Automatic Repeat Request Schemes for Infrared Wireless Communications

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Abstract

The effectiveness of employing a Stop-and-Wait (SW) Automatic Repeat Request (ARQ) protocol as well as a Go-Back-N (GBN) protocol to cope with transmission errors in infrared wireless connections is examined. Protocol performance for various link parameters, such as window size, packet size and timer time-out values is presented. High window size implementation results in better performance.

Introduction

The increasing number of laptop computers in markets creates a demand for their wireless connectivity. Infrared Data Association (IrDA) has been proven very successful in developing standards for wireless indoor point-to-point connections using the unregulated infrared spectrum [1]. It is a remarkable achievement for the IrDA 1.x standard to establish such a widespread deployment in such a wide range of devices within a relatively short time [2]. IrDA recently proposed the Advanced Infrared (AIr) standard for indoor optical wireless LANs. AIr standard employs the IrDA 1.x protocol stack. A new physical layer (AIr-PHY) is proposed that employs wide angle infrared ports [2]. IrLAP, the IrDA 1.x data link layer, was split into three sub-layers, the AIr Medium Access Control (AIr-MAC), the AIr Link Manager (AIr-LM) and the AIr Link Control (AIr-LC) sub-layers [3]. IrDA 1.x IrLAP performance is examined in [4][5]. This letter carries out an AIr LC performance evaluation. AIr-MAC is a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol employing a Request-To-Send / Clear-To-Send (RTS/CTS) reservation scheme to address the hidden station problem [2]. A successful reservation is always terminated by means of an End-Of-Burst / End-Of-Burst Confirm (EOB/EOBC) packet exchange. Infrared link quality is detrimented by background ambient light, sunlight, diffuse propagation paths and physical obstacles cause loss of line of sight. To improve link quality, AIr LC sub-layer utilizes a Go-Back-N (GBN) automatic repeat request (ARQ) retransmission scheme and AIr MAC sub-layer utilizes an optional Stop-and-Wait (SW) ARQ scheme [3]. This paper investigates the effectiveness of employing the SW ARQ scheme at the MAC layer when the GBN ARQ scheme at the LC layer is implemented. Packet level acknowledgement (PLACK) protocol utilizes the GBN ARQ scheme at the LC layer and the SW ARQ scheme at the MAC layer. No packet level acknowledgement (NoPLACK) protocol utilizes the GBN ARQ scheme at the LC layer and no ARQ scheme at the MAC layer. Analytical models for the utilization of the PLACK and NoPLACK protocols are presented. PLACK is compared to NoPLACK performance for different parameter values.

Analysis

The utilization of the PLACK protocol, U_{PLACK}, is calculated first. For packet error rate (PER) p_e and window size w, the probability $P_{s/i}$ that i reservations are needed to successfully transmit all packets is given by

$$P_{s/i} = \frac{(w+i-2)!}{(i-1)!(w-1)!}(1-p_e)^w p_e^{i-1} \qquad (1)$$

We have calculated the total time required, I_D, for a complete window transmission

$$I_D = \sum_{i=1}^{\infty} P_{s/i}\left(i(C_p + D) + (w+i-1)(t + F + 2d + p_1 + E)\right) \qquad (2)$$

where C_p is the average contention period, D is the total transmission time of the RTS/CTS/EOB/EOBC packets, t is the payload data transmission time, F is the data packet overhead transmission time, d is the one-way propagation delay, p_1 is the preparation time of a data packet and E is the time required for a packet acknowledgement. The time required for the LC layer acknowledgement (ACK) packet, is given by

$$I_A = \sum_{i=1}^{\infty}(1-p_{ack})p_{ack}^{i-1}\left(i(C_p + D) + i(t_{ack} + 2d + p_1 + E)\right) \qquad (3)$$

where p_{ack} and t_{ack} are the LC layer ACK packet error rate and transmission time respectively. U_{PLACK} is given by

$$U_{PLACK} = \frac{wt}{I_D + I_A} \qquad (4)$$

The utilization of the NoPLACK protocol is calculated as follows. The transmission time of data packets and the corresponding acknowledgement, R, is given by

$$R = 2(C_p + D) + w(t + F + p_1) + p_1 + t_{ack} + p_3 + d \qquad (5)$$

where p_3 is the processing time of an acknowledgement and other parameters are the same. The probability, p_i, that either the Poll bit or the corresponding Final bit are lost i times is given by

$$p_i = \left(p_e + (1-p_e)p_{ack}\right)\left(p_{ack} + (1-p_{ack})p_{ack}\right)^{(i-1)} \qquad (6)$$

and, I_R, the average window transmission time can be evaluated by

$$I_R = R + \sum_{i=1}^{\infty} p_i\left(T_t + C_p + D + p_1 + t_{ack} + p_3 + d\right) \qquad (7)$$

where T_t is the LC layer time-out period. NoPLACK protocol utilization is finally given by [4]

$$U_{NoPLACK} = t\frac{1-p_e}{p_e}\frac{\left(1-\left(1-p_e\right)^w\right)}{I_R} \tag{8}$$

A utilization ratio is defined to compare PLACK and NoPLACK protocol performance

$$U_{ratio} = \frac{U_{NoPLACK}}{U_{PLACK}} \tag{9}$$

The parameters used are as follows. AIr MAC specification [3] defines that D, E and F are 1.984 msec, 872 μsec and 250 μsec respectively. The processor speed is 100 MHz; p_1 and p_3 are both 40 μsec. The packet length l is 16Kbits, the link rate C is 4 Mbit/s, the LC layer ACK transmission time t_{ack} is 250 μsec and p_{ack} is approximated as $p_{ack}= p_e(l'/l)$, where l'=72 is the MAC ACK packet length. The one way propagation delay is 0.33 μsec and the average contention period C_p is 2.8 msec. The chosen C_p value corresponds to an infrared LAN having only two active stations, the transmitter and the receiver [3].

Results

Figure 1 compares PLACK and NoPLACK protocol utilization for different w values. It shows that the AIr protocol practically relies on large window sizes to achieve high channel utilization. Link utilization is very low for small window sizes for both protocols caused by the increased number of contention periods and RTS/CTS/EOB/EOBC exchanges. NoPLACK protocol achieves a higher utilization for low error rates because it does not spend time for transmitting unnecessary (in this case) acknowledgments. The situation is reversed for high error rates as the PLACK protocol immediately realizes a packet loss by the absence of the corresponding acknowledgment. Fig. 1 also shows that the employment of larger window sizes shifts the error rates from which the PLACK protocol outperforms the NoPLACK protocol to higher values.

Figure 2 plots U_{ratio} versus packet error rate (PER) for different LC time-out T_t values. It shows that as T_t decreases, the error rates from which the PLACK protocol outperforms the NoPLACK protocol shift to higher values. PLACK performance is independent of T_t values (eq. (4)), but NoPLACK performance degrades with increase in T_t (eq. (5)) because it relies on the successful transmission of the last data packet to carry the poll to the receiver. If the poll is lost, the situation is resolved by a transmitter's LC T_t expiration.

Figure 3 plots U_{ratio} versus PER for different packet sizes. Increasing packet size when the PER is stable corresponds to better bit error rate. Figure 3 identifies a specific PER value independent of packet length at which the PLACK and NoPLACK protocol performances are equal. Figure 3 also shows that decreasing packet length increases the NoPLACK superiority at low PER and also increases the PLACK superiority at high PER.

Conclusions

AIr protocol should implement large window sizes in order to achieve high channel utilization. This is due to the large time utilized for contention and for RTS/CTS/EOB/EOBC packet exchange for every successful reservation. The NoPLACK protocol outperforms the PLACK protocol for low error rates. The situation is reversed for high error rates leading to the conclusion that if some utilization loss (~10%) is acceptable at low PER, PLACK offers a robust choice. If NoPLACK implementation is chosen, increasing window size and lowering LC time-out values is of great importance.

References

[1] Knutson C., Joos D and Woodings R.,. "Infrared Data Communications in Wireless Personal Area Networks" *Proc. of the 5th World Multiconference on Systemics, Cybernetics and Informatics*, Orlando, Florida, July 22-25, 2001, vol. IV, pp. 427-431.

[2] Williams S., “IrDA: Past, Present and Future”, *IEEE Personal Communications,* Vol. 7, No.1, pp. 11-19, Feb 2000.

[3] IrDA: “Advanced Infrared (AIr) MAC and AIr LC Protocol Specifications”, (Infrared Data Association, 1999).

[4] Vitsas V. and Boucouvalas A. C., **‘**Simultaneous optimisation of window and frame size for maximum throughput IrDA links’**,** *IEE Electronics Letters*, 2nd August 2001, Vol.37, No.16, pp. 1042-1043.

[5] Robertson M., Hansen S., Sorenson F. and Knutson C., "Modeling IrDA Performance: The Effect of IrLAP Negotiation Parameters on Throughput." *Proceedings of the Tenth IEEE International Conference on Computer Communications and Networks (ICCCN)*, Phoenix, Arizona, October 15-17, 2001, pp. 122-127.

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Figure captions:

□ *U_{PLACK} , w=2 packets* ■ *$U_{NoPLACK}$,w=2 packets*
◇ *U_{PLACK}, w=4 packets* ◆ *$U_{NoPLACK}$, w=4 packets*
△ *U_{PLACK}, w=8 packets* ▲ *$U_{NoPLACK}$, w=8 packets*
x *U_{PLACK}, w=16 packets* * *$U_{NoPLACK}$, w=16 packets*
Fig. 1 Utilization versus packet error rate for various window sizes, C_p=2.8msec, l=16Kbits, T_t=5sec, C=4Mbit/s

□ *U_{ratio} ,T_t=5sec* △ *U_{ratio} ,T_t=10sec*
◇ *U_{ratio} ,T_t=7sec* x *U_{ratio} ,T_t=15sec*
Fig. 2 Utilization ratio versus packet error rate for various LC time-out values, w=8 packets, C_p=2.8msec, l=16Kbits, C=4Mbit/s

□ *U_{ratio} , l=2Kbits* △ *U_{ratio} , l=8Kbits*
◇ *U_{ratio} , l=4Kbits* x *U_{ratio} ,l=16Kbits*
Fig. 3 Utilization ratio versus packet error rate for various packet sizes, C_p=2.8msec, w=8 packets, T_t=5sec, C=4Mbit/s

Figure 1

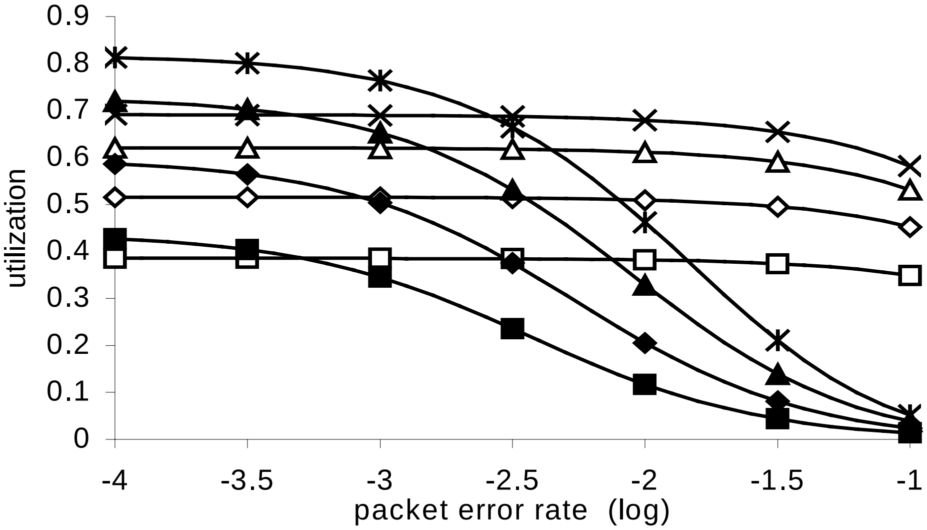

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
utilization
-4
-3.5
-3
-2.5
-2
-1.5
-1
packet error rate (log)

Figure 2

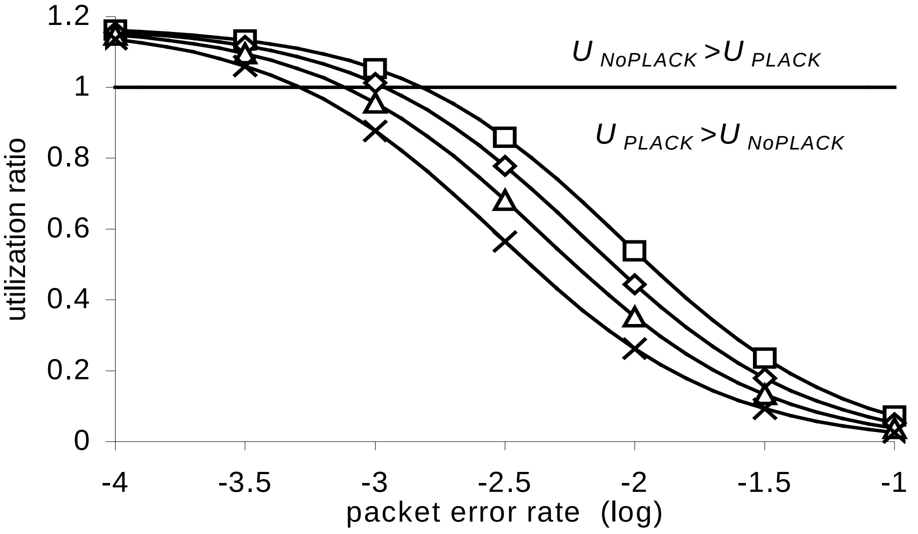
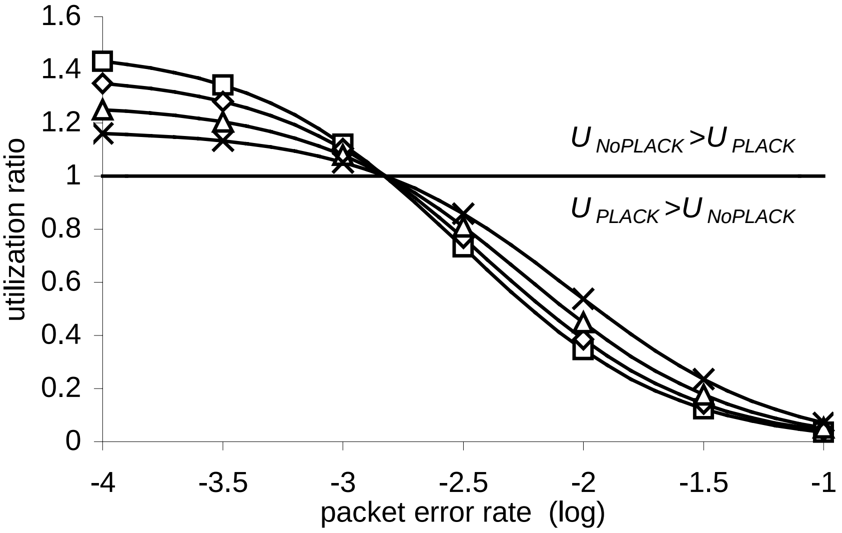

1.2
1
0.8
0.6
0.4
0.2
0
utilization ratio
-4
-3.5
-3
-2.5
-2
-1.5
-1
packet error rate (log)
$U_{NoPLACK} > U_{PLACK}$
$U_{PLACK} > U_{NoPLACK}$

Figure 3


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
utilization ratio
-4
-3.5
-3
-2.5
-2
-1.5
-1
packet error rate (log)
$U_{NoPLACK} > U_{PLACK}$
$U_{PLACK} > U_{NoPLACK}$