

Service Differentiation Support in Optical WLAN

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ABSTRACT

This paper focuses on improving the backoff scheme in MAC protocol defined in IEEE 802.11b for supporting different services in optical wireless networks. The characteristics of a diffuse infrared channel are described and a simulation environment for a diffuse infrared wireless network study is created. The proposal for service differentiation by offering different CW_{\min} is evaluated via simulations in network simulator *ns-2*. The results show that our proposals provide support for real-time applications in an optical WLAN environment.

Keywords: Infrared, WLAN, MAC, service differentiation

1. INTRODUCTION

The proliferation of wireless communications and the evolution of fibre-optic technique suggest that the future network will mainly consist of a fibre-optic backbone as the primary system with short-range wireless communication links providing additional mobility. Today, three major transmission technologies dominate the wireless office arena: microwave, spread spectrum RF, and infrared. The increasing frequency congestion and the regulation restrictions with radio suggest the seeking of other spectrum regions. With the potential for high bandwidths, infrared technology shows several attractive aspects for use as a wireless communication medium [1] [2].

The explosive growth of the Internet during the last decades prompts the integration of wireless networks with the fixed, for a ubiquitous Internet access. Unfortunately, most of the Internet protocols have been designed for wireline links, which have adequate bandwidth and low error rate. Running over wireless links, the performance of Internet applications is severely degraded by transmission errors and bandwidth congestion. Furthermore, the increasing requirements for multimedia over wireless networks in recent years have produced other challenges for wireless links.

Aiming at solving the wireless bandwidth limitation problems at the *Medium Access Control (MAC)* layer, this paper concentrates on the mechanism, *Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA)*, defined in IEEE 802.11b [3] for both radio and infrared media. Specifically, the *Backoff* scheme is studied. To support mixed traffic types in the network, such as voice and data, a further extension to the backoff scheme has been developed.

This paper is organised as follows: Section 2 gives a brief introduction to the backoff scheme defined in IEEE 802.11b. Section 3 describes the characteristics of diffuse infrared wireless links. Section 4 presents the parameters for simulations. In Section 5, an extension of the backoff scheme is proposed and evaluated, followed by the conclusions given in Section 6.

2. BACKOFF SCHEME IN IEEE 802.11b

CSMA/CA is adopted by the Distributed Coordination Function (DCF) in the IEEE 802.11b specification as the primary access method. The principle of the collision avoidance method is shown in Figure 1. For a station that intends to transmit, if it senses the channel busy, it will defer until the end of the ongoing transmission, and then wait for a period of the Distributed Coordination Interframe Space (DIFS) length, when the last frame detected on the medium is received correctly. The DIFS includes carrier sensing time, and is computed using the equation: $DIFS = SIFS + (2 \times \text{slot time})$, where SIFS is the Short InterFrame Space. After that, it randomly selects a time slot within the contention window (contention window). At the first transmission attempt, the contention window, (CW) = the minimum contention window (defined as CW_{min}), and is doubled at each retransmission, up to the maximum contention window (CW_{max}). If no other station has started transmitting before the slot is reached, it starts its own transmission. Collisions can now only occur in the case where two or more stations have selected the same slot. If another station has selected an earlier slot, the station freezes its backoff counter, waits for the end of this transmission, and then only waits for the slots remaining from the previous competition.

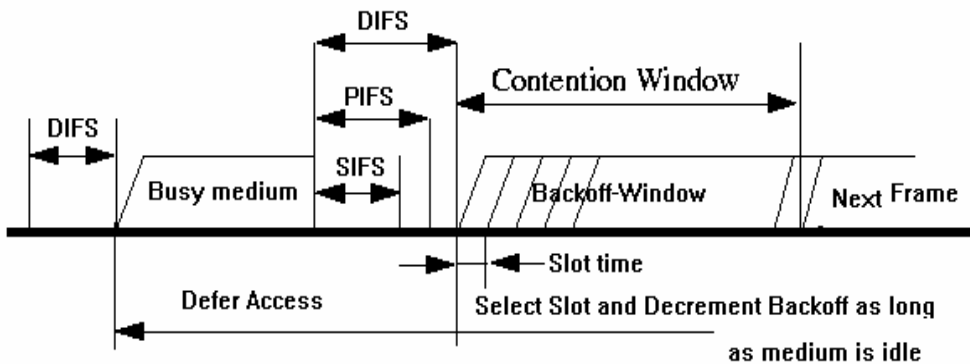


Figure 1: CSMA/CA access method

A backoff timer is set with a random backoff integer drawn from a uniform distribution over the interval $[0 \text{ to } \{CW - 1\}]$. The Backoff integer is the number of idle “slots” the station must wait until it is allowed to transmit. The value is decremented by one for each idle slot detected. The backoff timer suspends when the medium becomes busy, before the backoff integer reaches zero. The timer resumes only after the medium has been idle longer than the designated inter-frame space interval. The station starts transmitting the frame when the backoff timer reaches zero. For an i^{th} successive retry for access to the medium, the contention window becomes $2^i \cdot CW_{min}$. Upon a successful transmission, the contention window is returned to CW_{min} . The maximum contention window CW_{max} is given by $2^m \cdot CW_{min}$, where m is the maximum backoff stage. For each successive retransmissions, the values of CW increases exponentially (i.e. $CW_{new} = CW_{old} * 2 - 1$), until it reaches and then stays at CW_{max} . CW will be restored to CW_{min} after a successful transmission.

An example of the backoff procedure is shown in Figure 2. The effect of this is that, when multiple stations are deferring and going into random backoff, then the STA selecting the smallest backoff time using the random function will win the contention. To begin the backoff procedure, the station sets its backoff timer to a random backoff time. All backoff

slots occur following a DIFS period, during which the medium is determined to be idle for the duration of the DIFS period. The backoff procedure is suspended whenever the medium is determined to be busy during a backoff slot. The medium shall be determined to be idle for the duration of a DIFS period or EIFS, as appropriate, before the backoff procedure is allowed to resume. Transmission shall commence whenever the backoff timer reaches zero.

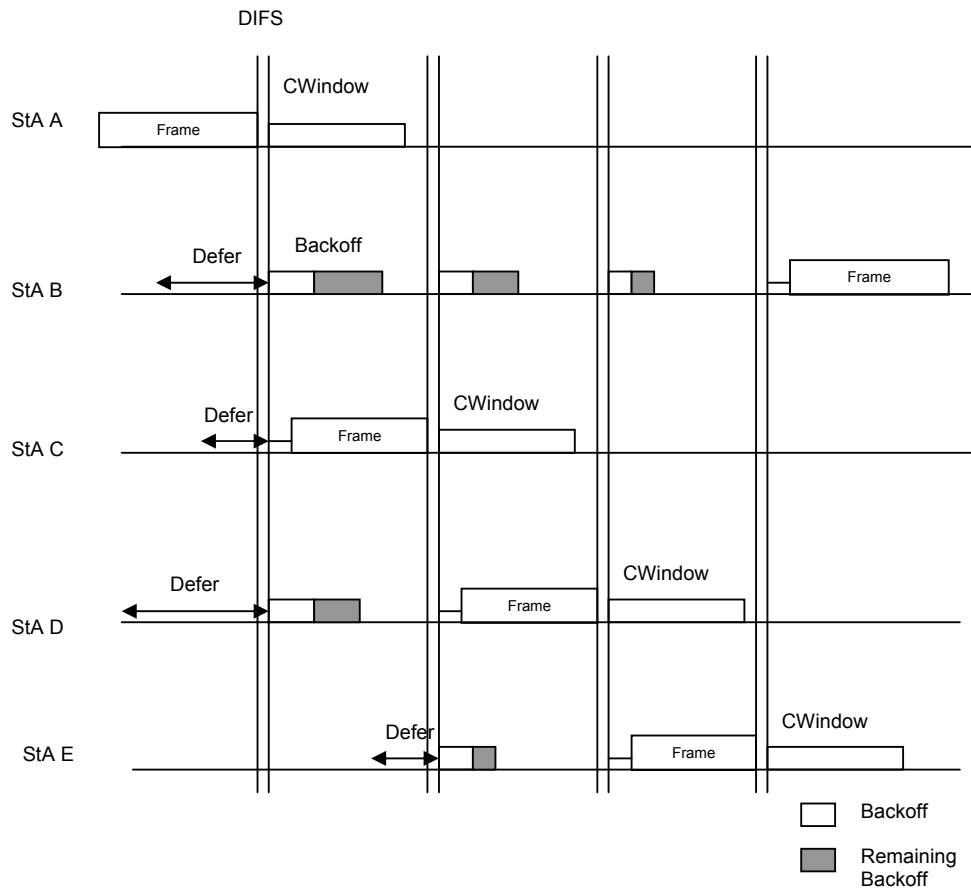


Figure 2: Backoff Procedure

3. DIFFUSE INFRARED CHANNEL

The fact that the infrared channel is different from multipath fading radio channels suggests a different approach to modelling. The IM/DD infrared channel can be modelled as a fixed, linear, baseband system with input $\mathbf{X}(t)$, output $\mathbf{Y}(t)$, impulse response $\mathbf{h}(t)$, with signal-independent, additive noise $\mathbf{N}(t)$, shown in Figure 3. \mathbf{R} presents the responsivity of the photodetector. The average transmitter power, \mathbf{P}_t , is the time average of $\mathbf{X}(t)$, and the average received optical power is given by:

$$P = H(0) \cdot P_t, \quad \text{where } H(0) = \int h(t) dt, \text{ is the channel d.c. gain [4] [5].}$$

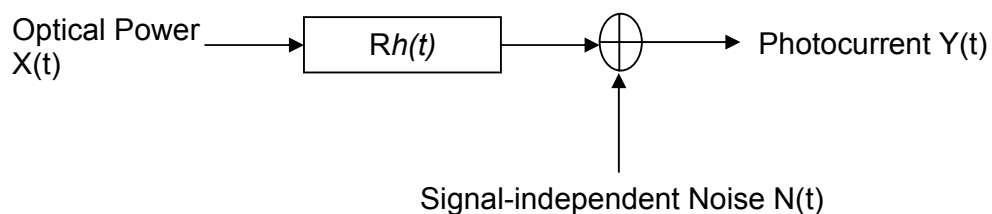


Figure 3: IM/DD infrared channel

Carruthers and Kahn described in their paper [6] that realistic multipath infrared channels can be characterised well by only two parameters: optical path loss and r.m.s. delay spread. Using the ceiling-bounce functional model, they developed a computationally efficient method to predict the path loss, and multipath power requirement of diffuse links, based on the location, s , of the transmitter and receiver within a room. Since their model is claimed to be simple but accurate, we follow their approach. The optical gain \mathbf{G}_0 for the shadowed and unshadowed channel, using a Lambertian of order 1, is:

$$G_0(\text{Unshadowed}) = 10^{0.18+1.00s} \int h_1(t) dt \quad (1)$$

$$G_0(\text{shadowed}) = 10^{-0.14+1.02s} \int h_1(t) dt \quad (2)$$

where $h_1(t)$ is the impulse response when the transmitter and receiver are at the same position, near the centre, in which case the ceiling appears to the transmitter to be well-approximated by an infinite plane. The r.m.s delay spread \mathbf{D} is:

$$D(\text{Unshadowed}) = \frac{a\sqrt{\frac{13}{11}}}{12(2.1 - 5.0s + 20.8s^2)} \quad (3)$$

$$D(\text{shadowed}) = \frac{a\sqrt{\frac{13}{11}}}{12(2.0 + 9.4s)} \quad (4)$$

Where \mathbf{a} is the minimum time required for a signal to travel from the transmitter, then be reflected from the ceiling, and then to strike the receiver, which is $2\mathbf{H}/\mathbf{c}$, \mathbf{H} being the ceiling height, and \mathbf{c} is the speed of light. In Eq. (1)-(4), the correction parameter \mathbf{s} was applied, which is the ratio of the horizontal transmitter-receiver separation to the TR diagonal of the room, for the case when the receiver is further separated from the transmitter and roams over a certain distance. Assuming that the receiver and transmitter are at the same height from the ceiling, then, for the receiver $(\mathbf{R}_x, \mathbf{R}_y, \mathbf{0})$, the transmitter $(\mathbf{T}_x, \mathbf{T}_y, \mathbf{0})$, when the length of the square room is \mathbf{L} , we have:

$$s = \frac{1}{L} \left(\frac{\sqrt{(R_x - T_x)^2 + (R_y - T_y)^2}}{\sqrt{\frac{R_x^2 + R_y^2}{R_y^2}}} \right) \quad (5)$$

4. SIMULATION IMPLEMENTATION

For our simulation we used *ns-2* [7], an event driven network simulator jointly developed by researchers at the University of California at Berkeley, the Laurence Berkeley National Laboratory and the University of Southern California. The simulator is written in C++ and Object Tcl, two object-oriented languages, the former compiled and the latter interpreted. In *ns-2* it is possible to modify the simulated objects and add any functionality desired. We used these features in our work, added the diffuse Infrared Channel model discussed above, modified the physical interface and set the node attributes that indicate the transceiver

characteristics to make the physical layer work as a diffuse infrared link. The default parameters used are shown in Table 1. All the parameters were chosen generally conform to the DFIR physical definition in the IEEE802.11 standard.

Characteristic	Value
SlotTime	8 μ s
SIFSTime	10 μ s
CCATime	5 μ s
RxTxTurnroundTime	0 μ s
PreambleLength	20 μ s(2 Mbps)
PLCPHeaderLength	20 μ s (2 Mbps)

Table 1. The PHY MIB parameters

In the simulation, all the mobile nodes moved in a 10 \times 10 meter flat, square area, 2m from the ceiling. The mobile nodes moved according to the *random waypoint* mobility model. In this model, each node picked a random destination and speed in the square area, and then travelled to the destination in a straight line. Once the node arrived at its destination, it paused, picked another destination, and continued onward. We assumed that the stations were homogeneous in the traffic generation, and there was no hidden terminal. A scenario that may fit these assumptions would be a classroom, meeting, army field, and stock market, in which users exchange information via their wireless terminals.

5. BACKOFF SCHEME EXTENSION

Though the DCF in the IEEE 802.11 standard can arbitrate access to the channel in a distributed manner, it does not provides any support for priority, since all stations in the basic service set the resources, or all the flows in one station compete for the resources and channel, with the same priority as stated in the description of CSMA/CA. On the other hand, the increasing requirements for multimedia over wireless networks urge the WLAN to provide support for both real-time and non-real-time services, which have different quality of service (QoS) requirements. WLAN is a Packet-based network, in which the protocols running over it are designed to efficiently transmit bursty, unpredictable asynchronous data. As a result, packets experience variable delays caused by congestion on the network. For non-real-time traffic, such as file transfer and e-mail, although these delays can adversely affect throughput of data traffic, there is no perceptible degradation of quality to the end user. However, for real-time services such as Voice over IP (VoIP), audio and video conferencing, the traffic is isochronous: it can have specific requirements for bandwidth, delay and jitter, but can tolerate some losses. The best effort transmission over W-LAN offers no timing assurance on the delivery of packets. Therefore, when both real-time and non-real-time traffic contend for the network bandwidth, especially in a WLAN environment, where the wireless media provides as little as 1Mbps/2Mbps of shared capacity, upon the differentiation on QoS requirement of the services, a QoS-aware access function is needed to optimise the MAC mechanism and make full use of the limited bandwidth.

The backoff scheme, however, implies the possibility of differentiating the services by offering different CW_{min} according to the traffic characteristics. Using this approach would allow the time-bound services higher priority for channel access. A simulation was carried to investigate this possibility. In this test, different CW_{min} values were set for two stations separately. Station A had $CW_{min} = 31$ and station B $CW_{min} = 63$. It meant that, during the

simulations, at the first transmission attempt, instead of 63, Station A started with CW_{\min} from 31. The packet size was set at 256 bytes, and the RTS/CTS scheme was used.

As it is already well known that large values of CW_{\min} introduce greater delay, only performance on throughput, for both stations, is shown in Figure 4. It shows that, for a smaller backoff time, Station A clearly had more chances of competing for the channel, especially as the network load increased.

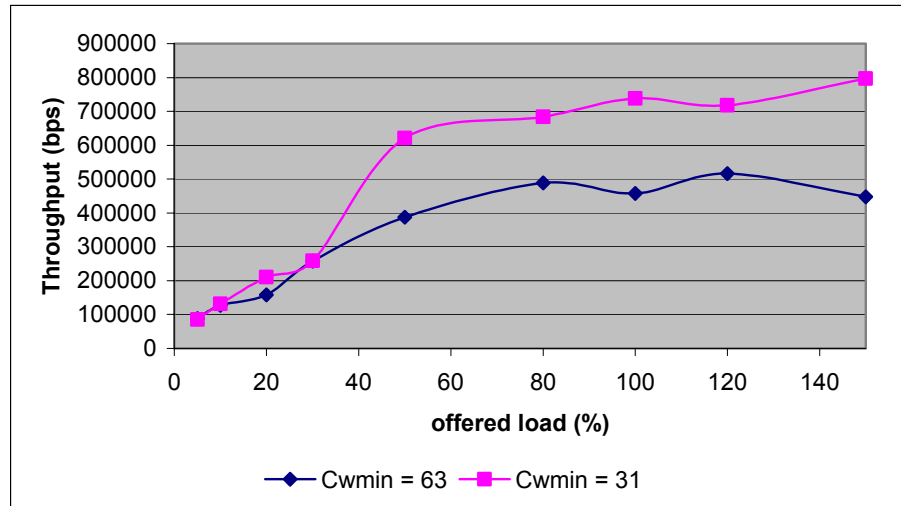


Figure 4: Throughput vs. CW_{\min}

Based on the simulations taken above, further simulations on service specific were carried out, to test the service differentiation proposal, based on the fact that the backoff window started from CW_{\min} . Here an example is given.

In this simulation, both voice conversation and file transfer applications were simulated. The voice conversation was based on the UDP protocol. It was assumed that there was a one-way, one-to-one, communication. The voice traffic characterised followed the model in [8]. The voice conversation participant alternated between periods of speaking and listening. The talkspurts and silent phases were assumed exponentially distributed with the mean value $t_1 = 1s$ and $t_2 = 1.35s$, respectively. The sender remained in each state for an exponentially distributed period of time, with the average talk period being 1 second and the average silent period being 1.35 seconds. The voice activity factor was $t_1/(t_1 + t_2) = 0.425$. This factor was valid for all schemes, as human speech patterns are independent of the encoding used. During the talkspurts phase, the sender transmitted data at a constant bit rate (CBR) at 100kbps, while the sender stayed idle during the silent phase.

The TCP protocol was adopted by the file transfer application. It was a one way transmission. The File Transfer Protocol (FTP) in *ns-2* was used in the simulations. In the file transfer model, whenever there was data at the sender part, it was sent immediately and continuously until the transmission finished.

In the simulations, a voice station and three other data stations were chosen. The data stations were added, one by one. In the first test, all the stations had the same priority as in legacy DCF, CW_{\min} being set to 63. In the second test, priority was introduced by setting the CW_{\min} for the voice station at 31. The CW_{\min} for each data station was still 63. The traffic from the data stations used TCP and transmitted at 2Mbps. As the network was

highly loaded in the simulation, RTS/CTS was implemented according to the recommendation in [9].

The simulation results of the performance of throughput and delay are shown in Figure 5 and Figure 6. It is noted that the throughput of the voice station was increased by ten times to make the effect visible in the figure. The simulations actually considered three network topologies: one voice, with one- to three data stations, separately. The network performance with the priority schemes shown in the figures indicated the support of both real-time and non-real-time applications.

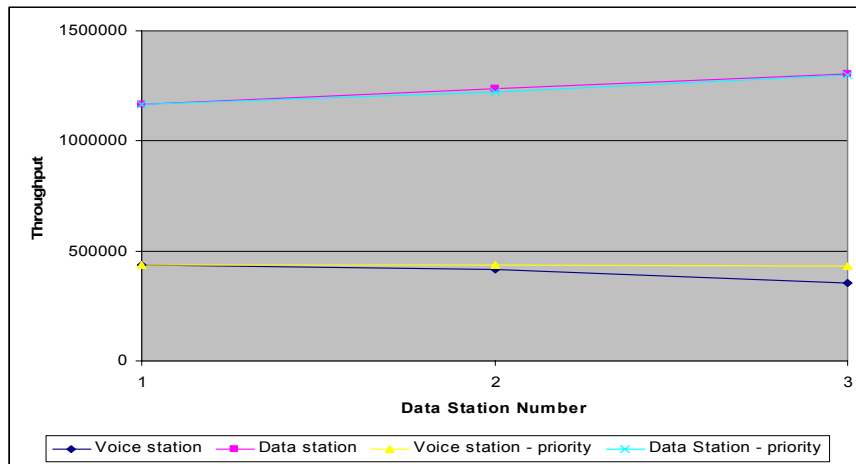


Figure 5: Throughput performance with priority and without priority

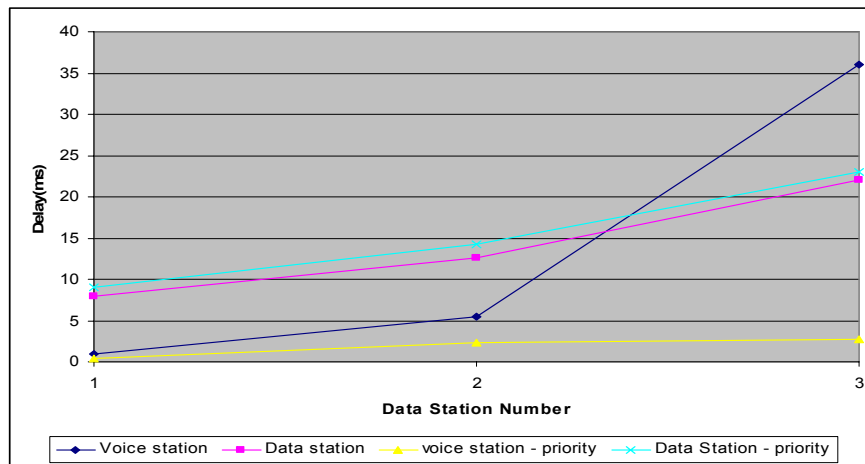


Figure 6: Delay performance with priority and without priority

6. CONCLUSIONS

In this paper a proposal for service differentiation by setting the value of CW_{min} as an extension of the backoff algorithm was verified by simulations using *ns-2*. The results identified and evaluated a very promising direction for relevant performance enhancements on the legacy MAC scheme, for supporting multimedia applications in optical wireless LANs.

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