IEEE P802.11

Wireless Access Method and Physical Layer Specification

PCF State Machine Definition

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Abstract

This submission defines a state machine that implements the Point Coordination Function (PCF) used to provide contention–free asynchronous service within the 802.11 MAC protocol. The PCF state machine is an optional extension of the MAC control state machine already defined in document 93–20b2. This submission also defines the modifications to the existing MAC receive state machine necessary to support operation of the PCF state machine and MAC control state machine necessary to support fully the contention–free asynchronous service.

Classification

Audience: MAC Group.

Type: Provides missing information. The PCF is defined in section 5.3 of document 93–20b2, but the MAC state machines in section 5.7 do not include PCF operations. These state machines implement PCF functionality as specified in the current draft.

Objective: Inclusion of the portions of this document relevant to PCF and CF–Async state machine definition into the Draft Standard.

Note:

This version, 94–207A, has been updated from the original version to reflect the changes to contention–free service resulting from the adoption of the material in document 94–236. This update is restricted solely to changes pertaining to contention–free service, and does not include the general changes to frame formats and frame addressing also contained in document 94–236. All changes in address filtering are expected to be equivalent for both DCF and PCF operation, and for CF_Data frames as well as Asynchronous_Data frames.

1. General Characteristics of the PCF and CF–Async Service

1.1 Introduction

The Point Coordination Function (PCF) of the 802.11 MAC protocol is an optional portion of station or AP functionality that provides contention–free asynchronous data frame delivery service. The optional nature of the PCF means that

- no station nor AP is required to be able to operate as a point coordinator, and
- no station is allowed to demand that contention–free asynchronous service be available in any given BSS.

However,

- all stations must be able to operate correctly while a PCF is active in their BSS, and
- any station may use contention–free asynchronous service while a PCF is active in their BSS.

The way that the PCF is defined in document 93–20b2, any station may serve as the point coordinator, subject to the limit of one point coordinator per BSS (and per BSA in the case of multiple, overlapping BSSes which are operating on the same PHY channel). In practice, there appears to be little benefit to locating the PCF anywhere but at the AP.

1.1 Coexistence of CF–Async and Contention–based Async Services

When a PCF is active in a BSS, all contention–free traffic is sent by, or sent in response to, contention–free frames sent by the PCF. In addition to conveying data, and acknowledgment to previous data, the contention–free frames sent by the PCF implicitly poll the recipient station, permitting a single CF_Data or CF_Data+Ack frame to be sent. (This polling became implicit with the elimination of the "CF–Poll" frame control bit in the adoption of document 94–236.)

- A station that is capable of sending CF_Data and CF_Data+Ack frames in response to a CF–frame received from the PCF is termed *CF–capable*. A station that serves as the point coordinator must be CF–capable, but not all CF–capable stations need to be able to serve as the point coordinator.
- Only CF–capable stations <u>generate</u> CF_Data and CF_Data+Ack frames. However, all stations may <u>receive</u> these frames. Non–CF–capable stations treat the reception of either of these types of frames as if they were asynchronous Data frames, and acknowledge receipt of such frames by transmitting an ACK frame. (The non–CF–capable station will never transmit a data frame during the contention–free period, so that station's inability to detect the piggybacked acknowledgment in a subsequent CF_Data+Ack frame is irrelevant.)
- This allows the PCF to send any outbound data frames in either the contention period or the contention–free period, without having to consider whether the addressee is CF–capable.

- Document 93–190 contained an example that illustrated the possibility of performing contention–free station–to–station transfers. While the opinion of this author is that such station–to–station transfers do not need to be provided in the standard, a minor modification to the state machines presented herein would permit such transfers to be supported.

1.2 Participation in Communication During the Contention–free Period

The existence of CF–capable stations is made known to the PCF as part of the association and reassociation process. The PCF maintains a "polling list" that includes zero or more of the associated CF–capable stations. There shall be a mechanism, through the use of an appropriate management frame, for a CF–capable station to be explicitly added to or removed from the polling list. There may also be implicit mechanisms by which a particular PCF adds and/or removes CF–capable stations to/from the polling list. The details of such mechanisms (including the activity–based additions to the polling list and inactivity–based deletions from the polling list used as examples in document 93–190 and present in document 93–20b2) do not need to be specified in the standard, because they may be implemented in arbitrary manners without impacting fundamental interoperability of the compliant equipment.

The "polling list" is a logical construct that defines the subset of CF–capable stations with which the PCF may communicate during the contention–free periods of the Superframes. A round–robin traversal of the polling list, which may require multiple Superframes under certain traffic conditions and Superframe durations, is the recommended technique. However, any method that provides non–preferential access to all stations on the polling list is allowable without affecting fundamental interoperability.

Document 93–20b2 specifies that polling of a station on the polling list for which the PCF has no directed data frame, as well as acknowledgment by a polled station that has no transmission pending, shall take place using CF_Data and CF_Data+Ack frames with a payload length of zero. The state machines defined herein use this mechanism. However, the author of this document strongly recommends that a control frame be defined for this purpose. The principal reason to define such a control frame is that receipt of any "data" frame implies the transfer of an MSDU, for which LLC needs to be informed. The use of a zero–length "data" frame for intra–MAC control purposes requires the handling of a special case wherein the "data" frame does not convey an MSDU. If such a control frame is adopted, these state transitions do not change, other than to substitute the control frame wherever a frame with "CF_lng = 0" would have been generated.

1.3 Managed Objects Relevant to Contention–free Service

The length of the Superframe shall be an SMT managed object (GET–REPLACE) at each PCF. The active Superframe length, as well as the timing of the start of the Superframe, must be disseminated within each BSS that has an active PCF. This is most easily accomplished using fixed fields or elements in Beacon frames.

The CF–capability and PCF–capability shall be MAC managed objects (GET) at each station.

In order to minimize the amount of the contention–free period wasted on retransmissions, a CF_retry_max MAC managed object (GET–REPLACE), separate from the Retry_max managed object used for asynchronous data retries, is recommended. However, the PCF will be able to function using the single Retry_max as currently specified.

The maximum duration of the contention–free period (CF_limit) is a calculated value, equal to the Superframe duration minus twice the maximum MSDU duration. Note that the last transmission of a CF_Data or CF_Data+Ack frame by the PCF must end at least one maximum MSDU duration before the CF_limit, because the addressed recipient might respond by sending a maximum–length MSDU in a CF_Data+Ack frame.

2. Modifications to the Receive State Machine

To accommodate contention–free asynchronous data frames, and to support the structure of the contention–free burst, the receive state machine requires two new state transitions, and modifications to two other state transitions, but no new states. The new transitions handle the recognition of CF_Data and CF_Data+Ack frames, setting the appropriate flags to permit these frames to be handled in an equivalent manner to Data and ACK frames. The principal modification prevents the detection of an ACK frame during the contention–free period (as might occur when a non–CF–capable station acknowledges the receipt of a CF_Data frame) from resetting the NAV. The other modification involves the name change from "CFACK" to "CFEND" adopted in document 94–236.

Figure 1 is a copy of the receive state machine diagram from document 93–20b2, with the necessary modifications. The new state transitions are marked with large black arrows in the right margin, while the modified transitions are marked with gray arrows. The remainder of the receive state machine is unchanged. The notes below apply to the added and modified portions of the diagram.

R14a, Received_Data: When the frame is valid and the frame type is Data, this transition shall be taken. Rx_flag shall be set. Original ID shall be set to MPDU ID (shown in 20b2 diagram, but not in 20b2 text).

R14b, Received_Unitdata: When the frame is valid and the frame type is Unitdata, this transition shall be taken. Original_ID shall be set to MPDU_ID.. Rx_flag shall be set. (This transition is described in the 20b2 text, but is not in the diagram and describes a frame type that is not on the current list of valid types, so I presume the continued presence of this text in 20b2 is an editorial oversight.)

[NEW] R14b, Received_CF_Data: When the frame is valid and the frame type is CF_Data, this transition shall be taken. Rx_flag shall be set, and Original_ID shall be set to MPDU_ID. If the station is CF–capable, the CF_flag shall be set. This setting of the CF_flag must occur prior to address validation because the control state machine, at CF–capable stations, must know of the receipt of CF frames independently of whether those frames are addressed to this station.

[NEW] **R14c, Received_CF_Data+Ack:** When the frame is valid and the frame type is CF_Data+Ack, this transition shall be taken. Rx_flag shall be set, and Original_ID shall be set to MPDU_ID. If the station is CF–capable, the CF_flag and ACK_flag shall be set. This setting of the CF_flag and ACK_flag must occur prior to address validation because the acknowledgment may apply to a frame sent by this station when the addressee of the subsequent CF_Data+Ack frame is the next station on the PCF's polling list.

R50a, Other_ACK: This transition shall be taken when the ACK receipt actions are complete and the MPDU_ID is not equal to the Original_ID. The ACK_flag shall be reset. The NAV shall be updated to indicate that the network is now free unless CFP=1 to indicate that the contention–free period is in progress, in which case the NAV is not modified.

State R6, CFEND Received: This state shall be entered when a valid CFEND frame is received.

R60, CFEND_complete: This transition shall be taken when the CFEND receipt actions are complete. The NAV shall be reset, which results in the occurrence of state transition C00f by the control state machine, to indicate the end of the contention–free period. The CFEND_flag shall be set.

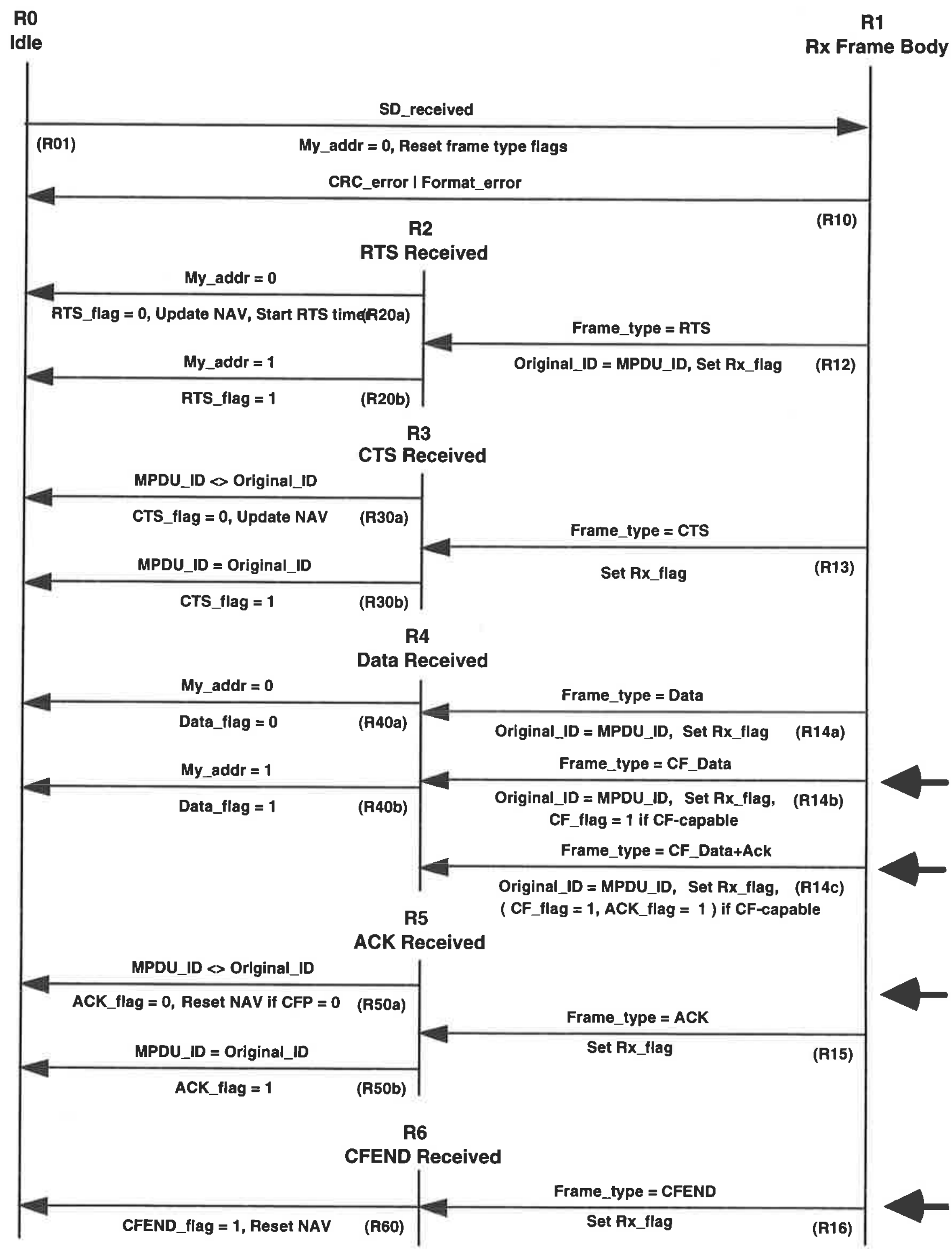

Figure 1: Modified Receive State Machine

3. Modifications to the Control State Machine

To coexist properly with contention–free periods generated by PCFs operating at other stations, and to handle data frame reception during the contention–free period as handled by the modified receive state machine, the control state machine requires two new state transitions, and modifications to two other state transitions, but no new states. The new states set the NAV to protect the contention–free period

Figure 2 is a copy of the control state machine diagram from document 93–20b2, with the necessary modifications. The new state transitions are marked with large black arrows to their right, while the modified transition is marked with a gray arrow. The remainder of the control state machine is unchanged. The notes below apply to the added and modified portions of the diagram. These modifications are needed at all stations, whether or not they are CF–capable. These modifications assume the existence of a new timer that shall be set to the Superframe duration and synchronized to indicate the expected starting time of each Superframe.

[NEW] C00e, Start_CF_period: This transition shall be taken when the Superframe timer indicates the expected start of the next Superframe and this station is not providing the PCF for the BSS. (The "!PCF" condition is true both for stations that are not capable of providing the PCF, as well as those that are capable of providing the PCF but are not presently doing so.) The NAV shall be set to the maximum contention–free period length, and the flag CFP shall be set =1 to indicate that the contention–free period is (expected to be) in progress.

[NEW] C00f, End_CF_period: This transition shall be taken when the NAV has counted to zero (or been reset) while the contention–free period is (expected to be) in progress, as indicated by CFP = 1. CFP shall be cleared to =0 to indicate the end of the contention–free period.

C06, Send_ACK: This transition shall be taken when a valid <u>asynchronous</u> data frame adddressed to this station, <u>or CF Data or CF Data+Ack frame addressed to this station (at a non–CF–capable station)</u>, is received.

C60, ACK_complete: This transition shall be taken when the transmission of the ACK frame is complete. The NAV shall be reset <u>if the contention–free period is not in progress, indicated by CFP = 0</u>.

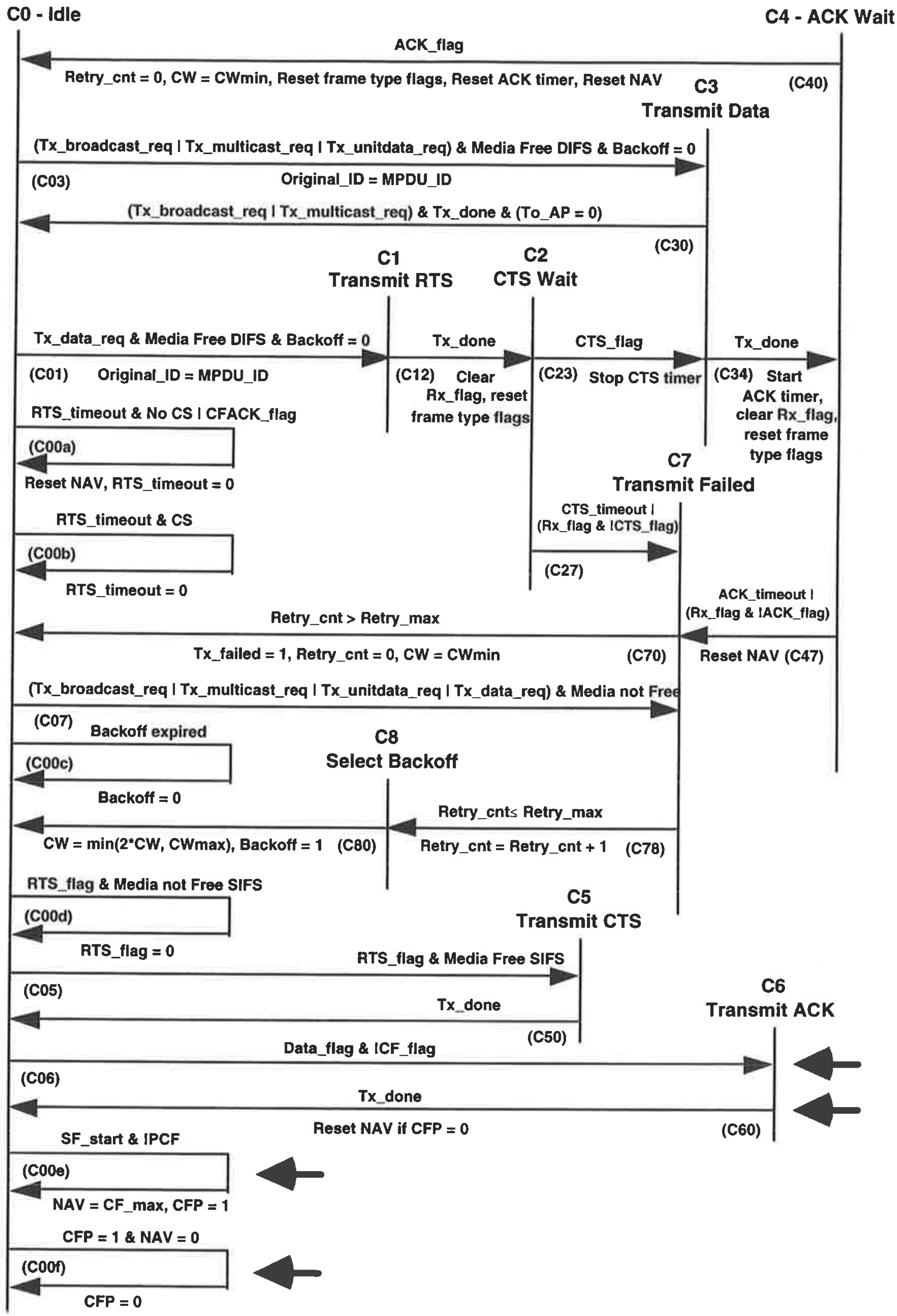

Figure 2: Modified Control State Machine

5. Control State Machine Extensions to Provide CF–Async Service

At CF–capable stations, the control state machine is extended to properly support contention–free transfers. These extensions are illustrated in Figure 3, and consist of two, disjoint groups of states, both of which are loops originating and terminating at the "Idle" state C0 of the control state machine. These states are designated "CFn" rather than "Cn" as in the main portion of the control state machine, to identify them as being exclusively applicable to the optional support for contention–free service.

- States CF1 – CF5 define the PCF operation, and are required only at stations capable of operating as the point coordinator.
- States CF6 – CF7 define the operation of CF–capable stations in response to CF_Data and CF_Data+Ack frames received from the PCF, and are required at all CF–capable stations.

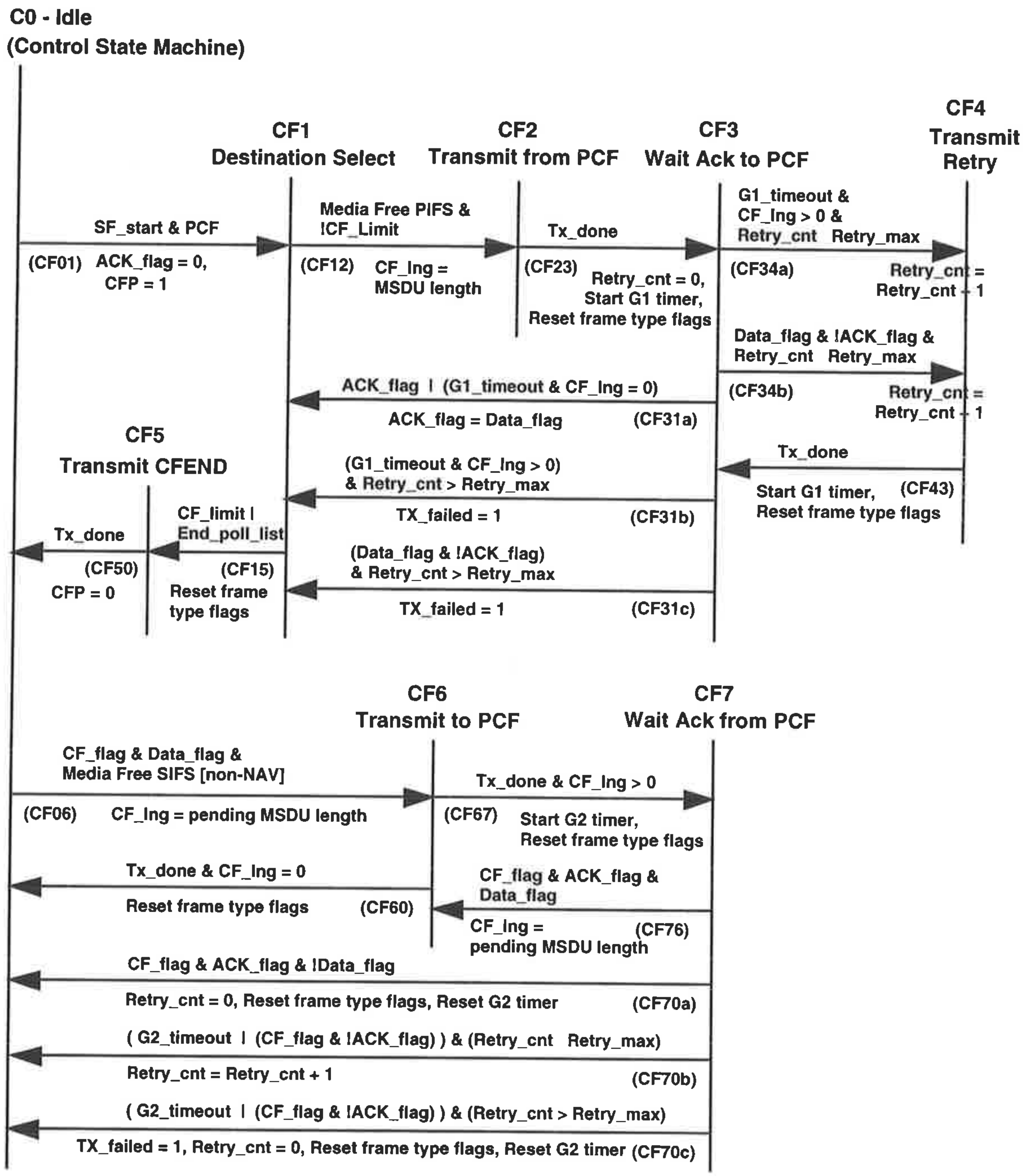

Figure 3: CF–Async Control State Machine Extensions

5.1 Notes to the CF–Async Control State Machine Extensions for PCF operation

CF01, Start_PCF_period: This transition shall be taken when the Superframe timer indicates the expected start of the next Superframe and this station is providing the PCF for the BSS. The ACK_flag shall be cleared so that the initial contention–free transmission will be a CF_Data frame and CFP shall be set =1 to indicate to the receive state machine that the contention–free period is in progress.

State CF1, Destination_select: Upon entry to this state the PCF selects the destination of the next CF–Async transmission from the polling list (generally the next station address on the polling list) and identifies the next directed MSDU awaiting transmission to that destination. If there is no MSDU awaiting transmission to the selected station, the MSDU length shall be set to zero.

CF12, Start_CF_transmission: This transition shall be taken when the next destination has been selected while sufficient time remains in the contention–free period and the medium has been free for the PIFS duration. The CF_lng indicator shall be set to the selected MSDU length, which may be zero if the pending transmission is exclusively for polling and/or acknowledgment.

CF15, End_PCF_period: This transition shall be taken when the entire polling list has been processed or when the transmission for the next selected destination from the polling list would begin after the CF_limit. The frame type flags (which includes the CF_flag) shall be reset.

State CF2, Transmit_from_PCF: In this state, if ACK_flag = 0 a CF_Data frame is formed, whereas if ACK_flag = 1 a CF_Data+Ack frame is formed. Once either type of frame is formed, the Tx_request shall be set.

CF23, Transmit_from_PCF_complete: This transition shall be taken when the transmission of the contention–free frame by the PCF is complete. The Retry_cnt and the frame type flags shall be reset, and a timer shall be started for the G1 (SIFS) interval.

State CF3, Wait_Ack_to_PCF: In this state the PCF is waiting for acknowledgment to its last transmitted contention–free data frame. This acknowledgment is required if the MSDU length of the transmission was >0, and this acknowledgment is permissible even if the MSDU length of the transmission was =0.

CF 31a, Ack_to_PCF_received: This transition shall be taken when an acknowledgment (either an ACK frame from a non–CF–capable station or a CF_Data+Ack frame) is received prior to the G1 timeout, or when a G1 timeout occurs after transmission of a frame with CF_lng = 0 (for which acknowledgment is not mandatory). The ACK_flag shall be set to the value of the Data_flag so that the data portion of a CF_Data+Ack frame sent to the PCF will be acknowledged in the subsequent transmission from the PCF.

CF31b, Tx_failure_without_response: This transition shall be taken when a G1 timeout occurs following transmission of a frame with CF_lng > 0, and the retry count has been exhausted. Tx_failed shall be set.

CF31c, Tx_failure_with_response: This transition shall be taken when a CF_Data frame is received when an acknowledgment is pending (CF_Data+Ack expected), and the retry count has been exhausted. Tx_failed shall be set.

CF34a, No_response: This transition shall be taken when a G1 timeout occurs following transmission of a frame with CF_lng > 0, and the retry count has not been exhausted. The Retry_cnt shall be incremented.

CF34b, Response_without_Ack: This transition shall be taken when a CF_Data frame is received when an acknowledgment is pending (CF_Data+Ack expected), and the retry count has not been exhausted. The Retry_cnt shall be incremented.

State CF4, Transmit_Retry: In this state the previous CF_Data or CF_Data+Ack frame shall be updated with the Retry FC–bit set =1. Tx_request shall be set after a PIFS interval since the end of the last frame (either transmission by this station in the case of non–response or reception of a non–acknowledgment frame by this station).

CF43, Transmit_retry_complete: This transition shall be taken when the transmission of the contention–free retry frame by the PCF is complete. The frame type flags shall be reset, and a timer shall be started for the G1 (SIFS) interval.

State CF5, Transmit_CFEND: In this state a CFEND frame shall be generated and Tx_request shall be set.
NOTE: It may be necessary to add a CFEND+Ack frame type, to be sent if this state is entered with ACK_flag = 1. This appears to be needed because, with the elimination of the "CF–Poll" FC–bit in document 94–236 there is no mechanism by which the PCF can acknowledge a received frame other than by sending a CF_Data+Ack frame, which implicitly permits the recipient to respond with another contention–free data frame. Accordingly, if the ACK_flag is set at when the CF_limit is reached, there does not seem to be a means to send the pending acknowledgment without the risk of excessive extension of the contention–free period.

CF50, CFEND_complete: This transition shall be taken when the transmission of the CFEND frame is complete. The end of the contention–free period shall be indicated by clearing CFP.

5.2 Notes to the CF–Async Control State Machine Extensions for Station Operation

CF06, Respond_to_CF_reception: This transition shall be taken when a CF_Data or CF_Data+Ack frame is received by this (CF–capable) station and the medium has been free, as measured by the local PHY's CCA function, for an SIFS duration. The NAV is not considered in this sensing of the medium because the NAV setting reflects the entire contention–free period at times when this transition is expected to occur. If a Tx_data_request is set at this station, CF_lng shall be set to the length of the MSDU awaiting transmission, whereas if Tx_data_request is reset, CF_lng shall be set to zero.

State CF6, Transmit_to_PCF: In this state, if ACK_flag = 0 a CF_Data frame is formed, whereas if ACK_flag = 1 a CF_Data+Ack frame is formed. This frame shall contain the MSDU awaiting transmission if Tx_request is set, or shall contain a zero–length MSDU if Tx_request is clear. Once either type of frame is formed, the Tx_request shall be set.

CF60, Response_complete: This transition shall be taken when the transmission of a contention–free frame, containing a zero–length MSDU, is complete. Since this transmission serves a control function, no acknowledgment is expected, so a direct return is made to Idle state. The frame type flags shall be reset.

CF67, Transmit_to_PCF_complete: This transition shall be taken when the transmission of a contention–free frame, containing a non–null MSDU, is complete. The frame type flags shall be reset, and a timer shall be started for the G2 (PIFS) interval.

State CF7, Wait_ACK_from_PCF: In this state the station is waiting for acknowledgment to its last transmitted contention–free data frame (with MSDU length >0).

CF70a, Ack_from_PCF_received: This transition shall be taken when a CF_Data+Ack frame addressed to a different station (hence ACK_flag set and Data_flag reset) is received prior to the G2 timeout. The Retry_cnt, G2 timer, and frame type flags shall be reset.

CF70b, Transmit_to_PCF_retry: This transition shall be taken when a G2 timeout occurs or a CF_Data frame is received when an acknowledgment is pending (CF_Data+Ack expected), and the retry count has not been exhausted. The Retry_cnt shall be incremented. The return to Idle state with this transmission still pending and the frame type flags remaining set permits immediate retry, via transition CF06, if the CF_Data frame was addressed to this station (Data_flag set). Otherwise, the next retry can be attempted either during the contention period or pursuant to the next contention–free poll of this station (which will probably be in the contention–free period of the next Superframe).

CF70c, Transmit_to_PCF_failure: This transition shall be taken when a G2 timeout occurs or when a CF_Data frame is received when an acknowledgment is pending (CF_Data+Ack expected), and the retry count has been exhausted. Tx_failed shall be set, and the Retry_cnt, G2 timer, and frame type flags shall be reset.

CF76, Data+Ack_from_PCF_received: This transition shall be taken when a CF_Data+Ack frame addressed to this station (hence both ACK_flag and Data_flag set) is received prior to the G2 timeout. If a Tx_data_request is set (for another pending transmission) at this station, CF_lng shall be set to the length of the MSDU awaiting transmission, whereas if Tx_data_request is reset, CF_lng shall be set to zero.