Effectiveness of Selective Reject (SREJ) Automatic Repeat Request (ARQ) scheme with RR-coding in Infrared Wireless LANs

V. Vitsas* and A. Boucouvalas
Multimedia Communications Research Group, School of Design, Engineering and Computing
Bournemouth University, Fern Barrow, Poole, Dorset, BH12 5BB, UK
{vvitsas, tboucouv} @bournemouth.ac.uk

***Abstract*- Advanced Infrared (AIr) protocol is the Infrared Data Association (IrDA) proposal for indoor optical wireless LANs. AIr utilizes a Go-Back-N (GBN) Automatic Repeat Request (ARQ) retransmission scheme at the LC layer to cope with transmission errors. AIr also utilizes Repetition Rate (RR) coding to reach stations with low Signal to Noise Ratios (SNR). This paper studies the effectiveness of replacing the GBN ARQ scheme with a Selective Reject (SREJ) ARQ scheme. An analytical model that evaluates the packet error rate as a function of SNR and RR is presented. By employing analytical models for the performance of GBN and SREJ ARQ schemes, the SNR gain for receivers equipped with infinite buffers implementing the SREJ ARQ scheme is studied.**

I. INTRODUCTION

The increasing usage of laptop computers leads to a demand for their wireless connectivity for Internet access and printing. In addition, the increasing number of mobile devices, such as digital cameras, mobile phones and PDAs leads to a demand for wireless connections for their information transfer needs. Infrared data Association (IrDA) has developed the widely accepted IrDA 1.x protocol standard for point to point infrared connections [1][2]. IrDA has extended the IrDA 1.x standard by introducing the Advanced Infrared (AIr) extensions to allow multipoint connectivity [1].

AIr standard introduces a new physical layer, AIr PHY [3], that supports wide angle infrared ports capable of operating at ±60 degrees. The IrDA 1.x link layer, IrLAP, is divided into three sub layers, the AIr Medium Access Control (AIr MAC) sub-layer [4], the AIr Link Manager (AIr LM) sub layer [5] and the AIr Link Control (AIr LC) sub layer [6]. Air MAC is responsible for defining procedures for medium access among the participating devices and AIr LM supports multiplexing of multiple client protocol on a single connection. AIr LC supports connections to multiple devices and reliable information transfer.

AIr PHY implements Repetition Rate (RR) coding to cope with transmission errors in links with high noise levels. The transmitter repeats RR times every transmitted symbol in order to increase the symbol capture probability at the receiver. AIr LC also implements a Go-Back-N (GBN) Automatic Repeat Request (ARQ) retransmission scheme to ensure reliable data transfer. This work studies the effectiveness of replacing the GBN ARQ scheme with a Selective Reject (SREJ) ARQ scheme when RR coding is implemented. An analytical model that calculates packet error rate as a function of Signal to Noise ratio (SNR) under the presence of RR coding is presented. By employing analytical models for the performance of GBN and SREJ ARQ schemes, the SNR gain of the SREJ ARQ scheme is studied for different link layer parameters. Utilization results for different window and packet sizes of the SREJ and GBN ARQ schemes are presented.

II. DESCRIPTION OF GBN AND SREJ ARQ SCHEMES

AIr MAC employs a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme and supports infrared medium reservation by employing the Request To Send / Clear To Send (RTS/CTS) control packet exchange. The information exchange procedure between two stations for the GBN ARQ scheme is described first. After a successful RTS/CTS exchange, the transmitter sends a window of data packets, polls the receiver by setting the Poll/Final (P/F) in a Receive Ready LC acknowledgment (LC ACK) packet and requests termination of medium reservation by sending an End Of Burst (EOB) control packet. The receiver confirms reservation termination by transmitting an End Of Burst Confirm (EOBC) control packet, following which the next contention period starts. The receiver contends for medium access using the RTS/CTS exchange and informs the transmitter of the in sequence correctly received data packets using an LC ACK packet. The transmitter reserves the channel and repeats the packet in error, the packets following it in the previous window transmission and, by taking advantage of the sliding window mechanism, transmits new packets to form a complete window transmission.

The SREJ ARQ system can be implemented as follows. The receiver must implement infinite buffers and must inform the transmitter not of the in sequence data packets received correctly but of all the correct data packets. The transmitter retransmits only the error packets, not the out of sequence correct packets and new packets to form a window transmission. Thus, a new packet numbering scheme should be implemented and the LC ACK packet should be altered to carry the additional information.

Figure 1 portraits the GBN protocol operation for a window size of 4. The transmitter reserves the medium using the RTS/CTS packet exchange, sends four data packets, polls the receiver using an LC ACK packet with the P/F bit set and terminates reservation by means of an EOB/EOBC packet exchange. Assuming packet 3 is lost, the receiver contends for medium access, reserves the medium and informs the transmitter of correct reception of two packets using an LC ACK packet. The LC ACK has the P/F bit set returning transmission control to the transmitter. The transmitter repeats packets 3 and 4, although packet 4 was originally received correctly. It also utilizes the sliding window procedure and transmits packets 5 and 6 to

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[*] on leave from Dept. of Information Technology, Technological Educational Institution, Thessaloniki, Greece

form a window transmission. Assuming all four packets in this window transmission are correctly received, the transmitter proceeds with transmission of new data packets after receiving the suitable acknowledgment.

Figure 2 presents the SREJ protocol operation. After a successful RTS/CTS control packet exchange, the transmitter sends four packets, polls the receiver using a LC ACK packet and terminates reservation. If again packet 3 is lost, the receiver acknowledges correct reception of three packets (packets 1, 2 and 4) using an LC ACK packet, passes packets 1 and 2 to the upper layer and stores packet 4 in the local memory. The transmitter repeats packet 3 and transmits new packets 5, 6 and 7 during the next medium reservation. Assuming all these packets are received error free, the receiver after passing packet 3 to the upper layer, recalls packet 4 from the local memory and passes packets 4, 5 and 6 to the upper layer. The receiver acknowledges that all packets are correctly received and the information exchange procedure continues. As a result, in this example, the SREJ ARQ scheme managed to transfer at the same time seven frames as compared to six frames of the GBN ARQ scheme at the expense of the storing packet 4 at the receiver until packet 3 is correctly received.

III. RR-CODING

Throughput efficiency depends on packet error rate. If SNR is low and packet error rate increases, RR coding may be employed to cope with transmission errors. AIr protocol utilizes 4-PPM encoding and RR coding, which is suitable for the implemented PPM encoding. The performance of L-PPM links has been studied in [7][8]. This section presents an analysis that evaluates the packet error rate as a function of SNR and RR.

Let's assume that the symbol duration T is divided into L slots and that only one slot contains a pulse with power $P\sqrt{LT}$, where P is constant. The remaining L-1 slots are empty or 'zero'. It is assumed that the pulse is a raised cosine signal given by

$$y(t) = \left| \frac{\sin(\pi t)}{\pi t} \frac{\cos(\pi \alpha t)}{1-4\alpha^2 t^2} \right| \tag{1}$$

where α is a raised cosine factor in the range [0,1]. We also consider interference caused by transmissions from other stations. It is also assumed that the interfering signal is of raised cosine shape and is given by

$$s(t) = \left| \frac{s_{\max}\sin(\pi t)}{\pi t} \frac{\cos(\pi \alpha t)}{1-4\alpha^2 t^2} \right| \tag{2}$$

where $s_{\max} = ISR\ P\sqrt{LT}$ and ISR is the interference to signal ratio. It is assumed that the interfering signal has a random phase with respect to the transmitted signal. Thus, at the time of sampling at the receiver, the interfering signal may have any amplitude within the symbol period. To evaluate interference significance to the original pulse reception, the amplitude of the interfering signal is quantized into a fixed number of discrete levels. We consider M levels at amplitudes

$$s_i = \frac{s_{\max}(2i-1)}{2M}, i=1,\ldots,M \tag{3}$$

The probability p_i that an interfering signal of amplitude s_i is received at the time of sampling at the receiver is given by

$$p_i = \sum_k \frac{|t_k - t_{k+1}|}{T} \tag{4}$$

where t_k is the instant time that the interfering signal amplitude crosses the quantization level of (i-1) to (i) and is calculated by $s(t)\,|_{t=t_k} = s_i - \frac{s_{\max}}{2M}$ and

$$\left| \frac{\sin(\pi t_k)}{\pi t_k} \frac{\cos(\pi \alpha t_k)}{1-4\alpha^2 t_k^2} \right| = \frac{i-1}{M} \tag{5}$$

and t_{k+1} is the instant time that the interfering signal amplitude crosses the quantization level of (i) to (i+1) and is calculated by $s(t)\,|_{t=t_{k+1}} = s_i + \frac{s_{\max}}{2M}$

$$\left| \frac{\sin(\pi t_{k+1})}{\pi t_{k+1}} \frac{\cos(\pi \alpha t_{k+1})}{1-4\alpha^2 t_{k+1}^2} \right| = \frac{i}{M} \tag{6}$$

At slots that a pulse is transmitted, the received power is

$$y_{1i} = P\sqrt{LT}\left[1 - ISR(1-s_i^n)\right] + \eta \quad i=1,\ldots,M \tag{7}$$

where $s_i^n = \frac{s_i}{s_{\max}}$ is the normalized quantized level and η is white Gaussian noise with zero mean and variance σ^2. The received power at 'zero' slots is,

$$y_{0i} = P\sqrt{LT}\, ISR(1-s_i^n) + \eta \quad i=1,\ldots,M \tag{8}$$

The conditional error probabilities for a 'pulse' and 'zero' slot in a L-PPM symbol are given by

$$p_{e1} = \sum_{i=1}^{M} p_i \mathbf{Q}\left(\frac{t_n - P\sqrt{LT}(1 - ISR(1-s_i^n))}{\sigma} \right) \tag{9}$$

$$p_{e0} = \sum_{i=1}^{M} p_i \left(1 - \mathbf{Q}\left(\frac{t_n - P\sqrt{LT}(ISR(1-s_i^n))}{\sigma} \right) \right) \tag{10}$$

where t_n is the normalized threshold and **Q**(x) is the standard error function defined as

$$\mathbf{Q}(y) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{y} e^{-\frac{(x)^2}{2}} dx \tag{11}$$

Note that $t_n = 0.3P\sqrt{LT}(1 + ISR_M)$ is used and that SNR can be defined as $SNR = 10\log\left(\left(P\sqrt{LT}\right)^2 / \sigma^2 \right)$.

If RR coding is employed and the transmitted symbol is repeated RR times, the receiver utilizes one counter for every symbol slot that counts the number of the received pulses in the corresponding slot. If only one counter has the maximum value, the pulse is captured in the corresponding slot. If two or more counters share the maximum value, the pulse is not captured and a packet error occurs. The probability that the 'pulse' slot counter has RR-i pulses is given by

$$\Phi_i^1 = \binom{RR}{i} (1 - p_{e1})^{RR-i} p_{e1}^i \tag{12}$$

where i is the number of pulses not received. The probability that a 'zero' slot has RR-j pulses is given by

$$\Phi_j^0 = \binom{RR}{j}(1-p_{e0})^j\, p_{e0}^{RR-j} \tag{13}$$

The probability that all 'zero' slot counters have values less than RR-i is given by

$$\Phi^{L-1} = \left(1-\sum_{j=0}^{i}\Phi_j^0\right)^{L-1} \tag{14}$$

and the successful symbol capture probability can be evaluated as

$$P_{sc} = \sum_{i=0}^{RR-1}\left[\Phi_i^1\left(1-\sum_{j=0}^{i}\Phi_j^0\right)^{L-1}\right] \tag{15}$$

Finally, the packet error rate , p_e, is given by

$$p_e = 1 - P_{sc}^{\;l/\log_2 L} \tag{16}$$

where l is the packet length.

IV. GBN AND SREJ THROUGHPUT EFFICIENCY

Assuming that the LC ACK packets are small enough to be always received error free, the window transmission time, $I_{W\text{-}ACK}$, is given by

$$I_{W-ACK} = 2(C_p + D) + w(t + F + p_1) + 2(p_1 + t_{ack}) \tag{17}$$

where C_p is the average contention period (including empty and collision slots) for a successful reservation, D is the reservation overhead that includes the transmission time of the RTS, CTS, EOB and EOBC frames, w is the window size, t is the payload data transmission time, p_1 is the preparation time of a data frame, F is the transmission time of data packet overhead and t_{ack} is the transmission time of the LC ACK packet. The payload data transmission time is given by

$$t = \frac{RR\, l}{C} \tag{18}$$

where RR is the Repetition Rate and C is the base data rate. The throughput efficiency of the GBN ARQ scheme (fig. 1) is given by [9][10]

$$S_{GBN} = \frac{t}{RR}\frac{1-p_e}{p_e}\frac{\left(1-(1-p_e)^w\right)}{I_{W-ACK}} \tag{18}$$

The throughput efficiency of the SREJ ARQ scheme (fig. 2) is given by

$$S_{SREJ} = \frac{t}{RR}\frac{w(1-p_e)}{I_{W-ACK}} \tag{19}$$

V. PERFORMANCE EVALUATION

Based on the analytical model that evaluates packet error rate when RR-coding is implemented and on the presented analytical models for the GBN and SREJ ARQ schemes, this section discusses the SNR gain of the SREJ ARQ scheme. AIr supports five RR values; the transmitter may repeat the transmitted symbol once, twice, four, eight and sixteen times. According to AIr MAC specification [4], reservation overhead D is 1.74 msec and F and t_{ack} are both 250 μsec. The processor speed is 100 MHz and p_1 is 40 μsec. The average contention period C_p is 2.8 msec. The chosen C_p value corresponds to an infrared LAN having only two contending stations, the transmitter and the receiver [5].

Figure 3(a) plots throughput efficiency versus SNR for all supported RR values and a window size of 2 packets. It shows that SREJ does not improve throughput efficiency because the window size is very small. Figure 3(b) plots the same results for a window size of 8 and shows that throughput is significantly increased for all SNR values. The reason is that high window size implementation requires fewer RTS/CTS control packet exchanges and fewer contention periods for transmitting the same amount of information data. Figure 3(b) also shows that SREJ ARQ protocol implementation results in a 1dB SNR improvement. If a window size of 32 is implemented (fig 3(c)), SREJ scheme results in a 1.5-2 dB SNR gain. Figures 3(a), 3(b) and 3(c) also indicate that the SNR gain is higher for the RR values of 2 and 4 and lowers if RR equals 1, 8 and 16.

Figure 3(d) plots throughput efficiency versus SNR for w=16 and l=8 Kbits. Direct comparison with figure 3(b) shows that if the window size is doubled and the packet size is halved, the same amount of information data is transmitted in every successful reservation attempt but a significantly lower throughput is achieved for high SNR. The reason is that the increased number of packets results in significant packet overhead during a successful reservation. However, the SREJ ARQ scheme results in significant SNR improvement and for certain SNR values results in high throughput. If the window size is doubled (w=32) and the packet size is halved (l=4 Kbits), figure 3(e) shows a throughput decrease for high SNR but a higher SNR improvement for the SREJ ARQ scheme. As a conclusion, for a specific SNR, the suitable ARQ scheme combined with optimum values for window size, packet size and repetition rate should be selected for maximum throughput.

VI. CONCLUSIONS

This paper presents an analytical model to compute packet error rate for a station's signal to noise ratio. It employs this model to evaluate the SNR gain if the Selective Reject ARQ scheme is implemented. Results indicate that the SNR gain is negligible if a small window size is implemented. An SNR gain of 1-2 dB is achieved for high window sizes and the SNR gain is increased if the transmitted symbol is transmitted two and four times. Results indicate that proper selection of window size, packet size, repetition rate and ARQ scheme is of great importance if maximum throughput is to be achieved.

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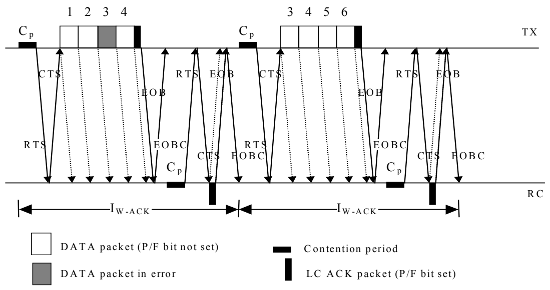


Fig.1 GBN ARQ protocol

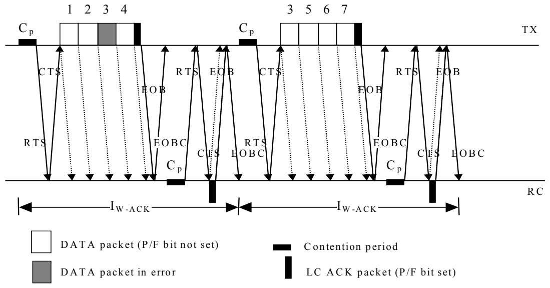
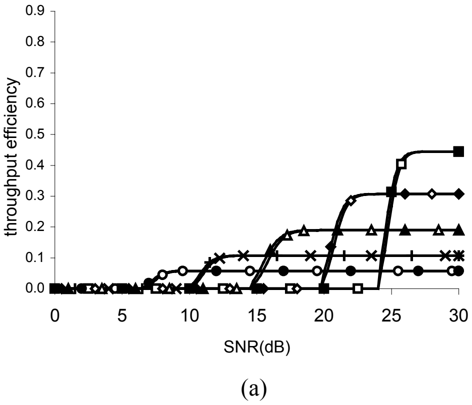
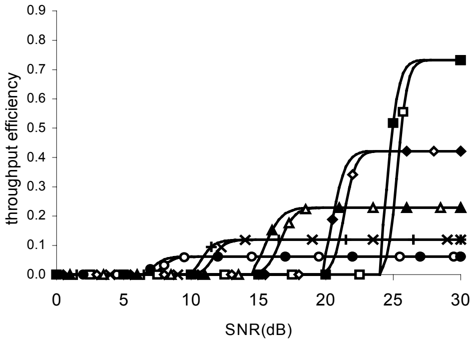


Fig.2 SREJ ARQ protocol



(a)



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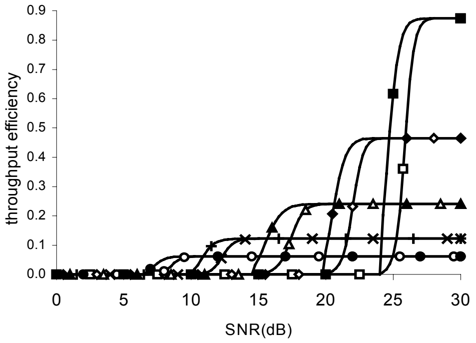

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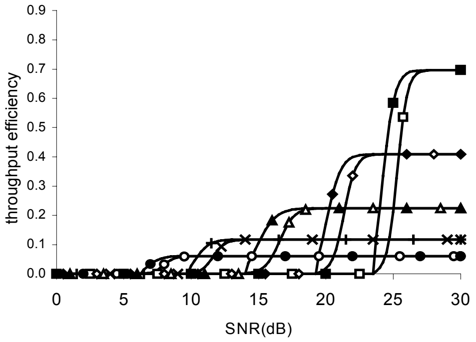
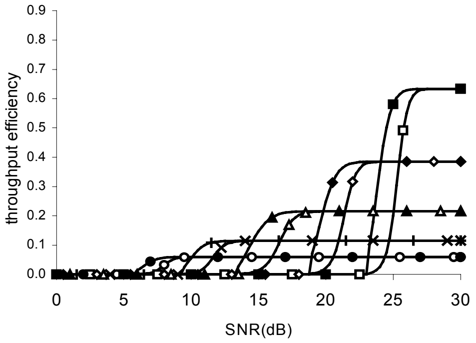


(d)



(e)

□ *GBN, RR=1*	■ *SREJ, RR=1*
◇ *GBN, RR=2*	◆ *SREJ, RR=2*
△ *GBN, RR=4*	▲ *SREJ, RR=4*
× *GBN, RR=8*	+ *SREJ, RR=8*
○ *GBN, RR=16*	● *SREJ, RR=16*

Fig.3 Throughput efficiency versus SNR for various RR values, C=4Mbit/s, ISR=10%, t_n=0.3, α=0.75, M=16, (a) w=2 packets, l=16Kbits, (b) w=8 packets, l=16Kbits, (c) w=32 packets, l=16Kbits, (d) w=16 packets, l=8Kbits, (e) w=32 packets, l=4Kbits.