmission $Nl/2$, is equal to the acknowledgment time in bits $t_{ack}C$ plus the number of overhead bits in the window transmission Nl'. The term Nl' can safely be neglected in Eq. 9 because when optimum window size values are utilized, the optimum N value is very small at high BER and term Nl' can be safely neglected.

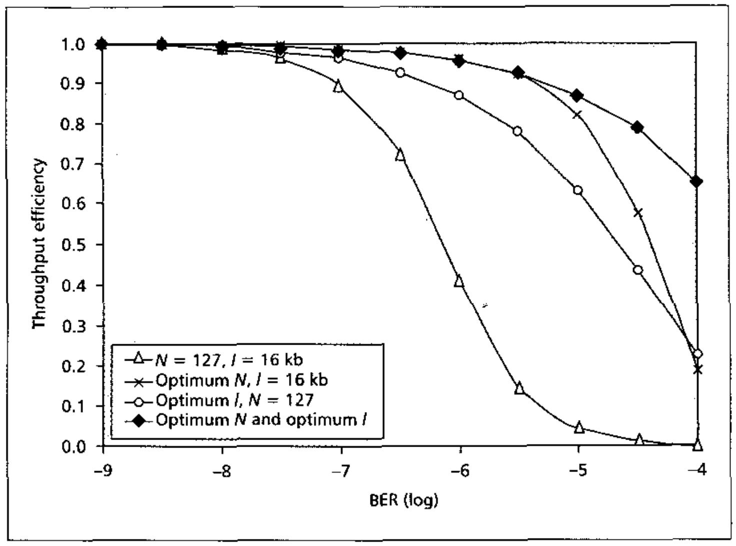
Maximum throughput performance can be achieved if the window and frame size parameters are simultaneously adjusted. The analytical model yields that simultaneously optimum window and frame size values are given, to a good approximation, by [15]

$$N_{opt} \approx \sqrt{\frac{2t_{ack}C}{l'}} \qquad l_{opt} \approx \sqrt{\frac{l'}{p_b}}. \quad (12)$$

Figure 5 compares the throughput performance of a 16 Mb/s link with t_{ta} = 0.1 ms employing N = 127 frames and l = 16 kb with the throughput achieved by implementing optimum window or frame size values given by Eqs. 9 and 10, respectively. It shows that throughput is significantly improved for a wide range of BER (from 10^{-7} to 10^{-4}) if optimum window or frame size values are employed by reducing the effect of out-of-sequence frame transmissions. For low BER, throughput for optimum N values is higher than throughput 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 = 16 kb), has a high frame error probability in high BER links, and often the P-bit is lost. Figure 5 also shows that applying optimum window and frame size values simultaneously (given by Eq. 12) results in better performance overall.

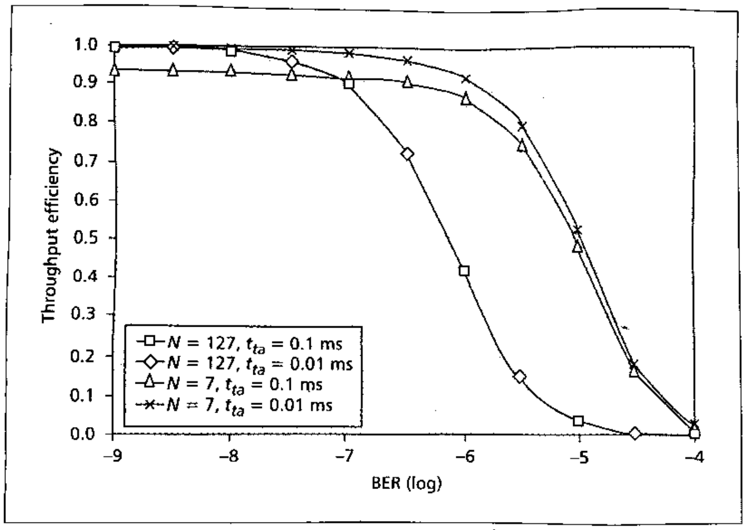


■ Figure 5. *Throughput efficiency against BER, C = 16 Mb/s, t_{ta} = 0.1 ms.*



■ Figure 6. *Throughput efficiency against BER, C = 16 Mb/s, t_{ta} = 0.01 ms, P-bit in S-frame.*

If optimum window and/or frame size values are implemented at high BER, the main detrimental factors to throughput are the hardware latency and the time utilized on the primary's F-timer expiration when the P-bit is lost. The primary can minimize the probability of P-bit loss by setting the P-bit not in I-frames but only in S-frames that are very small, do not carry information data, and have low frame error probability. Figure 6 shows the resulting performance when t_{ta} is reduced to 0.01 ms and the P-bit is set only in S-frames. Figure 6 shows that the t_{ta} reduction significantly improves the throughput for the optimum N, and the simultaneous optimal N and l cases. As a result, 16 Mb/s links employing a small t_{ta} of 0.01 ms and the proposed P-bit modification achieve good throughput performance even for a 10^{-4} BER by employing simultaneously optimum window and frame size values.

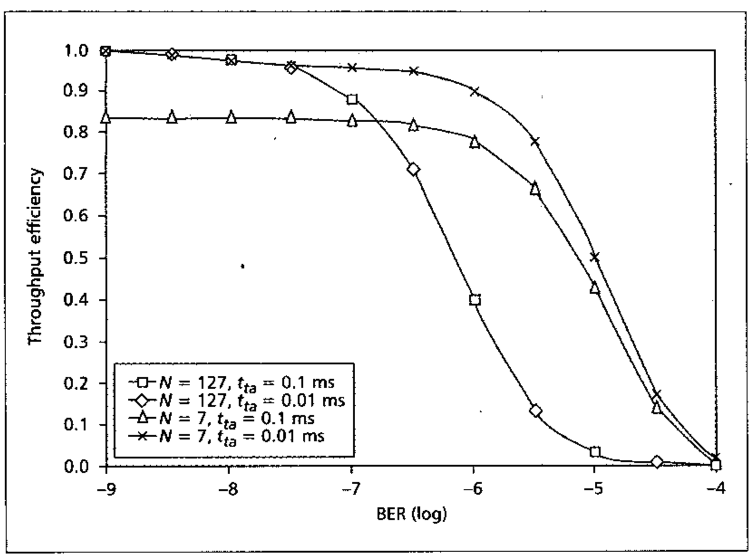


■ Figure 7. *Throughput efficiency vs. BER for* C = *40Mb/s,* l = *16 kb.*

Use of the Existing IrLAP Layer in Future High-Data-Rate IrDA Links

It is expected that IrDA will develop new IrPHY specifications supporting higher data rates to address application requirements for faster information transfers [16, 17]. The question arises of how well the existing definition of IrLAP fares on performance with the predicted future increases of data rates, if the links do not employ the adaptation to optimum window and frame size values. By examining the throughput efficiency, we discuss whether the future IrPHY specifications should decrease to the maximum t_{ta} value defined in the current IrPHY VFIR specification, version 1.3 (t_{ta} = 0.1ms) [6], as related to the window size that IrLAP implements.

Figure 7 plots throughput efficiency vs. BER for C = 40 Mb/s, and different window size and t_{ta} values. It shows that for a window size of 127 frames, reducing t_{ta} to 0.01 ms is not beneficial as no throughput increase is observed. For N = 127 frames, IrLAP throughput is vulnerable to BER increase. If IrLAP implements a window size of seven frames (N = 7), reducing t_{ta} to 0.01 results in throughput improvement at low BER. In addition, the low window size value of 7 renders the link more robust to BER increase. Figure 8 plots the same results for C = 100 Mb/s. Reducing t_{ta} to 0.01 ms is again not beneficial for N = 127. However, for N = 7 frames, reducing t_{ta} to 0.01 ms significantly improves throughput at low BER. As a conclusion, the t_{ta} value defined in the future IrPHY specifications should not be reduced further if future high-data-rate (40 Mb/s or 100 Mb/s) IrDA links are expected to operate as good-quality links with low BER. In this case, IrLAP should implement a window size value of 127 frames. If it is desired that the future high data rate links should simultaneously be more robust to BER increase, a lower t_{ta} of 0.01 ms should be defined and the IrLAP should utilize low (or optimum) window sizes at high error rate infrared links.



■ Figure 8. *Throughput efficiency vs. BER for* C = *100 Mb/s,* l = *16 kb.*

Conclusions

The performance of the IrDA link layer protocol, IrLAP, has been examined with the aid of a mathematical model. We derive the throughput equation, which gives insights for the physical and link layer requirements for optimum performance. The model is employed to study the physical layer requirements for the predicted future increases of the IrDA 1.x data rates (40 Mb/s and 100 Mb/s) as related to the implemented link layer parameters. We conclude that, if future high data rate links are expected to operate at low BER, a t_{ta} = 0.1 ms should be defined and IrLAP should utilize a window size of 127 frames. If operated at high BER (most likely), then a t_{ta} = 0.01 ms is needed and IrLAP should utilize the low window size value of seven frames.

The throughput efficiency of the proposed IrDA 1.x extension to 16 Mb/s (VFIR) has also been studied. The proposed implementation of the larger window size of 127 frames at 16Mb/s becomes questionable as it renders link performance very vulnerable to BER increase. We derive optimum window and frame size values for any BER. Analytical results show that IrLAP throughput is highly improved by simultaneously employing optimum window and frame sizes. This suggests that adaptive algorithms that adjust window and frame size to optimum values for the experienced link BER are beneficial. Reducing the minimum turnaround time and setting the P-bit only in S-frames, combined with the optimum use of window and frame size, highly improves throughput, especially at high error rates. The analytical results and optimum values derived can be very useful to link designers in improving IrLAP performance.

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Analytical results show that IrLAP throughput is highly improved by simultaneously employing optimum window and frame sizes. This suggests that adaptive algorithms that adjust window and frame size to optimum values for the experienced link BER are beneficial.