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# PACKET DELAY PERFORMANCE COMPARISON OF THE IEEE 802.11 AND IRDA AIR CSMA/CA PROTOCOLS IN HIGH-SPEED WIRELESS LANS

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**ABSTRACT**
During the past few years the wireless technology market has experienced a tremendous growth. IEEE and Infrared Data Association (IrDA) have developed 802.11 and Advanced Infrared (AIr) protocols, respectively, in order to cope with modern communication needs. This paper develops a simple and accurate analysis to evaluate saturation performance of the IEEE 802.11 and AIr protocols. We present an extensive evaluation by taking into account all the factors and parameters that affect packet delay performance. Finally, we propose suitable values for certain physical and link layer parameters that reduce average packet delay and, thus, improve the services that the IEEE 802.11 and AIr protocols provide to various communication and multimedia applications.

**KEY WORDS**
Wireless LANs, packet delay, IEEE 802.11, IrDA AIr, performance comparison

## 1. Introduction

Wireless Local Area Networks (WLANs) are becoming more and more popular attracting the interest of researchers, system integrators and manufacturers of wireless devices [1].

Infrared Data Association (IrDA) was established in 1993 aiming to develop and promote communication standards especially suited for low cost, short range, point-to-point communications at a wide range of speeds using the infrared spectrum. The developed IrDA 1.x standard has been implemented on various computer platforms and became widely available on personal computers and peripherals. To cope with the increasing wireless LAN connectivity need and to overcome several IrDA 1.x protocol limitations, such as point to point and range restrictions, IrDA proposed the Advanced Infrared (AIr) standards [2]-[3] for indoor WLANs.

On the other hand, the Institute of Electrical and Electronics Engineers (IEEE) has developed the 802.11 standard family [4]-[5], in order to deal with the modern wireless connectivity needs. The IEEE 802.11 protocol turned into the dominant standard for WLANs and is deployed almost everywhere including offices, public places and homes.

## 2. Related Work and Motivation

Several research efforts have been carried out to model study and improve the performance of both the IrDA AIr and IEEE 802.11 protocols. Both wireless technologies utilize CSMA/CA (Carrier Sensing Multiple Access with Collision Avoidance) schemes at the MAC (Medium Access Control) sub-layer with Request-To-Send/Clear-To-Send (RTS/CTS) medium reservation that operate in a very similar manner. However, there are significant differences in the collision avoidance and medium access methods.

Simulation studies are presented in [6],[7] for IrDA AIr and [8], [9] for IEEE 802.11. Authors in [10] presented a comparison of the two protocols but did not provide an extensive analysis and their work was limited only to throughput performance. Recently, considerable research activity has concentrated on modeling the MAC layers of both protocols by employing mathematical analytical approaches. Vitsas in [11] developed a simple mathematical analysis by utilizing a bi-dimensional Markov chain and calculated AIr throughput performance. In [12] we have extended the performance analysis presented in [11] by providing a more elegant derivation and simple mathematical equations for the average packet delay of the AIr protocol. Bianchi in [13] and Wu in [14] also used Markov chain models to analyze DCF operation and calculated the saturated throughput of IEEE 802.11 protocol. In [15], by means of Markov chain modelling, we calculated the packet delay and other performance metrics for IEEE 802.11 protocol. Furthermore, in [16] and [17] we further extended previous work by proposing certain enhancement mechanisms in order to improve the IEEE 802.11 protocol performance. More specifically, in [17] we suggested the employment of packet bursting in order to reduce overhead costs (i.e. backoff time and less RTS/CTS exchanges). The main idea of packet bursting was based on the transmission of more than one data packets when a station attains control of the medium while retaining the long-term fairness provided by the IEEE 802.11 protocol. Moreover, research in [18] has shown that even though the data rate can be infinitely high, the MAC efficiency is still bounded by a maximum value. Thus, both protocols attempt to minimize the existing overhead, which is the main reason for system inefficiency[1].

By considering the above issues, a detailed evaluation of both protocols turns out to be essential for the optimal employment of either the IrDA AIr or IEEE 802.11 protocols in order to match modern communication needs.

In this paper, we provide a detailed comparison between IrDA AIr and IEEE 802.11 with packet bursting enhancement. This thorough comparison based on the characteristics of each protocol combined with analytical results will give us a benchmark of how each factor affects performance. In particular, we explore the dependency of the packet delay performance on contention window, data rate, network size as well as physical parameters of each protocol. Finally, we propose suitable values for certain physical and link layer parameters that reduce average packet delay and, thus, maximise performance for both protocols.

## 3. Overview of Protocol Details

Although, in both the AIr MAC and the IEEE 802.11 MAC a burst of data packets can be transmitted in each reservation (when in IEEE 802.11 no packet bursting is considered, only one data packet at a time transmitted), there are principle differences between them that are summarized as follows:

- The maximum data rate of AIr is 4 Mbps [3]. The maximum data rate of 802.11 is 54 Mbps [5].
- AIr uses non-directed IR line-of-sight links. IEEE 802.11 mainly uses radio transmission techniques.
- The AIr MAC uses a linear adjustment (both up and down) of the contention window. The 802.11 MAC uses an exponential (up only) adjustment of the contention window and resets it to the minimum value after a successful packet transmission.

### 3.1 IrDA Advanced Infrared (AIr) MAC protocol

AIr MAC utilizes CSMA/CA techniques to minimize collision probability. A station wishing to transmit and regardless of the transfer mode it employs, it first invokes the Collision Avoidance (CA) procedures in an effort to minimize collisions with other stations. In the SDATA transfer mode, which is presented with detail in figure 1, a contending station always invokes the CA procedures before an RTS packet transmission. The contention period is slotted and a station is allowed to transmit only at the beginning of each slot time ($\sigma$). A competing station for medium access first senses the medium; if the medium is busy, it waits for the transmitting station to finish and for the beginning of the next contention period.

The contending station then initialises its backoff counter by selecting an integer random number of CAS to defer transmission in order to minimize the collision probability with other transmissions. If the reservation attempt failed (the RTS transmission collided), then the AIr protocol employs the linear backoff i.e. the next backoff value will be selected in the range $\left[0,\left(W+4\right)-1\right]$ and so forth, where $W$ represents the initial Contention Window ($CW$) size. The backoff counter is uniformly selected in the range $\left[0,W_i-1\right]=\left[0,\left(W+4i\right)-1\right],\ i\in(0,m)$ where $i$ is defined as the backoff stage that identifies the number of retransmissions suffered by an RTS packet and $W_i$ is the current $CW$ size. We define for convenience $W=CW_{min}$. Let $m$ be the 'maximum backoff stage' defined as $CW_{max}=W+4m$. According to the definition, we have $W=W_0=CW_{min}$ and $W_m=CW_{max}$.

If during the station's deferral period another transmission is observed, the station freezes its CAS timer and restarts it again when the ongoing transmission is finished (the medium becomes free again) and the next contention period is started. When the CAS timer reaches zero, the station attempts to reserve the channel by transmitting an RTS packet. While a transmitter is sending a packet, it blinds its own receiver such that it cannot receive remote infrared pulses. The receiving station waits a minimum Turn-Around Time (TAT) to allow for the transmitter's receive circuitry to recover and responds with a CTS packet. After the successful RTS/CTS exchange, the transmitting station, after a TAT delay, transmits a burst of data packets and requests termination of current reservation by transmitting an End-Of-Burst (EOB) packet. The receiving station responds with an End-Of-Burst-Confirm (EOBC) packet confirming reservation termination. The reservation time duration is advertised in the Reservation Time (RT) field of the RTS packet and echoed in the CTS packet. Thus, stations being able to hear only the RTS or the CTS packet refrain from transmitting for the entire reservation period.

### 3.2 IEEE 802.11 MAC Protocol

The IEEE 802.11 protocol follows similar collision avoidance procedures with AIr by employing the Distributed Coordination Function (DCF) as the essential MAC method. IEEE 802.11 DCF defines two access mechanisms to employ packet transmission; the default, two-way handshaking technique called basic access and the optional four-way handshaking RTS/CTS reservation scheme. The latter handshaking scheme involves the transmission of short *request-to-send* (RTS) and *clear-to-send* (CTS) control packets prior to the data packet transmission in order to shorten the collision duration. Figure 2 illustrates the procedure followed in IEEE 802.11 with packet bursting enhancement (in this example a burst of two data packets is being considered).

[1] The overhead refers to backoff, inter-frame spacing, acknowledgement (ACK) packets and physical (PHY) layer headers.

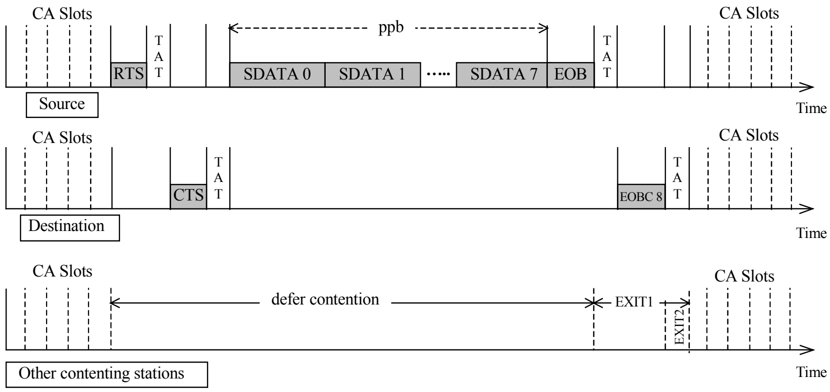



Figure 1 Reserved access with Sequenced transfer (SDATA) in AIr MAC

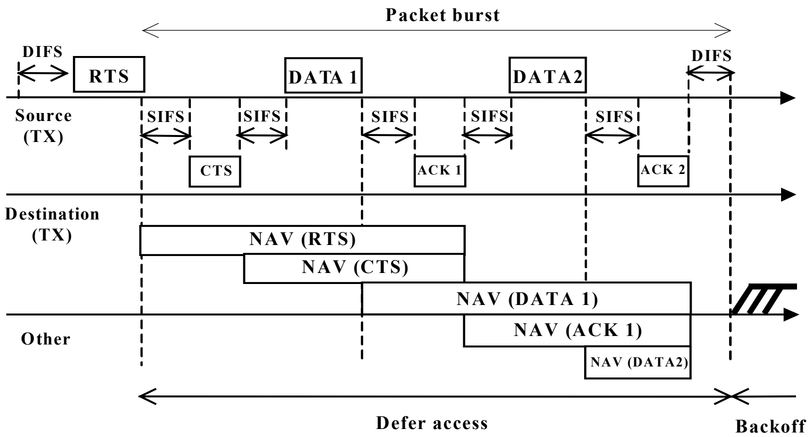



Figure 2 Packet bursting with RTS/CTS exchange in IEEE 802.11 MAC

In DCF, if the medium is sensed to be idle for a time interval greater than the Distributed Inter-Frame Space (DIFS), the station proceeds with the packet transmission. If the medium is sensed busy, the station waits until the current transmission is over. The station then defers for a randomly selected time interval to minimize collisions before transmitting. Before initiating packet transmission, each station's backoff timer is uniformly chosen in the interval $[0,W_i\ -1]$ where $W_i$ is the current contention window size and $i$ is the backoff stage. The value of $W_i$ depends on the number of failed transmissions of the packet; at the first transmission attempt, $W_0 = W$. After each retransmission due to a packet collision or error, $W_i$ is doubled up to a maximum value, $W_{m'} = W \cdot 2^{m'}$ where $m'$ is the number of backoff stages. After the packet successful reception, the destination station sends back an immediate positive acknowledgment (ACK) after a time interval equal to Short Inter-Frame Space (SIFS). If the source station does not receive an ACK, the data packet is assumed to have been lost and a retransmission is scheduled.

## 4. Mathematical Analysis

In both protocols, the probability $p$ that a transmitted packet collides is assumed to be constant and independent of the number of collisions that the packet has previously suffered and is given by [12]-[17]:

$$p = 1 - (1 - \tau)^{n-1} \tag{1}$$

where $\tau$ is the transmission probability of a packet and $n$ the number of contending stations. However, the two protocols reach different equations for $\tau$ since they employ different contention window adjustment mechanisms used in collision avoidance procedures.

When the AIr protocol is considered, $\tau$ is equal to [12]:

$$\tau = \frac{2}{(W+1) + 4p\left(\dfrac{\left((1-p)^{m+1} + (2m+1)p^{m+1} - (m+1)p^{m}\right)}{\left((1-p)^{m+1} - p^{m+1}\right)(1-2p)}\right)} \tag{2}$$

When the IEEE 802.11 protocol is considered, $\tau$ is given by [13]:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1) + pW(1-(2p)^{m'})} \tag{3}$$

Equations (1) (2) and (1) (3), for AIr and 802.11 protocols respectively, form nonlinear systems that can be easily solved by utilizing numerical methods (the proof of the uniqueness can be found in [11] and [15]).

The average delay $E[D]$ for a successfully transmitted packet, which is defined to be the time interval from the time a packet is at the head of the queue ready for transmission, until its successful reception can be computed for both protocols as:

$$E[D] = E[X]\,E[slot] \tag{4}$$

where $E[X]$ is the average number of time slots needed for a successful packet transmission and $E[slot]$ is the average length of a slot time. For both IEEE DCF and AIr, $E[X]$ is calculated as:

$$E[X] = \frac{1}{\tau(1-p)ppb} = \frac{1}{\tau(1-\tau)^{n-1} ppb} \quad (5)$$

where *ppb* is number of data packets that a station transmits before releasing the medium.

The average slot duration can be evaluated by considering that a random slot is empty with probability 1-$P_{tr}$ , with probability $P_{tr}P_s$ the slot contains a successful reservation and with probability $P_{tr}(1-P_s)$ the slot contains a collision. Thus, the average length of a slot time $E[slot]$ is equal to:

$$E\left[slot\right] = (1-P_{tr})\sigma + P_{tr}P_sT_s + P_{tr}(1-P_s)T_c \quad (6)$$

where $\sigma$ is the duration of an empty slot, $T_s$ and $T_c$ are the time durations the medium is sensed busy due to a successful reservation and a collision involving two or more simultaneous packet transmissions respectively.

For AIr WLANs employing the reserved transfer mode with sequenced data (SDATA packet) (figure 1), the time duration of $T_s$ *and* $T_c$ [2] are equal to [12]:

$$\begin{aligned} T_S &= D_{over} + ppb(t + F_S) \\ T_c &= \sigma \end{aligned} \quad (7)$$

where $D_{over}$ is the reservation overhead that includes the transmission time of the RTS, CTS, EOB and EOBC packets as well as the TAT delays that follow these packets, $F_S$ is the transmission time of the SDATA packet overhead (preamble, robust header, CRC, etc) and *t* is the data packet transmission time.

For IEEE 802.11 WLANs, the time duration of $T_s$ *and* $T_c$ is given by [17]:

$$\begin{cases} T'_S = DIFS + T_{RTS} + T_{CTS} + ppb\,T_{DATA} + (2ppb+1)SIFS + ppb\,T_{ACK} + (2ppb+2)\delta \\ T'_C = DIFS + T_{RTS} + SIFS + T_{CTS} + 2\delta \end{cases} \quad (8)$$

where $\delta$ is the propagation delay, $T_{DATA}$ , $T_{ACK}$ , $T_{RTS}$ and $T_{CTS}$ is the time required to transmit the DATA, ACK, RTS and CTS packets, respectively.

Finally, if we substitute equations (5)-(8) into equation (4), the average packet delay $E[D]$ can be easily calculated for both protocols.

## 5. Performance Evaluation

To have a valid comparison between the two protocols, we consider the same data payload size of 16384 bits, no retry limits and comparable data rate; 4 Mbit/s for IrDA AIr and 5.5 Mbit/s for IEEE 802.11. Unless otherwise specified, the values reported in the following figures have been obtained using the system parameters in table I.

Figure 3 illustrates how the RTS packet collision and transmission probabilities, $p$ and $\tau$ respectively, are affected from the network size and the various backoff parameters for both AIr and 802.11 protocols. The figure plots both probabilities as a function of the number of stations n and for different *CW* and *m* values. When no *CW* size adjustment is enforced after a successful reservation or collision ($m$=0), the figure demonstrates that the collision probability is highly dependent on the number of stations for both protocols. A large network size results in a higher collision probability and, thus, in an increased number of collisions. When AIr protocol is employed, higher values for $p$ are attained comparing to 802.11. This easily is explained if we consider that 802.11 reacts faster because of the utilized exponential backoff scheme comparing to the linear increase of contention window in AIr. In particular, $\tau$ is decreased for $n$ values less than 25; for larger network size scenarios $\tau$ attains roughly the same values having a slight decreasing trend.

Figure 4 studies the impact of the backoff and system parameters on both 802.11 and AIr protocols performance by employing the previously derived mathematical analyses. In particular, the figure explores the dependency of performance on the *CW* size. Packet delay results are plotted versus number of stations when no *CW* size adjustment is imposed ($m$=0) after a successful reservation or collision. The figure shows that packet delay is not practically affected when a large *CW* size is implemented (*CW*=32) for any network scenario. Conversely, when a lower *CW* size is being used, packet delay is highly dependent on the network size $n$. When $n$ increases, the increased number of collisions results in high packet delay values and, therefore, in significant performance degradation, especially for small *CW* size values. Thus, for a given network size and when no *CW* size adjustment is implemented, an appropriate *CW* size value should be chosen in order to obtain minimum packet delay and as a result maximum performance.

| **Parameter** | **IrDA AIr** | **IEEE 802.11** |
|---|---|---|
| Packet payload, $l$ | 16384 bits | 16384 bits |
| Slot time, $\sigma$ | 800 $\mu$s | 20 $\mu$s |
| RTS packet | 244 $\mu$s | 176 $\mu$s |
| CTS packet | 232 $\mu$s | 152 $\mu$s |
| ACK packet | 232 $\mu$s | 152 $\mu$s |
| Data rate, $C$ | 4 Mbit/s | 5.5 Mbit/s |
| Minimum *CW*, $W_0$ | 8 | 32 |
| Number of *CW* sizes, $m'$ | 20 | 5 |

Table I AIr and 802.11 MAC parameter values

| **IrDA AIr** | | | **IEEE 802.11** | | |
|---|---|---|---|---|---|
| Parameter | *RR=16* | *RR=1(opt)* | Parameter | *802.11b* | *opt* |
| *TAT* | 200 $\mu$s | 10 $\mu$s | *Slot time* ($\sigma$) | 20 $\mu$s | 5 $\mu$s |
| *CAS* ($\sigma$) | 800 $\mu$s | 50 $\mu$s | *SIFS* | 10 $\mu$s | 10 $\mu$s |
| $F_s$ | 252 $\mu$s | 132 $\mu$s | *DIFS* | 50 $\mu$s | 20 $\mu$s |
| $D_{over}$ | 1740 $\mu$s | 500 $\mu$s | | | |

Table II AIr and 802.11 parameters for improved performance

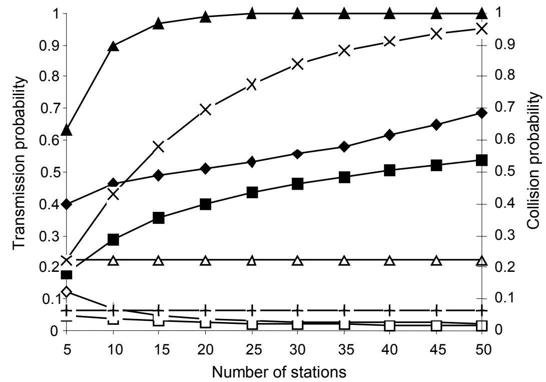
[2] A collision always lasts exactly one CAS slot.

Next we propose suitable values for certain physical and link layer parameters that reduce average packet delay and, thus, maximise performance for both protocols. In AIr we consider the case of transmitting the Robust Header (RH) field[3] of all packets using Repetition Rate equal to *RR*=1 (instead of *RR*=16) for scenarios in which only one data packet of 16 Kbits (*ppb*=1) is transmitted as well as for lower minimum turnaround time (*TAT*) and CAS slot size ($\sigma$) values. The optimized set of values for AIr utilized to derive figure 5 are displayed in table II. This time is determined by the maximum propagation delay of the WLAN. A very efficient implementation for IEEE 802.11 [19] can reduce the slot time to 5 $\mu s$. The resulting parameters for 802.11 are summarized in the column "opt." of Table II. Although we can see that the employment of the optimised parameters results in an improvement of the packet delay in both protocols (a considerable enhancement when AIr is employed), it appears that the overhead is still significant and limits the overall performance.

All previous analyses in [6], [7], [14] and [17] considered a fixed packet size. We intuitively understand that overall performance highly depends on packet size apart from other parameters. Therefore, figure 6 examines the dependency of performance on the packet size by plotting packet delay versus *l*, for three different representative network sizes (*n* = 5, 25 and 50) and for both protocols. As it is expected, in both AIr and 802.11 packet delay increases when packet size increases, especially in large network scenarios (in all cases 802.11 achieves lower packet delay values). However, it is understandable that throughput efficiency is improved when large size packets are transmitted since in this way the negative effect on performance of the packet overhead is minimized. This is a strong indication that we are dealing with a trade off on delay/throughput performance especially as the network size increases.

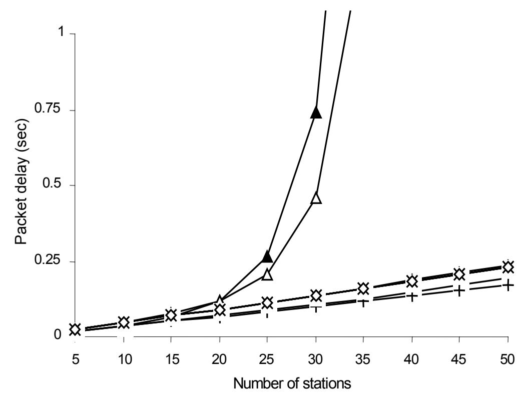
The effect of the number of packets per burst (*ppb*) on performance of both 802.11 and AIr protocols is examined in figure 7 by plotting packet delay versus network size for different *ppb* values (*ppb*=1,3 for 802.11 and *ppb*=1, 16 for AIr). Results show that performance is significantly improved by putting multiple packets in a burst packet transmission. The situation is justified by noting that for each packet transmission a separate set of overhead information and delays (reservation time, inter-frame spaces, backoff time and acknowledgements) is needed.

With packet bursting, instead of several sets of overhead for each packet, only one set of overhead information will be used. In this way, the packet delay can be reduced and the performance is significantly improved. Another useful observation is that when AIr is employed, the performance is considerably enhanced when *ppb*=16 compared to the case of *ppb*=1.



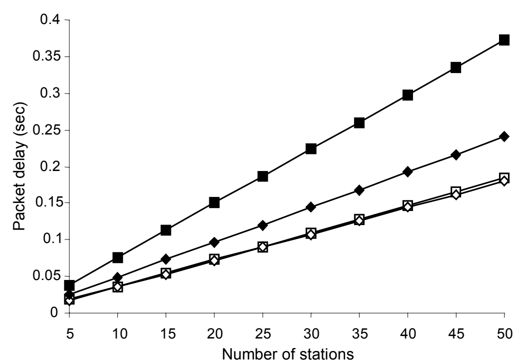

△ $\tau$, *CW*=8, *m*=0, AIr ▲ *p*, *CW*=8, *m*=0, AIr
+ $\tau$, *CW*=32, *m*=0, 802.11 x *p*, *CW*=32, *m*=0, 802.11
◇ $\tau$, *CW*=8, *m*=20, AIr ◆ *p*, *CW*=8, *m*=20, AIr
□ $\tau$, *CW*=32, *m*=5, 802.11 ■ *p*, *CW*=32, *m*=5, 802.11

Figure 3 Transmission and collision probabilities versus *n*, (802.11, *ppb*=3 and AIr, *ppb*=16 for various *CW* and *m*)




△ *CW*=8, *m*=0, AIr ▲ *CW*=8, *m*=0, 802.11
◇ *CW*=32, *m*=0, AIr ◆ *CW*=32, *m*=0, 802.11
x *CW*=8, *m*=20, AIr + *CW*=32, *m*=5, 802.11

Figure 4 Packet delay versus *n*, (802.11, *ppb*=3 and AIr, *ppb*=16 for various *CW* and *m*)




□ standard parameters, 802.11 ■ standard parameters, AIr
◇ optimized parameters, 802.11 ◆ optimized parameters, AIr

Figure 5 Packet delay versus *n*, for optimized parameters (802.11, *ppb*=1, *CW*=32, *m*=5 and AIr, *ppb*=1, *CW*=8, *m*=20)

[3] The RH field contains the essential information required by the AIr PHY and MAC layers to co-ordinate medium access.

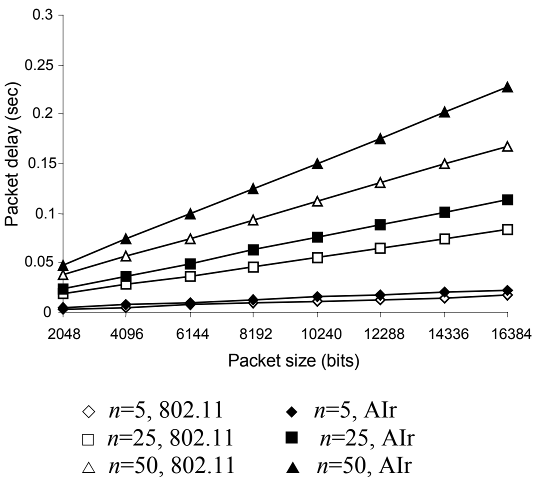



Figure 6 Packet delay versus *l*,
(802.11, *ppb*=3, *CW*=32, *m*=5 and AIr, *ppb*=16, *CW*=8, *m*=20)

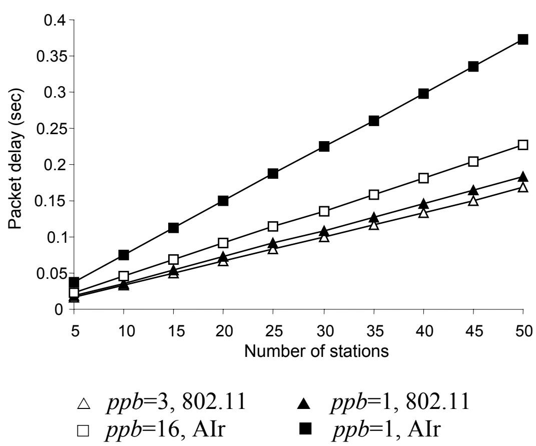



Figure 7 Packet delay versus *n*, for various *ppb* values
(802.11, *CW*=32, *m*=5 and AIr, *CW*=8, *m*=20)

## 6. Conclusion

This paper compares the performance of the IEEE 802.11 and IrDA AIr protocols by examining the average packet delay in relation to network size, packet size and collision avoidance parameters. This thorough comparison based on the characteristics of each protocol combined with analytical results will give us a benchmark of how each factor affects performance. Results indicate that the appropriate adjustment of the protocol parameters enhances performance and improves the services that the IEEE 802.11 and AIr protocols provide to various communication and multimedia applications. Finally, in both protocols there is a trade-off between throughput efficiency and packet delay performance as the packet payload and network size increases.

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