Effectiveness of Packet Level Acknowledgement in Infrared Wireless LANs

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Abstract- **Infrared Data Association has developed the Advanced Infrared (AIr) protocol standard for infrared wireless LANs. AIr employs a Go-Back-N automatic repeat request (ARQ) scheme at the Link Control layer to deal with transmission errors. Alternatively, an optional Stop-and-Wait ARQ scheme at the Medium Access Control (MAC) layer may be employed. The effectiveness of employing the optional Stop-and-Wait ARQ scheme at the MAC layer is examined. Results presented in the literature for this issue have led to misleading conclusions due to poor selection of parameter values and inconsistencies in the analysis. Analytical models for protocol performance are presented and protocol utilization for various parameter values is studied.**

I. INTRODUCTION

The increasing number of laptop computers in the market today leads to an increasing demand for freedom from wired connectivity and for wireless LANs. Infrared Data Association (IrDA) was established in 1993 by leading IT companies aiming to develop standards for indoor wireless connectivity using the infrared spectrum. IrDA developed the IrDA 1.x platform architecture for point to point, half duplex, short range and narrow beam connections [1][2][3]. The IrDA 1.x standard has been widely adopted by manufacturers. The success of IrDA 1.x can be measured by the increasing number of mobile devices on market today capable of using their embedded infrared port for their wireless communication needs. Over 40 million new devices are manufactured every year employing IrDA compatible infrared ports [1].

IrDA recently proposed the Advanced Infrared (AIr) standard for wireless LANs. A new physical layer, AIr PHY [4], is developed employing wide angle infrared ports operating at an angle of ± 60 degrees. AIr PHY uses a four-slot Pulse Position Modulation with Variable Repetition encoding (4PPM/VR) format with a base data rate of 4Mbit/s [5]. Transmission rate varies from 256 Kbit/s to 4 Mbit/s, trading speed for range. IrLAP, the IrDA 1.x data link layer [6], was split into three sub-layers, the AIr Medium Access Control (AIr-MAC) [7], the AIr Link Manager (AIr-LM) [8] and the AIr Link Control (AIr-LC) [9] sub-layers.

Infrared link quality degrades with background ambient light, diffuse propagation paths and physical obstacles causing loss of line of sight. A retransmission scheme is therefore required to ensure reliable information transfers. AIr LC sub-layer utilizes a Go-Back-N (GBN) automatic repeat request (ARQ) scheme and the AIr MAC sub-layer utilizes an optional Stop-and-Wait (SW) ARQ scheme. This paper examines the need of employing the SW ARQ scheme at the MAC layer when the GBN ARQ is implemented at the LC layer. This issue has already been examined in [10][11][12] but poor selection of parameter values and inconsistencies in the presented analysis have led to the misleading results expressed in these references. This paper presents an analytical model for the utilization of links employing the GBN ARQ retransmission scheme at the LC layer and no ARQ scheme at the MAC layer. It also presents an analytical model for links simultaneously employing the GBN ARQ scheme at the LC layer and the SW ARQ scheme at the MAC layer. Figures presented in [10][11][12] are plotted using realistic parameter values and the correct analytical models presented. Our plots indicate that protocol comparison results are quite different from results presented in [10] [11] and [12]. Utilization results for various link parameters, such as window size, packet size and time out values are presented. The effectiveness of employing the optional SW ARQ scheme at the MAC layer for various links is finally studied.

II. SYSTEM DESCRIPTION

The question answered in this work is "*Do we really need a SW ARQ scheme at the MAC layer when a GBN ARQ scheme is implemented at the LC layer?*". Packet level acknowledgment (PLACK) protocol utilizes the GBN ARQ scheme at the LC layer and the SW ARQ scheme at the MAC layer. No packet level acknowledgment (NoPLACK) protocol utilizes the GBN ARQ scheme at the LC layer and no ARQ scheme at the MAC layer. NoPLACK relies on the LC layer GBN ARQ scheme to handle packet errors.

When the sender's MAC layer receives a transmit request from the LC layer, it contends for channel access. It first awaits a random number of Collision Avoidance (CA) Slots (this is the Collision Avoidance part of the protocol) and transmits a Request To Send (RTS) packet to the destination. The receiver responds with a Clear To Send (CTS) packet confirming medium reservation. The transmitter then initiates a burst transmission (a window of packets), followed by an End Of Burst (EOB) packet. The receiver confirms termination of current reservation by means of an End Of Burst Confirm (EOBC) packet. Stations hearing the RTS/CTS exchange refrain from transmitting until the EOB/EOBC exchange.

If the PLACK protocol is used, the transmitter waits for a MAC Acknowledgement (MAC ACK) packet after a data packet transmission. When it receives the MAC ACK packet, it proceeds with the transmission of the next data packet. If the MAC ACK packet is not received due to a packet loss, the transmitter terminates the current reservation without releasing the poll [7]. It contends again for medium access in order to transmit the remaining packets within the LC time out period. When it transmits the last data packet in a window transmission, it sets the Poll/Final (P/F) bit soliciting a

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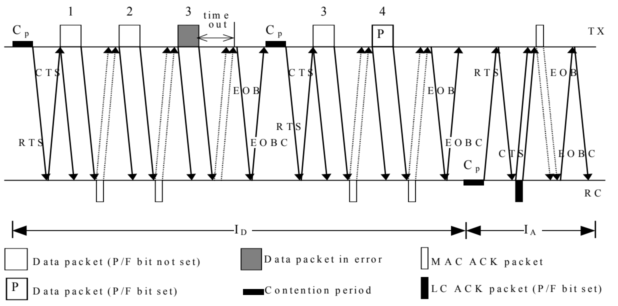

Fig. 1. PLACK protocol (SW ARQ at the MAC layer and GBN ARQ at the LC layer).

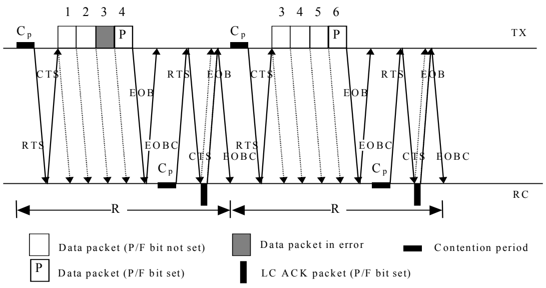

Fig. 2. NoPLACK protocol (no ARQ at the MAC layer and GBN ARQ at the LC layer).

response from the receiver's LC layer. The receiver then contends for medium access to transmit the Receive Ready LC acknowledgement (LC ACK) packet required by the implemented GBN ARQ protocol at the LC layer [10][11][9].

If the NoPLACK protocol is used, the transmitter sends a window of data packets after a successful reservation attempt. The last packet has the P/F bit set soliciting a response from the receiver's LC layer. The receiver contends for medium access and acknowledges in sequence correctly received packets. If all data packets are correctly received, the transmitter sends a new window of packets. Otherwise, it repeats the error packet, the packets following it and, by taking advantage of the sliding window mechanism, it transmits new packets to form a complete window transmission. If the last data packet that contains the P/F bit is lost, the receiver does not acknowledge correctly received packets because it assumes that the transmitter intends to transmit more packets before asking for a response. The situation is resolved by a transmitter's LC layer time out. The transmitter then sends a Receive Ready Acknowledgement (LC ACK) packet with the P/F bit set soliciting a response from the receiver [9].

Fig. 1 and 2 show PLACK and NoPLACK protocol operation respectively for a window size of 4. In fig. 1, after a successful RTS/CTS exchange, the transmitter (TX) sends the first packet to the receiver (RC) and waits for the responding MAC ACK packet. It then proceeds with the transmission of the next packet. Assuming packet 3 is lost, the transmitter realises the packet loss by a timer expiration for the corresponding MAC ACK packet. The transmitter terminates current reservation by using the EOB/EOBC exchange and contends again in order to transmit the remaining two packets as the PLACK protocol can not take advantage of the sliding window mechanism. The last packet (packet 4) has the P/F bit set forcing the receiver to acknowledge correctly received packets at the LC layer. In fig. 2 (NoPLACK protocol), the transmitter sends a full window of packets after the RTS/CTS exchange, sets the P/F bit in the last packet (packet 4) and terminates reservation by using the EOB/EOBC exchange. Assuming packet 3 is again lost, the receiver responds with an LC ACK packet acknowledging correct reception of two packets. The transmitter contends again and retransmits erred packet 3 and packet 4 (despite the fact that packet 4 was originally received correctly). By taking advantage of the sliding window mechanism, it also transmits two new packets (5 and 6) to form a complete window transmission. The receiver is polled by the P/F of the last packet in the window transmission (packet 6) and acknowledges correct reception of the new window of packets.

III. SYSTEM ANALYSIS

The utilization of the PLACK protocol can be calculated as follows. For packet error rate p_e and window size w, the probability $P_{s/i}$ that the successful transmission of all w packets requires i reservations is given by [11]

$$P_{s/i} = C_{i-1}^{w+i-2}(1-p_e)^w p_e^{i-1} \tag{1}$$

where

$$C_{i-1}^{w+i-2} = \frac{(w+i-2)!}{(i-1)!(w-1)!} \tag{2}$$

The time required to transmit w packets if i reservations are required is given by

$$T_D(i) = i(C_p + D) + (w+i-1)(t + F + 2d + p_1 + E) \tag{3}$$

where C_p is the average contention period (including empty and colliding slots) for a successful reservation, D is the total transmission time of the RTS/CTS/EOB/EOBC packets, t is the information 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 needed for a packet acknowledgement. E includes the processing time of the received data packet, the MAC ACK packet preparation time, the minimum turn Around Time (TAT) delays, the MAC ACK transmission time and the processing time of the received MAC ACK packet. The total time, I_D, required for a complete window transmission consisting of w packets is given by

$$I_D = \sum_{i=1}^{\infty} P_{s/i} T_D(i) \tag{4}$$

The time required for the LC ACK packet, which follows the successful transmission of w packets is given by

$$I_A = \sum_{i=1}^{\infty} (1 - p_{ack}) p_{ack}^{i-1} T_A(i) \tag{5}$$

where

$$T_A(i) = i(C_p + D) + i(t_{ack} + 2d + p_1 + E) \tag{6}$$

and p_{ack} and t_{ack} are the LC ACK packet error rate and transmission time respectively. The other parameters are as described above. The PLACK protocol utilization can now be calculated by

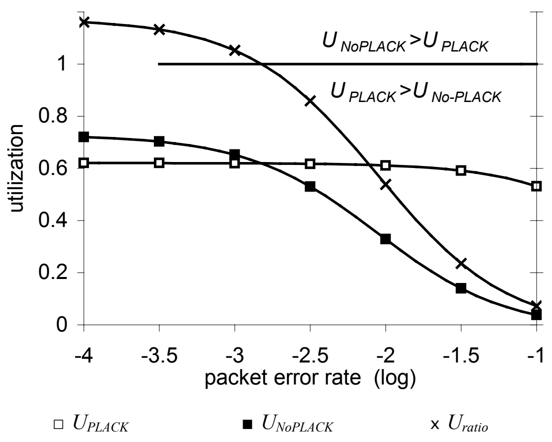

Fig. 3. Utilization and utilization ratio versus packet error rate, w=8 packets, l=16 Kbits, C_p=2.8 msec, T_t=5 sec, C=4 Mbit/s.

$$U_{PLACK} = \frac{wt}{I_D + I_A} \tag{7}$$

The utilization of the NoPLACK protocol can be evaluated as follows. The probability that the P/F bit is lost once is given by

$$q_1 = p_e + (1 - p_e)p_{ack} \tag{8}$$

Considering that after the first P/F bit loss, the P/F bit is always carried by LC ACK packets, the probability that the P/F bit is lost i times is given by

$$q_i = (p_e + (1 - p_e)p_{ack})(p_{ack} + (1 - p_{ack})p_{ack})^{(i-1)} \tag{9}$$

The average window transmission time, I_R, is given by

$$I_R = R + \sum_{i=1}^{\infty} q_i (T_t + P) \tag{10}$$

where R is the time required for the transmission of w data packets and the corresponding LC ACK packet, T_t is the LC layer time out period and P is the time required for an LC ACK transmission. R is given by

$$R = 2(C_p + D) + w(t + F + p_1) + p_1 + t_{ack} + p_3 + d \tag{11}$$

and P is given by

$$P = C_p + D + p_1 + t_{ack} + p_3 + d \tag{12}$$

where p_3 is the processing time of an acknowledgement and the other parameters are as described above.

Considering that packets correctly transmitted but following an erroneous packet transmission are considered as out of sequence and are discarded by the receiver, the probability r_k that packet k is the first erroneous packet during a successful reservation is given by

$$r_k = (1 - p_e)^{k-1} p_e, \; k=1,2,\dots,w \tag{13}$$

The probability that all w packets transmitted during a successful reservation are correctly received is

$$r_{w+1} = (1 - p_e)^w \tag{14}$$

The utilization of the NoPLACK protocol is finally given by

$$U_{NoPLACK} = \frac{1}{I_R}\left[\sum_{k=1}^{w+1}(k-1)tr_k\right] =$$

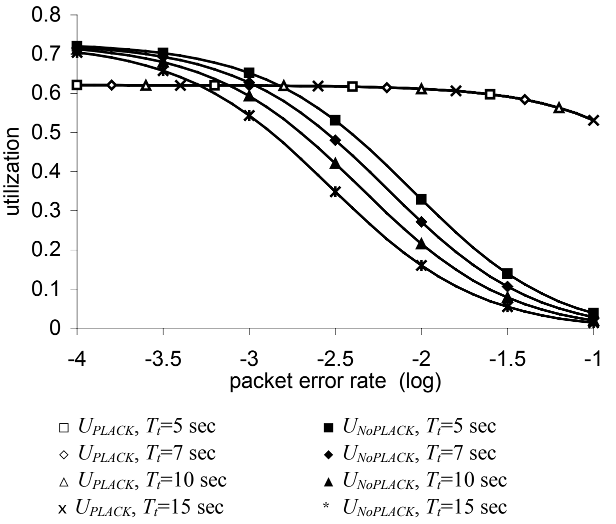

Fig. 4. Utilization versus packet error rate for various LC time out values, w=8 packets, l=16 Kbits, C_p=2.8 msec, C=4 Mbit/s.

$$= t\frac{(1 - p_e)}{p_e}\frac{\left(1 - (1 - p_e)^w\right)}{I_R} \tag{15}$$

IV. PERFORMANCE EVALUATION

A utilization ratio can be defined as

$$U_{ratio} = \frac{U_{NoPLACK}}{U_{PLACK}} \tag{16}$$

This utilization ratio is used to compare PLACK and NoPLACK protocol performance. If $U_{ratio} > 1$ then the NoPLACK protocol performs better than the PLACK protocol. The situation is reversed if $U_{ratio} < 1$ and both protocols achieve the same performance if $U_{ratio} = 1$. The parameters used in this performance evaluation are as follows. The processor speed is 100 MHz and p_1 and p_3 are both 40ms. According to [7][11], D, E and F are 1.984 msec, 872 μsec and 250 μsec respectively. The one way propagation delay is 0.33 μsec, 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 link data rate is 4 Mbit/s and 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 [8].

Fig. 3 compares PLACK and NoPLACK utilization by plotting U_{PLACK} and $U_{NoPLACK}$ versus packet error rate. It shows that NoPLACK outperforms PLACK protocol for low error rates but the situation is reversed for high error rates. When error rate is low, PLACK utilization is low because it separately acknowledges all received packets. When error rate is high, NoPLACK utilization significantly decreases due to out of sequence packet transmissions following an error packet. U_{ratio} is also plotted in fig. 3 and indicates that NoPLACK is a better choice for packet error rates less than approximately 0.0014 for the selected link parameters. Fig.3 shows that PLACK always outperforms NoPLACK at high error rates, which contradicts with fig. 4(a) of [10], fig. 9(a) of [11] and fig. 7.9 of [12].

Fig. 4 plots utilization versus packet error rate for different

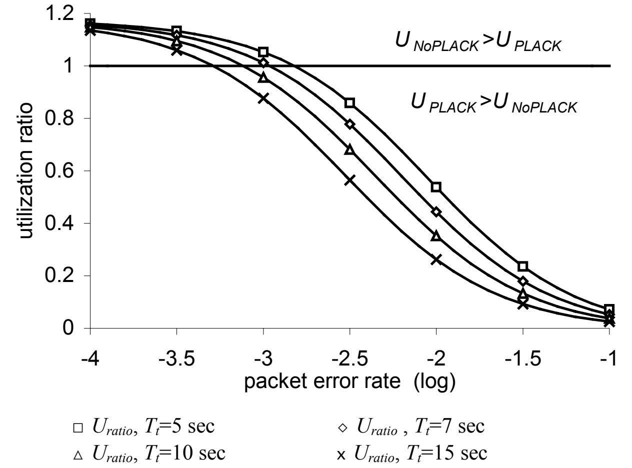

Fig. 5. Utilization ratio versus packet error rate for various LC time out values, w=8 packets, l=16 Kbits, C_p=2.8 msec, C=4 Mbit/s.

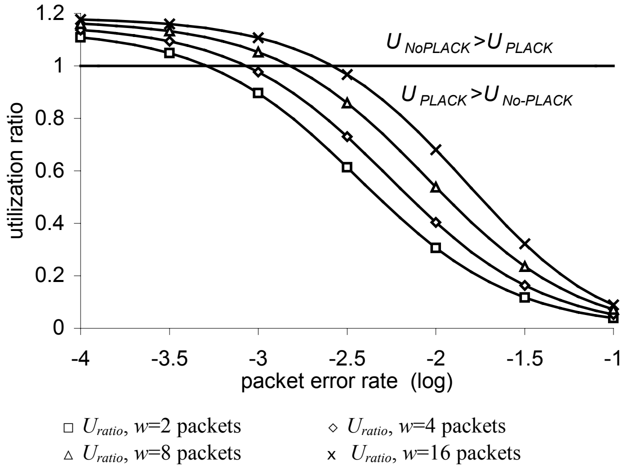

Fig. 7. Utilization ratio versus packet error rate for various window sizes, l=16 Kbits, C_p=2.8 msec, T_t=5 sec, C=4 Mbit/s.

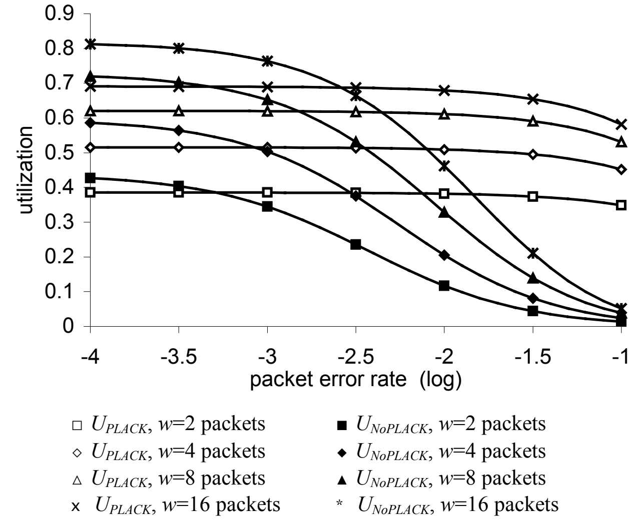

Fig. 6. Utilization versus packet error rate for various window sizes, l=16 Kbits, C_p=2.8 msec, T_t=5 sec, C=4 Mbit/s.

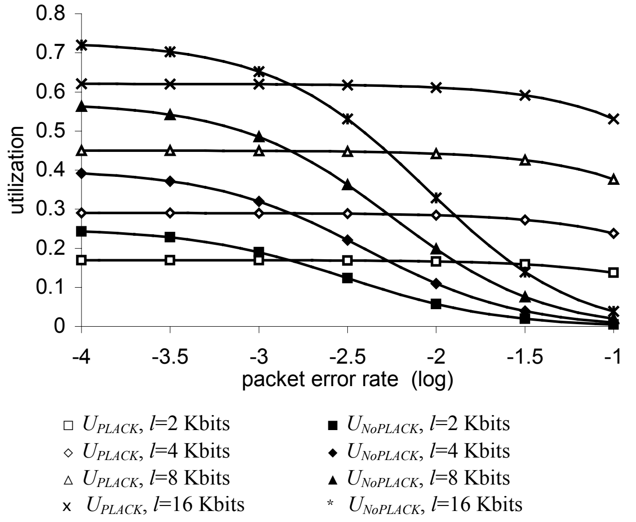

Fig. 8. Utilization versus packet error rate for various packet sizes, w=8 packets, C_p=2.8 msec, T_t=5 sec, C=4 Mbit/s.

LC time-out T_t values. It shows that PLACK utilization is independent of the implemented T_t period but NoPLACK utilization decreases if T_t increases. The reason is NoPLACK sets the P/F bit in the last data packet in a window transmission to poll the receiver. If the P/F bit is lost, the receiver's LC layer does not acknowledge correctly received packets because it assumes that the transmitter wishes to send more data packets before soliciting a response. The situation is resolved by a transmitter's LC layer time-out, following which the transmitter sends an LC ACK packet with the P/F bit set soliciting a response from the receiver [9]. As a result, NoPLACK utilization degrades with T_t increase. If the last packet carrying the P/F bit is lost in the PLACK protocol, the loss is realized by a MAC time-out expiration for the missing MAC ACK packet. As the MAC time out period is significantly smaller than the LC time out period, PLACK recovers much faster than NoPLACK in the event of a P/F bit loss. Fig. 5 plots the utilization ratio for the same link parameters to allow direct comparison with fig. 4(b) at [10], fig. 9(b) at [11] and 7.10 at [12]. It also shows that as T_t decreases, the error rates from which the PLACK protocol outperforms the NoPLACK protocol shift to higher values.

Fig. 6 plots utilization versus packet error rate for different window sizes and indicates that the AIr protocol should implement a high window size value to reach high utilization regardless of the implemented retransmission protocol. This is in order to reduce the time portion utilized on contention periods and reservation control packets which significantly degrades utilization. Fig. 7 plots U_{ratio} versus packet error rate for the same parameters and shows that employment of larger window sizes shifts the error rates from which the PLACK protocol outperforms the NoPLACK protocol to higher values. Larger window sizes increase NoPLACK utilization more at low error rates because PLACK utilizes more ACK packets during a larger window transmission.

Fig. 8 plots utilization versus packet error rate for different packet sizes. Increasing packet size when the packet error rate is stable results in better link quality. As a consequence,

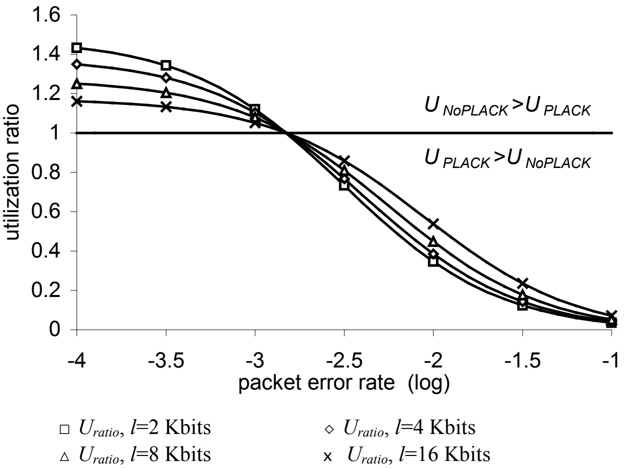

Fig. 9. Utilization ratio versus packet error rate for various packet sizes, w=8 packets, C_p=2.8 msec, T_t=5 sec, C=4 Mbit/s.

higher utilization is always achieved. Fig. 9 plots U_{ratio} versus packet error rate for the same parameters and shows that the packet error rate from which the PLACK protocol outperforms the NoPLACK protocol is independent of the packet length. Fig. 9 shows that decreasing packet length increases the NoPLACK superiority at low packet error rates and also increases the PLACK superiority at high packet error rates.

V. CONCLUSIONS

In this paper, we evaluate the performance of packet level acknowledgement (PLACK) and no packet level acknowledgement (NoPLACK) protocols for infrared wireless LANs. NoPLACK protocol achieves a higher performance at low error rates but PLACK protocol outperforms NoPLACK at high error rates. NoPLACK utilization highly degrades with error rate increase but PLACK is robust. NoPLACK performance highly depends on the LC time out period because it relies on the successful transmission of the last packet in a window transmission to carry the P/F bit to the receiver. As contention periods and RTS/CTS/EOB/EOBC exchange significantly degrade performance, PLACK and NoPLACK protocols achieve high utilization only for large window and packet sizes. Smaller LC time out periods and larger window size employment shift the error rates from which the PLACK protocol outperforms the NoPLACK protocol to higher values.

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