An Efficient Scheduling Scheme for High Speed IEEE 802.11 WLANs

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Abstract— **The emergence of high speed WLANs, such as the IEEE 802.11a and IEEE 802.11g, has provided an alternative solution for mobile users to access a network in addition to the popular IEEE 802.11b solution. Although the channel data rate of those emerging high speed WLANs is five times higher than that of 802.11b, some recent studies have shown that the throughput of IEEE 802.11 drops as the channel data rate increases, and the throughput upper limit do exist when the channel data rate goes to infinite high. These findings indicate that the performance of a WLAN will not be efficiently improved by merely increasing the channel data rate. In this paper, we propose a new protocol scheme that makes use of an out-of-band signaling (OBS) technique. The proposed scheme provides better bandwidth usage compared to the in-band signaling technique in the existing scheme and is compatible with the existing IEEE 802.11 standard.**

I. Introduction

In recent years, we have witnessed the soar in popularity of wireless local area networks (WLANs) especially among the mobile users. This popularity is partly promoted by the adoption of the IEEE 802.11b standard [1] by the industry. The emergence of high speed WLANs, such as the IEEE 802.11a [2] and IEEE 802.11g [3], has provided an alternative solution for mobile users to access a network in addition to the popular IEEE 802.11b solution. The IEEE 802.11a and 802.11g provide data rates up to 54 Mbps while the IEEE 802.11b provides data rates up to 11 Mbps. Although the channel data rate of the emerging high speed WLANs is five times higher than that of 802.11b, some recent studies ([4], [5]) have shown that the throughput of IEEE 802.11 drops as the channel data rate increases, and the throughput upper limit do exist when the channel data rate goes to infinite high. These findings indicate that the performance of a WLAN will not be efficiently improved by merely increasing the channel data rate.

The IEEE 802.11 [6] specifies two mechanisms for transmission which are the distributed coordination function (DCF) and the point coordination function (PCF). DCF makes use of CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) with binary exponential backoff for contention purpose. PCF is an optional contention-free service which makes use of polling by the centralized point coordinator. DCF itself employs two techniques for packet transmission. The default is a two-way handshaking method called basic access method. The other technique employs a four-way handshaking method, known as Request-To-Send/Clear-To-Send (RTS/CTS).

In this paper, we introduce a MAC layer scheduling scheme to improve the performance of a high speed WLAN with the use of a separate low speed channel for signaling. Intuitively, the use of an additional channel for signaling may result in higher overall bandwidth consumption since two channels are needed in a network. Surprisingly, our study indicates that the current in-band signaling method on the high speed channel actually causes higher bandwidth wastage compared to our proposed out-of-band signaling (OBS) method, the bandwidth gained from the high speed channel exceeds the bandwidth used on the signaling channel. Hence, the overall system performance is improved. Furthermore, the OBS scheme also allows the continuing performance improvement of IEEE 802.11 WLANs as the data rate on the high speed channel increases.

One important property of our OBS scheme is that it uses the IEEE 802.11 MAC protocol standard for wireless channel access, which makes it backward compatible with the existing IEEE 802.11 WLANs. This is important as the IEEE 802.11 WLANs have already been widely deployed. The OBS scheme can coexist with the existing MAC operations without affecting the proper operation of the existing MAC protocol operation. To take the benefits from the new scheduling scheme, both the access point (AP) and the station must have the OBS scheme implemented, otherwise, the scheduling scheme will be disabled.

This paper is organized as follow. Section II provides brief summary of the IEEE 802.11 MAC protocol, emphasizing on the working of the DCF and PCF mechanisms. Section III explains the mechanism of the proposed OBS scheme. Section IV provides the performance evaluation of the scheme.

II. IEEE 802.11 MAC Protocol

This section briefly summarizes the IEEE 802.11 MAC protocol. For detailed description, readers can refer to the IEEE 802.11 standard [6].

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A. Distributed Coordination Function

The DCF employs CSMA/CA MAC protocol with binary exponential backoff. The DCF does not use collision detection function as the stations cannot detect collision by listening their own transmission. Instead it employs handshaking method which makes use of positive acknowledgment.

The basic access mechanism employs a two-way handshaking method (see Fig. 1a). When a station has a new packet to transmit, it will monitor the channel activity. If the channel is detected idle for a period of time called distributed interframe space (DIFS), a random backoff interval is selected. The backoff counter is decremented as long as the channel is sensed idle, stopped when channel activity is detected, and reactivated when the channel is sensed idle for more than a DIFS again. The station transmits its packet when the backoff counter reaches zero.

The DCF uses a slotted binary exponential backoff technique. The period following an idle DIFS is slotted and the backoff time counter is measured in terms of slot time. The slot time is the time needed for any stations to detect transmission from any other stations. It accounts for the propagation delay, the time needed to switch from the receiving to the transmitting state and the time to notify the MAC layer about the state of the channel.

The backoff time is uniformly chosen in the range (0,CW-1), where CW is the current contention window. At the first transmission attempt, CW is set equal to the minimum contention window (CW_{min}). After each unsuccessful transmission, CW is doubled until it reaches the maximum contention window (CW_{max}).

When the destination station successfully receives a packet, it will transmit an acknowledgment packet (ACK) after a short interframe space (SIFS). If the sender does not receive the ACK within a specified ACK timeout, or it detects the transmission of a different packet on the channel, it reschedules the packet transmission according to the previous backoff rules.

The DCF also defines an optional four-way handshaking method (see Fig. 1b) for packet transmission, which is known as RTS/CTS method. When a station is ready for a transmission, it performs the previous backoff technique. The sender transmits a special RTS frame. When the receiver receives the RTS packet, it responds with CTS frame after a SIFS. The sender may then transmit the packet only if the CTS frame is correctly received.

The RTS and CTS frames carry the information of the length of the packet to be transmitted, which is used to update a network allocation vector (NAV) by other stations. The NAV contains the information about the period of time in which the channel will remain busy hence a station can delay transmission by detecting either RTS or CTS to avoid collision. The RTS/CTS method improves the system performance, especially when large packets are transmitted, as it reduces the length of the frames involved in the contention process.

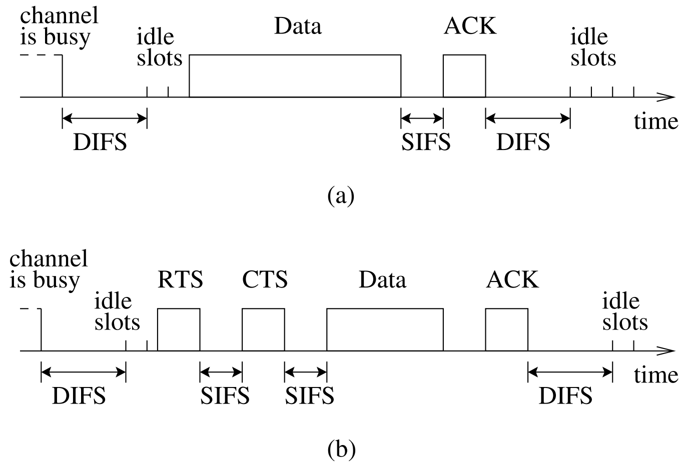

Fig. 1. IEEE 802.11 DCF: (a) Basic access method. (b) Four-way handshaking method.

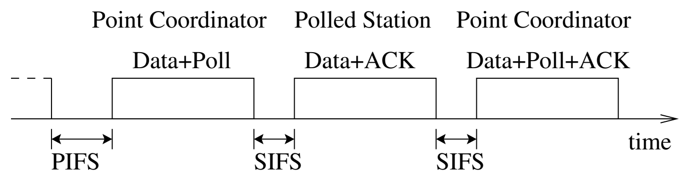

Fig. 2. IEEE 802.11 PCF.

B. Point Coordination Function

The IEEE 802.11 also specifies the optional PCF (see Fig. 2) which is implemented on top of the DCF. The PCF operation makes use of polling by the point coordinator or the AP hence it is contention free. The point coordinator uses point coordination interframe space (PIFS) when issuing polls. The PIFS is longer than SIFS but shorter than DIFS, hence the point coordinator can take control of the channel and stop all the asynchronous traffic while it issues polls and receives responses. In PCF, the ACK can be combined with data or poll frame, thus it has less overhead compared to DCF.

III. Out-of-Band Signaling

Wireless imposes large overhead on the data transmission. Most of this overhead is due to the preamble that must be sent prior to any packet transmission. For example, the time to transmit the preamble of the OFDM used in the IEEE 802.11a and 802.11g is 20 μs. Transmission of 1 kbyte data with data rate 54 Mbps takes 148 μs, hence the preamble transmission alone takes more than 10% of the total transmission time. The CSMA/CA also requires positive acknowledgment, which adds up to the transmission overhead.

The performance of DCF is greatly influenced by the collisions that occur on the channel. When collisions occur, retransmissions are required which cause bandwidth wastage. The RTS/CTS method is proposed to help reducing the bandwidth wastage by reducing the size of the packets involved in collisions, however with a large number of users, collisions occur quite often. The PCF eliminates the collisions but it is

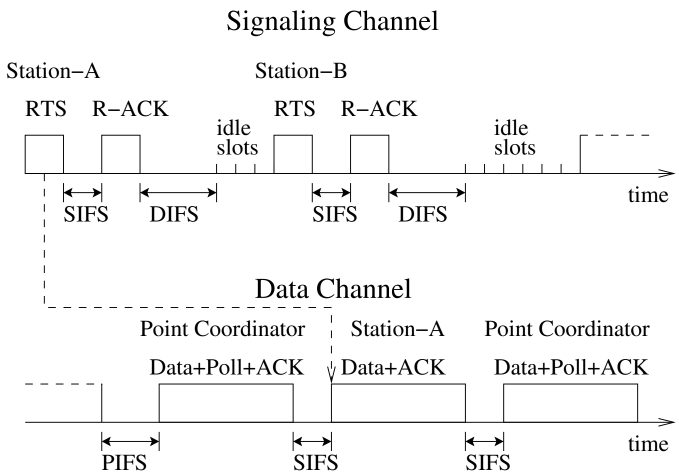

Fig. 3. The OBS scheme using out-of-band signaling.

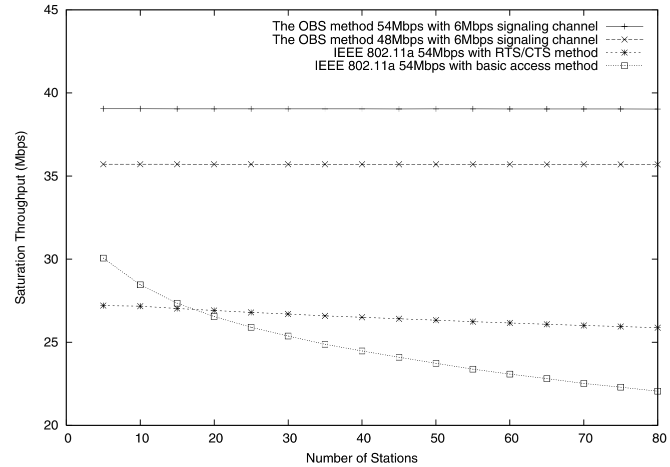

Fig. 4. Saturation throughput of the high speed channel.

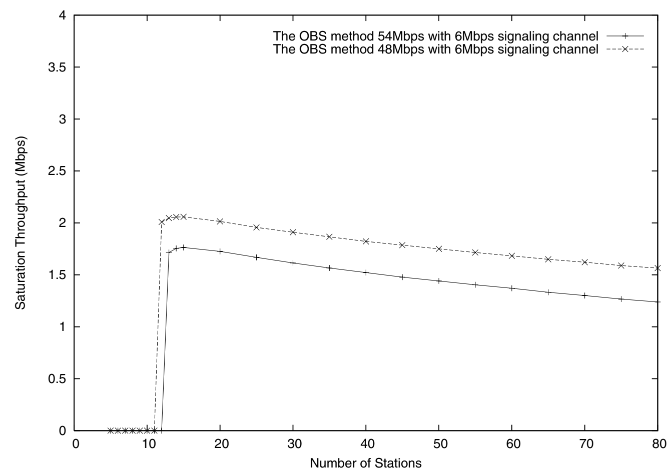

Fig. 5. Saturation throughput of the low speed (signaling) channel.

TABLE I
PARAMETERS OF IEEE 802.11A

Slot Time	$9\mu s$
Propagation Delay	$1\mu s$
SIFS	$16\mu s$
DIFS	$34\mu s$
Preamble Length	$20\mu s$
CW_{min}	16

not effective when many of the stations do not have packet to transmit.

The proposed OBS scheme can be briefly described as follows. We propose to use an unused channel operating at a lower speed for the channel assignment purposes. The actual data transmissions will be scheduled on the high speed channel. When a station is ready for a data transmission, it executes the DCF on the low speed channel to schedule its RTS control frame transmission. Once the AP receives the RTS frame, the AP then schedules the data transmission to the next PCF period on the high speed channel and acknowledges the request (see Fig. 3).

This mechanism improves the performance as the costly idle periods and transmission collisions are avoided entirely on the high speed channel. As PCF imposes less overhead compared to the DCF (as ACK and poll can be combined with data), this mechanism has less overhead on data transmission. Therefore higher utilization can be achieved on the high speed channel.

When the high speed channel is congested, data transmissions can be scheduled on the low speed channel on the AP's discretion. Hence the low speed signaling channel can also contribute to the overall throughput of the system. The OBS scheme also allows easy implementation of priority transmission. As the AP regulates all data transmissions, the AP could schedule the priority packets to be transmitted before any of the queuing transmissions.

IV. PERFORMANCE ANALYSIS

To illustrate the performance advantage of the OBS scheme, we study the performance under various load conditions using computer simulations. Furthermore, we also analyze the performance based on the analytical framework developed in [4].

A. Simulation Study

In Figs. 4-5, we present the saturation throughput of the high speed and low speed channels (both implementing IEEE 802.11a with different data rates) obtained from our simulations. The results are also compared to that of a WLAN with the current configuration (i.e. IEEE 802.11a without the OBS scheme). The packet size used in the simulation is 1500 bytes. Table I shows some of the IEEE 802.11a parameters.

It should be noted that the zero throughput on the low speed channel when the number of stations is small occurs because the number of stations is not enough to fill the transmission queue on the high speed channel, hence no transmission is scheduled on the low speed channel. The results confirm that the use of a separate low speed channel for signaling proposed

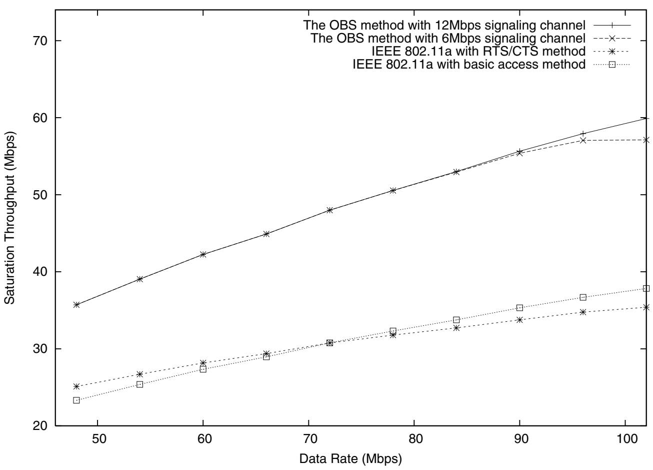

Fig. 6. Saturation throughput versus data rate with 30 stations.

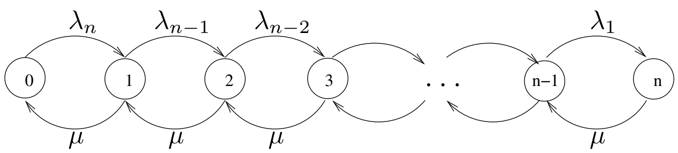

Fig. 7. State transition diagram of the birth-death process representing the state of the data channel's queue.

in this paper achieves higher overall system performance.

Based on our results (see Figs. 4-5), if the OBS scheme is implemented, the throughput can be improved almost up to 50% compared to that of the existing IEEE 802.11a without the OBS scheme under heavy load conditions. This goodput improvement on the high speed channel already exceeds the data rate of the low speed channel used for signaling, thus the overall system performance is improved.

In Fig. 6, we present the saturation throughput versus the data rate of the channel with a fixed number of stations. Note that the gap between the OBS scheme and the existing scheme become wider as the data rate increases. Therefore the OBS scheme can support higher data rate compared to the existing scheme. The saturation throughput of the system with 6 Mbps signaling channel reaches its maximum with 100 Mbps data channel. Note that increasing the signaling channel's bitrate allows the saturation throughput of the data channel to grow further.

B. Saturation Analysis

We focus our analysis on the saturation throughput of the data channel. The throughput of the data channel depends on whether there are stations waiting to be polled to transmit data. Stations that have successfully transmitted RTS on signaling channel will wait to be serviced on the data channel's queue. This queue can be modeled into a birth-death process i.e. G/D/1 queue if we assume constant packet size.

Fig. 7 shows the state transition diagram of the birth-death process for the data channel's queue. We derive the arrival rate based on the formulas in [4]. The arrival rate of the data channel's queue is the service rate of the signaling channel with different number of users contending. Assume there are n users in the system. When there are k users in the data channel's queue, there are $n - k$ users contending on the signaling channel. As we assume constant packet size, the service rate for a packet transmission is constant. This model fully characterizes the performance of the data channel as the performance depends only on whether the queue is filled or empty.

To derive the service rate of the signaling channel, first we need τ, which is the probability that a station transmits in a randomly chosen slot time expressed as follow [4]

$$\tau = \frac{2(1-2p)}{(1-2p)(CW_{min}+1) + pCW_{min}(1-(2p)^m)}. \quad (1)$$

The variable p is the probability that a transmitted packet encounters a collision which is given by

$$p = 1 - (1-\tau)^{n-1}. \quad (2)$$

CW_{min} is the minimum backoff window size and m is the maximum backoff stage where $CW_{max} = 2^m CW_{min}$. For complete derivations of τ and p, please refer to [4].

The probability P_{tr} that in a slot time there is at least one transmission given n active stations is derived as

$$P_{tr} = 1 - (1-\tau)^n \quad (3)$$

and the probability P_s that a transmission is successful is derived as

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n}. \quad (4)$$

With P_s and P_{tr}, the service rate of the signaling channel, which is the arrival rate of the data channel, can be expressed as

$$\lambda_n = \frac{P_s P_{tr}}{(1-P_{tr})\sigma + P_{tr}P_sT_s + P_{tr}(1-P_s)T_c} \quad (5)$$

where σ is the slot time. The values of T_s and T_c, the average time the channel is sensed busy because of a successful transmission and the average time the channel is sensed busy during a collision respectively, are given by

$$\begin{cases} T_s = RTS + SIFS + \delta + R\_ACK + DIFS + \delta \\ T_c = RTS + DIFS + \delta \end{cases}. \quad (6)$$

The service rate of the data channel is derived from the cycle time of the data transmission. According to Fig. 3, the cycle time of data transmission is given by

$$T_{cycle} = T_{POLL} + SIFS + \delta + T_{DATA} + SIFS + \delta \quad (7)$$

assuming no retransmission is required and the access point does not transmit any data to stations (if the access point transmits data, the cycle time will be longer and the service rate of the data channel will be lower but the utilization will be higher). The poll also acts as the acknowledgment of the previous data transmission. The service rate of the data channel is given by

$$\mu = \frac{1}{T_{cycle}}. \quad (8)$$

TABLE II

ARRIVAL RATE WITH VARYING NUMBER OF STATIONS

Number of Stations, n	Arrival Rate (packets/sec), λ
5	5501.16
15	5275.52
25	5103.22
35	4969.83
45	4858.83
55	4762.49
65	4676.59
75	4598.56

TABLE III

SERVICE RATE WITH VARYING PACKET SIZE

Packet Size (bytes)	Service Rate (packets/sec), μ
2500	2231.40
2000	2673.27
1500	3333.33
1000	4426.23
500	6585.37

We achieve maximum channel utilization when the queue is fully utilized, i.e. if the queue is saturated where the arrival rate is higher than the service rate. Assume π_i is the stationary probability of the system being in state i, $i = 0, 1, \ldots, n$ (see Fig. 7). The condition to fully utilize the system, i.e. $\pi_0 = 0$ is when $\widehat{\lambda}/\mu \geqslant 1$ with $\widehat{\lambda} \leqslant \lambda_i, i = 1, 2, \ldots, n$. Table II shows the numerical results of some arrival rate values with varying number of stations contending on the signaling channel. Table III shows the numerical results of some service rate values with data rate of 54 Mbps and different constant packet sizes.

We see that packet size of 1 kbytes is enough to saturate the system (the IEEE 802.11 allows packet size up to 4 kbytes), although on a lower packet size, the data channel's queue would not be saturated. Fig. 8 shows the performance of the OBS scheme compared to the existing using packet size of 500 bytes collected from simulation. The result shows that the OBS scheme still provides better throughput when the queue is not filled all the time.

V. CONCLUSION

In this paper, we have presented a new protocol scheduling scheme for WLANs that makes use of the out-of-band signaling technique. One important characteristic of the scheme is its compatibility with the existing IEEE 802.11 MAC protocol. The saturation throughput performance is studied. The results assert that the OBS technique performs better than the in-band signaling technique used by the existing scheme. The results also suggest that our OBS scheme is more effective compared to the existing scheme for higher data rate WLANs. Furthermore increasing the signaling channel's bitrate allows the saturation throughput of the data channel to grow further for higher data rate WLANs.

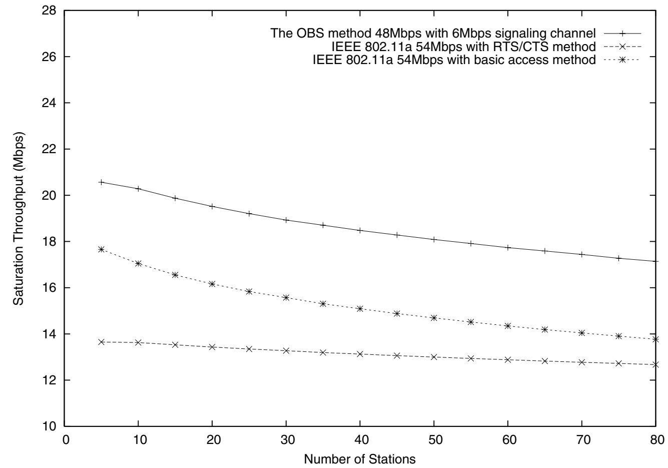

Fig. 8. Saturation throughput of the high speed channel with 500 bytes packet size.

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