Chapter 8. Contention-Free Service with the PCF

To support applications that require near real-time service, the 802.11 standard includes a second coordination function to provide a different way of accessing the wireless medium. The point coordination function (PCF) allows an 802.11 network to provide an enforced "fair" access to the medium. In some ways, access to the medium under the PCF resembles token-based medium access control schemes, with the access point holding the token. This chapter describes medium access under the PCF, detailed frame diagrams for the PCF frames, and how power management operations interact with the PCF.

The PCF has not been widely implemented. This chapter is included for two reasons. Readers interested in the standard itself may also be interested in how the PCF works. It is also possible that products based on the PCF may someday hit the market, in which case, network engineers will need to understand the PCF so they can implement it. But most readers can skip this chapter safely.

8.1 Contention-Free Access Using the PCF

If contention-free delivery is required, the PCF may be used. The PCF is an optional part of the 802.11 specification; products are not required to implement it. However, the IEEE designed the PCF so stations that implement only the distributed coordination function (DCF) will interoperate with point coordinators.

Contention-free service is not provided full-time. Periods of contention-free service arbitrated by the point coordinator alternate with the standard DCF-based service. The relative size of the contention-free period can be configured. 802.11 describes the contention-free periods as providing "near isochronous" services because the contention-free periods will not always start at the expected time, as described in Section 8.1.3.

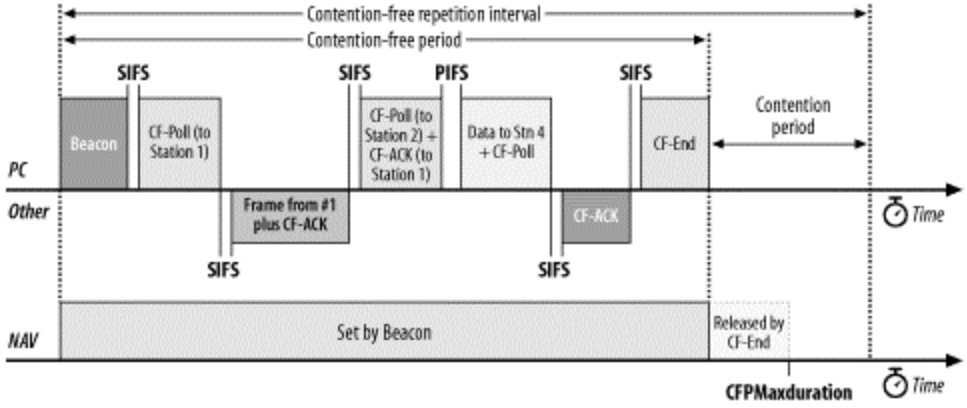
Contention-free service uses a centralized access control method. Access to the medium is restricted by the point coordinator, a specialized function implemented in access points. Associated stations can transmit data only when they are allowed to do so by the point coordinator. In some ways, contention-free access under the PCF resembles token-based networking protocols, with the point coordinator's polling taking the place of a token. Fundamentals of the 802.11 model remain in place, however. Although access is under the control of a central entity, all transmissions must be acknowledged.

8.1.1 PCF Operation

Figure 8-1 shows a transfer using the PCF. When the PCF is used, time on the medium is divided into the contention-free period (CFP) and the contention period. Access to the medium in the former case is controlled by the PCF, while access to the medium in the

latter case is controlled by the DCF and the rules from Chapter 7. The contention period must be long enough for the transfer of at least one maximum-size frame and its associated acknowledgment. Alternating periods of contention-free service and contention-based service repeat at regular intervals, which are called the contention-free repetition interval.

Figure 8-1. Using the PCF



8.1.1.1 Reserving the medium during the contention-free period

At the beginning of the contention-free period, the access point transmits a Beacon frame. One component of the beacon announcement is the maximum duration of the contention-free period, *CFPMaxDuration*. All stations receiving the Beacon set the NAV to the maximum duration to lock out DCF-based access to the wireless medium.

As an additional safeguard to prevent interference, all contention-free transmissions are separated only by the short interframe space and the PCF interframe space. Both are shorter than the DCF interframe space, so no DCF-based stations can gain access to the medium using the DCF.

8.1.1.2 The polling list

After the access point has gained control of the wireless medium, it polls any associated stations on a *polling list* for data transmissions. During the contention-free period, stations may transmit only if the access point solicits the transmission with a polling frame. Contention-free polling frames are often abbreviated CF-Poll. Each CF-Poll is a license to transmit one frame. Multiple frames can be transmitted only if the access point sends multiple poll requests.

The polling list is the list of privileged stations solicited for frames during the contention-free period. Stations get on the polling list when they associate with the access point. The Association Request includes a field that indicates whether the station is capable of responding to polls during the contention-free period.

8.1.2 Transmissions from the Access Point

Generally, all transmissions during the contention-free period are separated by only the short interframe space. To ensure that the point coordinator retains control of the medium, it may send to the next station on its polling list if no response is received after an elapsed PCF interframe space. (Such a situation is illustrated in Figure 8-1.) The access point polled the second station on its list but received no response. After waiting one PCF interframe space, the access point moves to the third station on the list. By using the PCF interframe space, the access point ensures that it retains access to the medium.

The access point may use several different types of frames during the contention-free period. During this period, the point coordinator has four major tasks. In addition to the "normal" tasks of sending buffered frames and acknowledging frames from the stations, the point coordinator can poll stations on the polling list to enable them to send frames; it may also need to transmit management frames.

Time in the contention-free period is precious, so acknowledgments, polling, and data transfer may be combined to improve efficiency. When any subset of these functions are combined into a single frame, the result is a bit strange. A single frame could, for example, acknowledge the receipt of the previous frame, poll a different station for buffered data, and send its own data to the station on the polling list.

Several different frame types can be used in the contention free period:

Data

> The standard vanilla Data frame is used when the access point is sending a frame to a station and does not need to acknowledge a previous transmission. The standard Data frame does not poll the recipient and thus does not allow the recipient to transmit any data in return. The Data-Only frame used in the contention-free period is identical to the Data frame used in contention-based periods.

CF-Ack

> This frame is used by stations to acknowledge the receipt of a frame when no data needs to be transmitted. Contention-free acknowledgments are longer than the standard control frame acknowledgment, so this frame may not be used in actual implementations.

CF-Poll

> CF-Poll frames are sent by the access point to a mobile station to give the mobile station the right to transmit a single buffered frame. It is used when the access point does not have any data for the mobile station. When a frame for the mobile station is available, the access point uses the Data+CF-Poll frame type.

Data+CF-Ack

This frame combines data transmission with an acknowledgment. Data is directed to the frame recipient; the acknowledgment is for the previous frame transmitted and usually is not for the recipient of the data.

Data+CF-Poll

This frame is used by access points to transmit data to a mobile station and request one pending frame from the mobile station. The Data+CF-Poll can only be sent by the access point during the contention-free period.

CF-ACK+CF-Poll

This frame acknowledges the last frame from one of the access point's clients and requests a buffered frame from the next station on the polling list. It is directed to the next station on the polling list, though the acknowledgment may be intended for any mobile station associated with the access point.

Data+CF-ACK+CF-Poll

This frame brings together the data transmission, polling feature, and acknowledgment into one frame for maximum efficiency.

CF-End

This frame ends the contention-free period and returns control of the medium to the contention-based mechanisms of the DCF.

CF-End+CF-Ack

This is the same as the CF-End frame but also acknowledges the previously transmitted Data frame.

Any Management

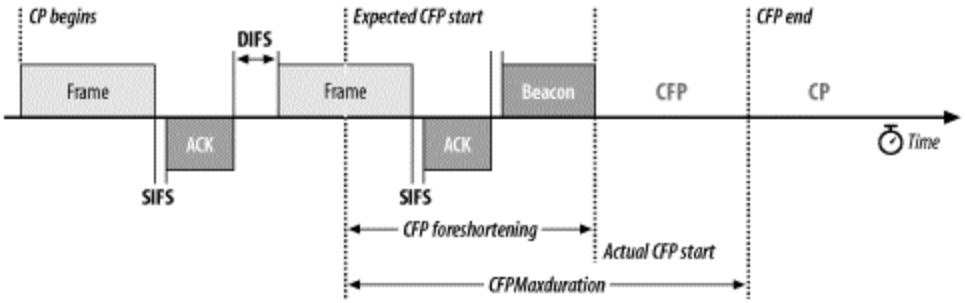
No restriction is placed by the standard on which management frames can be transmitted during the contention-free period. If the rules applying to a particular frame type allow its transmission, the access point may transmit it.

8.1.3 Contention-Free Period Duration

The minimum length of the contention period is the time required to transmit and acknowledge one maximum-size frame. It is possible for contention-based service to overrun the end of the contention period, however. When contention-based service runs

past the expected beginning of the contention-free period, the contention-free period is *foreshortened*,as in Figure 8-2.

Figure 8-2. Data+CF-Ack and Data+CF-Poll usage



When the contention-free period is foreshortened, the existing frame exchange is allowed to complete before the beacon announcing the start of contention-free operation is transmitted. The contention-free period is shortened by the amount of the delay. Contention-free service ends no later than the maximum duration from the expected beginning point, which is referred to as the Target Beacon Transmission Time (TBTT).

The point coordinator may also terminate the contention-free period prior to its maximum duration by transmitting a CF-End frame. It can base this decision on the size of the polling list, the traffic load, or any other factor that the access point considers important.

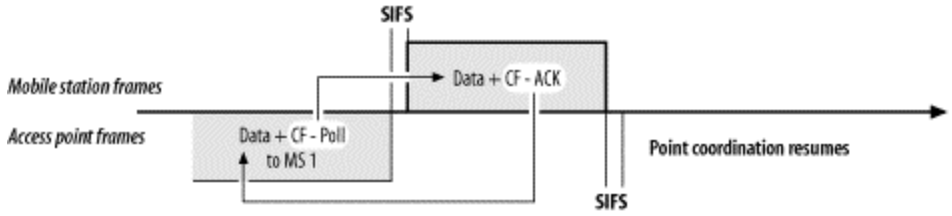
8.2 Detailed PCF Framing

Several frame types are used exclusively within the contention-free period. They combine, in various states, data transmission, acknowledgment, and polling. This section describes when various frames are used and how the different functions interact during frame exchanges.

Data+CF-Ack

The Data+CF-Ack frame combines two different functions for transmission efficiency. Data is transmitted in the frame payload, and the frame implicitly acknowledges the receipt of data received one short interframe space previously. Generally, the data and the acknowledgment are intended for two separate stations. In Figure 8-3, the contention-free acknowledgment is coupled with the data for transmission to the access point in the previous frame, but the data may be intended for any station on the 802.11 network.

Figure 8-3. Data+CF-Ack usage



This frame is used only in infrastructure networks because it is transmitted during the contention-free period. It may be transmitted by either the access point or a mobile station. During the contention-free period, however, the access point is responsible for polling, and it is unlikely that it would transmit this frame subtype because it does not include a poll.

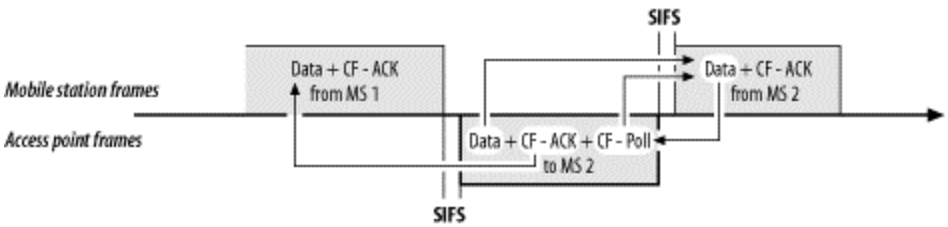
Data+CF-Poll

The Data+CF-Poll frame is used by access points in infrastructure networks during the contention-free period. When the access point does not need to acknowledge any outstanding frames, it sends a Data+CF-Poll to transmit data to the recipient and allows the recipient to send one buffered frame in response. The data in the frame body must be intended for the recipient of the poll; the two operations cannot be "split" across two different receivers. In Figure 8-3, the access point uses a Data+CF-Poll frame to send one frame to the mobile station and to solicit the response.

Data+CF-Ack+CF-Poll

The Data+CF-Ack+CF-Poll frame is used by access points in infrastructure networks during the contention-free period. When the access point has data to transmit, must acknowledge a frame, and needs to poll a station on the polling list, all the functions can be combined into one frame. Figure 8-4 illustrates the usage of Data+CF-Ack+CF-Poll. As with Data+CF-Ack, the components of the Data+CF-Ack+CF-Poll frame are generally intended for different stations. The data transmission and polling must be intended for the same station, but the acknowledgment is for the previous transmission.

Figure 8-4. Usage of Data+CF-Ack+CF-Poll



The figure begins with mobile station 1 (MS1) transmitting a Data+CF-Ack frame. The Data must go to the access point, but the CF-Ack is used to

acknowledge the previous Data frame transmitted by the access point. (That frame is not shown in the figure.) Moving down the polling list, the access point then polls mobile station 2 (MS2). However, the access point must acknowledge the data from MS1, which it does by transmitting a frame with a CF-Ack component. When the access point also has data to transmit, all three features can be combined into one omnibus frame. The Data and CF-Poll components are intended for the recipient of the frame, but the CF-Ack is intended for the transmitter of the *previous* frame. MS1 must listen to the access point frames to note the acknowledgment.

CF-Ack (no data)

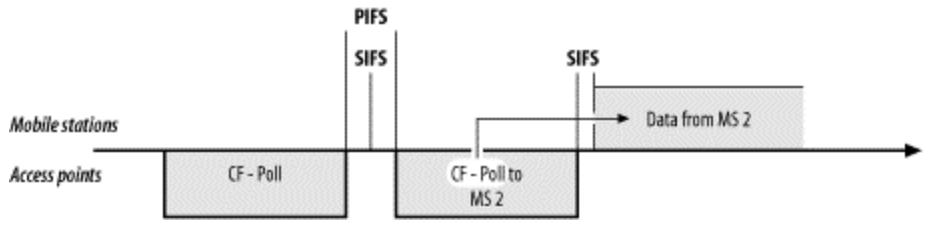
When only an acknowledgment is required, a header-only frame with just the CF-Ack function can be transmitted. In Figure 8-4, if MS2 had no data to transmit, it would have responded with a CF-Ack frame.

CF-Poll (no data)

CF-Poll can also be transmitted by itself. Naturally, only access points perform this function, so the CF-Poll frame is transmitted only by access points in infrastructure networks during the contention-free period.

"Naked" CF-Polls are transmitted when the access point has no buffered data for the recipient and does not need to acknowledge the receipt of previous frames. One common situation in which no acknowledgment is necessary is when the access point transmits a CF-Poll and the polled station has no data and does not respond. If the access point has no data for the next station on the polling list, it transmits a CF-Poll, as in Figure 8-5.

Figure 8-5. CF-Poll framing usage

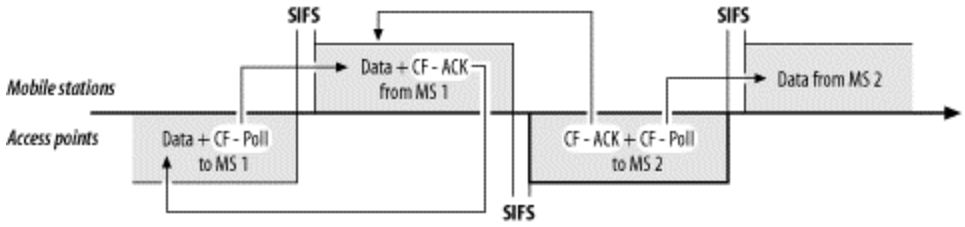


In Figure 8-5, the access point attempts to transmit data to MS1 but does not receive a response. After the PCF interframe space has elapsed, the access point can proceed down the polling list to MS2. No frame from MS1 needs to be acknowledged, and if the access point has no data for MS2, it can use a CF-Poll to allow MS2 to send data.

CF-Ack+CF-Poll (no data)

The final subtype of Data frame is the CF-Ack+CF-Poll, which is also transmitted by access points. Like all CF-Poll frames, it is used only during the contention-free period and only by access points. It incorporates the acknowledgment function and the polling function into a frame with no data. Figure 8-6 illustrates its usage.

Figure 8-6. CF-Ack+CF-Poll usage



The scenario is a slight variation on the previous setting. Instead of a timeout waiting for MS1 to respond, MS1 returns a frame. When the access point takes control of the medium, it uses a CF-Ack+CF-Poll to acknowledge receipt of the frame from MS1 and notifies MS2 that it is allowed to send a frame.

8.2.1 Contention-Free End (CF-End)

When the contention-free period ends, the access point transmits a CF-End frame to release stations from the PCF access rules and begin contention-based service. The format of the CF-End frame is shown in Figure 8-7. Four fields make up the MAC header of the CF-End frame:

Frame Control

The frame subtype is set to 1110 to indicate a CF-End frame.

Duration

CF-End announces the end of the contention-free period and thus does not need to extend the virtual carrier sense. Duration is set to 0. Stations that receive the CF-End frame cut the virtual carrier sense short to resume contention-based access.

Address 1: Receiver Address

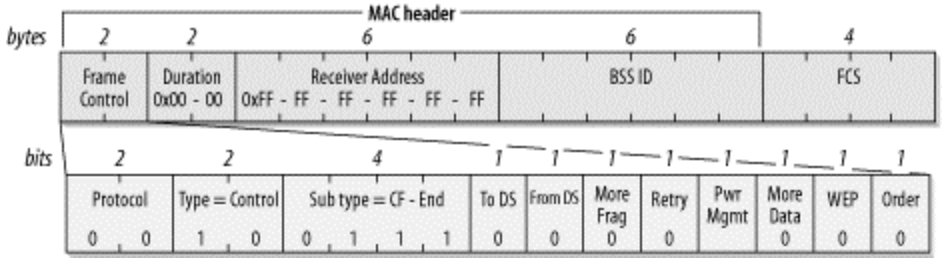
CF-End is relevant to the operation of all mobile stations, so the receiver address is the broadcast address.

Address 2: BSSID

CF-End is announced by the access point to all the stations associated with its BSS, so the second address field is the BSSID. In infrastructure networks, the

BSSID is the address of the wireless interface in the access point, so the BSSID is also the transmitter address.

Figure 8-7. CF-End frame



8.2.2 CF-End+CF-Ack

When the contention-free period ends, the access point transmits a CF-End frame to release stations from the PCF access rules and then begins contention-based service using the DCF. If the access point must also acknowledge receipt of data, it may simultaneously end the contention-free period and acknowledge the previous frame by using the CF-End+CF-Ack frame, which combines both functions. The format of the CF-End+CF-Ack frame is shown in Figure 8-8. Four fields make up the MAC header of the CF-End+CF-Ack frame:

Frame Control

The frame subtype is set to 1111 to indicate a CF-End+CF-Ack frame.

Duration

CF-End+CF-Ack announces the end of the contention-free period and thus does not need to extend the virtual carrier sense. Duration is set to 0.

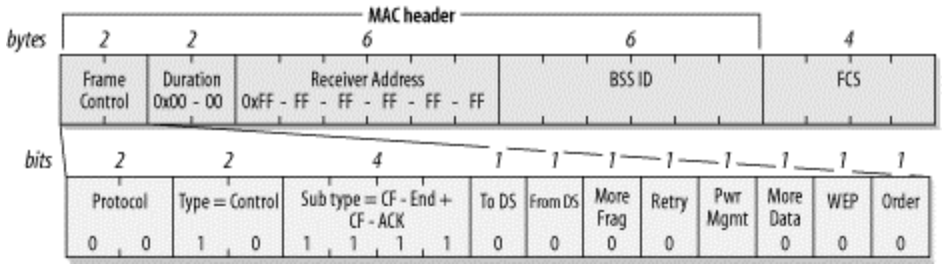
Address 1: Receiver Address

CF-End+CF-Ack is relevant to the operation of all mobile stations, so the receiver address is the broadcast address.

Address 2: BSSID

CF-End+CF-Ack is announced by the access point to all the stations associated with its BSS, so the second address field is the BSSID. In infrastructure networks, the BSSID is the address of the wireless interface in the access point, so the BSSID is also the transmitter address.

Figure 8-8. CF-End+CF-Ack frame



8.2.2.1 CF Parameter Set

Access points that support contention-free operation may include the CF Parameter Set information element, which is shown in Figure 8-9. CF Parameter Set elements are included in Beacon frames to keep all mobile stations apprised of contention-free operations. They are also included in Probe Response frames to allow stations to learn about contention-free options supported by a BSS. Four fields make up the CF Parameter Set information element:

CFP Count

This field, which is one byte in length, tells how many DTIM frames will be transmitted before the start of the next contention-free period. Zero indicates that the current frame is the start of contention-free service.

CFP Period

This one-byte field indicates the number of DTIM intervals between the start of contention-free periods.

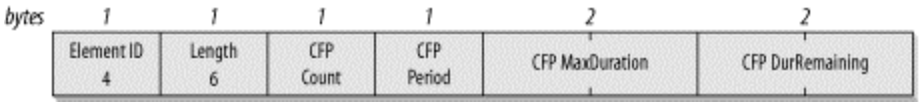
CFP MaxDuration

This value is the maximum duration of the contention-free period as measured in time units (TUs). Mobile stations use this value to set the NAV to busy for the entire contention-free period.

CFP DurRemaining

This value is the number of TUs remaining in the current contention-free period. Mobile stations use it to update the NAV throughout the contention-free period. When DCF-based contention-free service is provided, it is set to 0.

Figure 8-9. CF Parameter Set information element



8.3 Power Management and the PCF

Power conservation during the contention-free period is similar to power conservation during the contention-based period, with a few minor exceptions. The basic distinction between the two is that frame delivery must obey the PCF rules, so buffered frames can be delivered only to CF-Pollable stations. Stations that do not support PCF operations must wait until contention-based service resumes before retrieving buffered frames.

Stations on the polling list are not allowed to sleep during the contention-free period. When the access point is performing its point coordination functions, it may poll any station on the polling list at any time. Frames destined for stations on the polling list do not need to be buffered during the contention-free period because those stations do not sleep.

Frame buffering is identical under contention-free and contention-based service. By maintaining power-saving status for each station, the access point can buffer frames for any station in a low-power mode. Broadcast and multicast frames are buffered whenever an associated station is in a low-power mode.

In addition to the buffer status associated with contention-free service, the access point also sets bits in the TIM for any station it intends to poll. The reason for setting these bits is related to how buffered frames are delivered. Like contention-based service, DTIM frames trigger the transmission of broadcast and multicast frames. If the total time required to transmit multicast and broadcast frames exceeds the Beacon interval, the access point will transmit one Beacon interval's worth of buffered frames and stop. Remaining frames will, however, cause the access point to keep the bit corresponding to AID 0 set.

After transmitting the buffered broadcast and multicast frames, the access point goes through the list of AIDs whose TIM bits are set in increasing order and transmits any pending data. Transmissions are conducted according to the rules of the PCF, so it is not necessary to include a delay before beginning transmission. Stations on the polling list are added to the TIM, so they will be included in this process. Multiple buffered frames can be transmitted, but this is entirely up to the access point implementation—in contention-free service, mobile stations can transmit only when given permission by the access point. A station is not allowed to resume sleeping until all frames have been delivered to it, as indicated by a 0 More Data bit. When a station is cleared to resume sleeping, it sleeps until the next DTIM transmission. DTIM frames signal the beginning of the contention-free period, so all stations that implement the PCF are required to wake up for every DTIM.

If a station switches from a low-power mode to the active mode, any frames buffered for it are transferred to the point coordination function for delivery during the contention-free period. The transfer does not result in immediate delivery, but the access point can place the frames into a queue for transmission as soon as the point coordination function permits.