IEEE P802.11

Wireless Access Method and Physical Layer Specification

Updated MAC State Machines

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Abstract

This submission contains a replacement for section 6.7 (MAC state machines) of the D1.2 draft standard. The current section (formerly 5.8) is sufficiently out of date that only complete replacement is appropriate to bring the state machines to a level which matches the remainder of the document. This submission is an attempt to create state machines which properly describe the MAC, not to redefine MAC operation. The author of this submission requests that reviewers inform him directly about errors, omissions, and ambiguities in this set of state machines. If these state machines are adopted for inclusion in the draft, the author of this submission volunteers to work with the editors to correct these state machines and update them to match other changes to the draft. NOTE: In some cases the information needed for or yielded from certain state transitions exposes under– or over–defined aspects of the text of other sections of the draft. This document makes no attempt to supply or change such text. Also, the creation of these state machines began with the D1 draft, and there may be places where update to D1.2 is incomplete — still these state machines are believed to be much superior to those in the D1 through D1.2 drafts, and a much better starting point for further corrections and improvements.

Desired Outcome

Adoption of the remainder of this document as a replacement for section 6.7 of the D1.2 draft.

6.7. MAC State Machines

MAC operation is described by 7 state machines, each of which operates concurrently. The functions of these state machines are summarized below and detailed in subsequent sections. The relationship of and communication among these state machiens is depicted in figure 6–xx(1).

1. The **MAC Data Service (MD) state machine** provides the MAC data service interface to the LLC sublayer.

2. The **MAC Management Service (MM) state machine** provides the MAC management service interface ot the adjacent sublayer management entity and station management entity.

3. The **Distribution Serivces (DS) state machine** operates only at access points, and provides distribution services and interfaces with the distribution system (if any).

4. The **MAC Control (C) state machine** provides the distributed coordination function and (optionally) the point coordination function for transfer of frames over the wireless medium provided by the PHY layer.

5. The **MAC Management (M) state machine** provides the MAC management functions of the station, including time synchronization, power mangement, and maintenance of the MAC management information base.

6. The **Transmitter (T) state machine** handles transfer of frames to the PHY layer for transmission on the wireless medium.

7. The **Receiver (R) state machine** handles reception and validation of frames received by the PHY layer from the wireless medium.

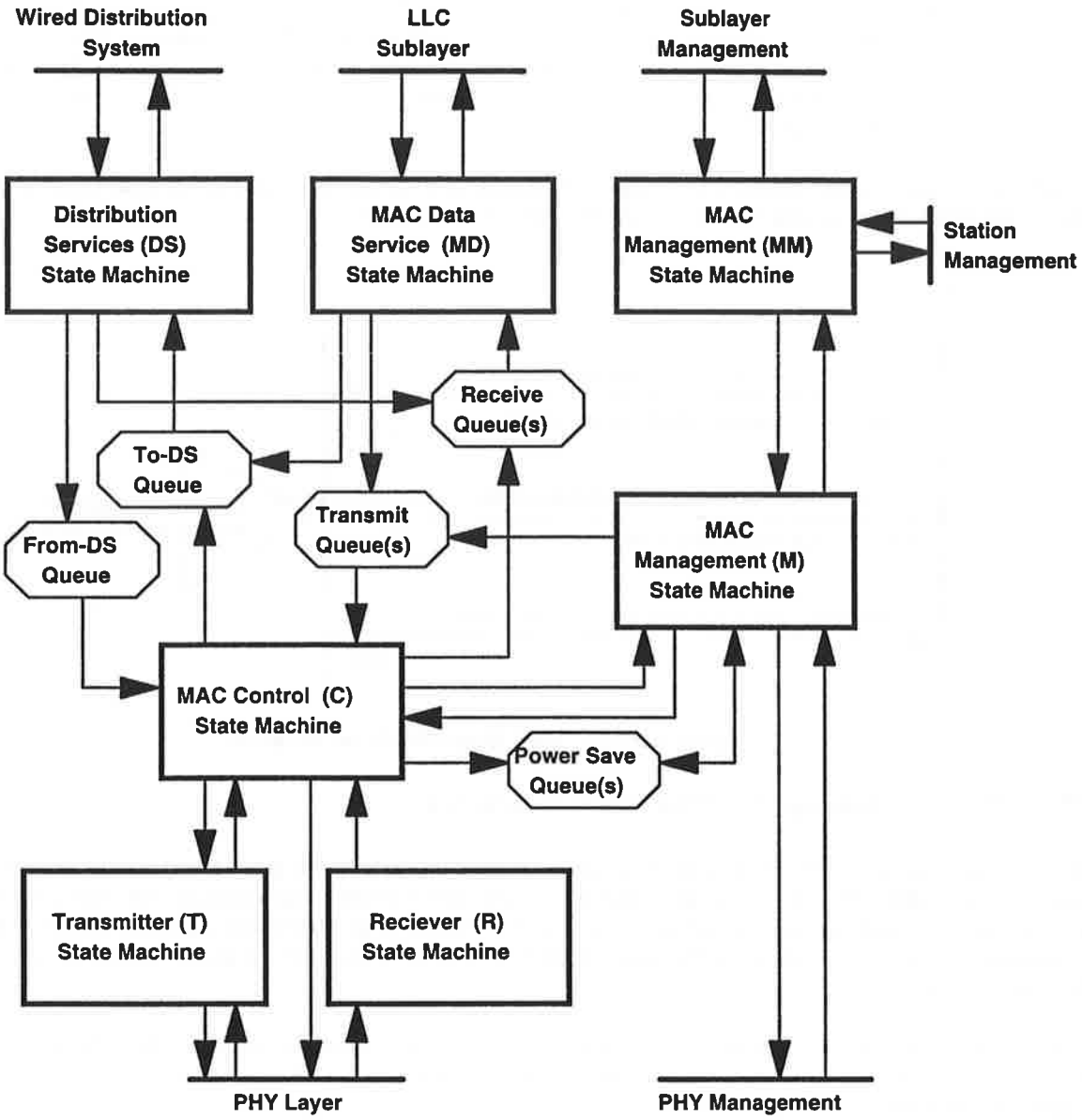


Figure 6-xx(1): MAC State Machine Overview.

6.7.1. Graphical Representation of State Machines

States are indicated by vertical bars that are labeled above the bar. The state labels are a descriptive title and a state number. Each state number has a prefix letter to identify the state machine. This is illustrated in figure 6-xx(2).

Transitions are indicated by horizontal bars that terminate in an arrowhead. A loop transition that returns to the state it leaves includes a vertical section as part of the transition bar. The conditions that must be met in order to make a given transition are listed above the transition bar. The actions that are taken when a particular transition is made are listed below the transition bar. Transitions are labelled with a string enclosed in brackets. This string includes the that

identifies the state machine, and two numbers, separated by a colon. These numbers are the state numbers of the originating state and the terminating state of the transition. For example, "[C0:1]" is the transition from state C0 to state C1 in the control state machine. If there is more than one transition between the same two states, a letter is appended to each of the transition labels to render each label unique. For example, "[R2:0a]" and "[R2:0b]" are two unique transitions from state R2 to state R0.

In addition to actions taken on transitions, actions may also be taken as part of a state. If this is the case, the actions to be taken in the state are specified in the notes on the particular state machine.

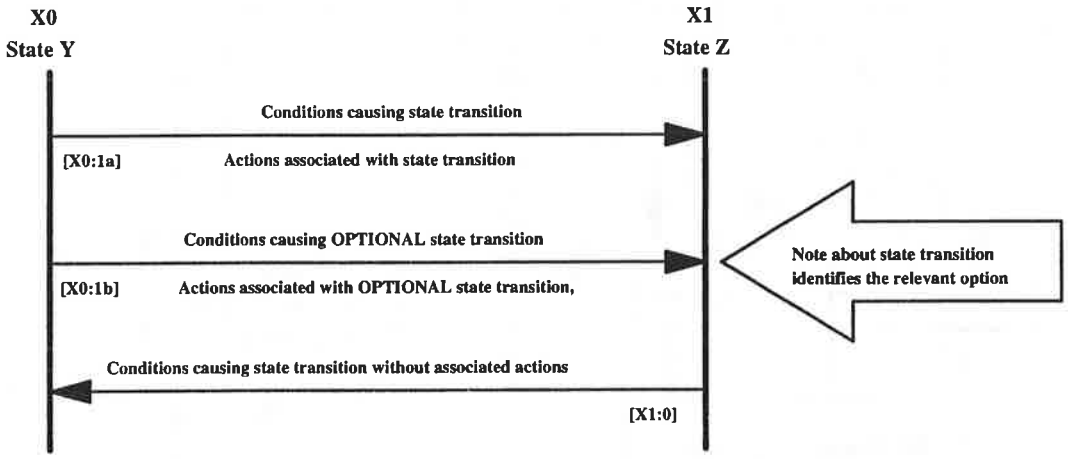


Figure 6-xx(2): MAC State Machine Notation

6.7.2. General Note on the MAC State Machines

All control functions of a given type, applied to a given counter, flag, or variable are in a single state machine. Either all updates to the counter, flag, or variable take place in the same state machine or all assertions (set, start, etc.) take place in one state machine, while all negations (clear, reset, stop, etc.) take place in another state machine. Many of these entities, including most counters, queues, and MIB elements, are treated as global variables, and may be read or tested in any of the state machines.

All actions of a given type (e.g. update the NAV) are either associated with states, and specified in the notes for the relevant states; or are associated with state transitions, and are specified below the state transition arrow for the relevant transitions, but not both.

All timed activities are based on counters which trigger or enable state transitions, rather than being implicit side effects of the time interval expiring.

6.7.2.1. Operational Assumptions

All state machines operate continuously and simultaneously.

At initialization of a MAC sublayer entity, each of the state machines starts in state 0.

All state transitions require zero time.

Counters with specified limit values continue counting from zero on the clock cycle after reaching their limit values.

6.7.2.2. Notation Conventions

Local variable names begin with the letters designating the state machine to which the variable is local.

Counter names begin with T_ and the associated limit variable (if any) begin with L_. Counter control operations are Start( ), which starts the counter from its current value; Stop( ), which stops the counter at its current value; Reset( ), which stops the counter and sets the counter value =0; Restart( ), which sets the counter value =0 and starts the counter; and Timeout( ), which has a value of true (=1) if the counter has reached its limit value since the last such test and a value of false (=0) otherwise.

Flag names begin with F_ and flags may be either true (=1) or false (=0). Flag operations are Set( ), which sets the flag value to true (=1); and Clear( ), which sets the value value to false (=0).

Operators are "&" for and; "|" for or; "!" for not; "=" for equality comparison; and ":=" for assignment.

Functions include CRC(accumulator, value) which updates the value of the 4–octet variable in the first argument, using the CRC–32 polynomial and the 1–octet value in the second argument.

Numeric constants are in decimal unless preceded by "0b" to designate binary or "0h" to designate hexadecimal.

6.7.3. MAC Data Service (MD) State Machine Definition

Figure 6-xx(3): MAC Data Service State Machine

6.7.3.1. Notes to the MAC Data Service State Machine

6.7.4. MAC Management Service (MM) State Machine Definition

<< to be supplied when further definition is available on the MAC management service interface >>

<< placeholder for diagram >>

Figure 6-xx(4): MAC Management Service State Machine

6.7.4.1. Notes to the MAC Data Management Service State Machine

<< to be supplied when further definition is available on the MAC management service interface >>

6.7.5. Distribution Services (DS) State Machine Definition

Figure 6-xx(5): Distribution Services State Machine

6.7.5.1. Notes to the Distribution Services State Machine

6.7.6. MAC Control (C) State Machine Definition

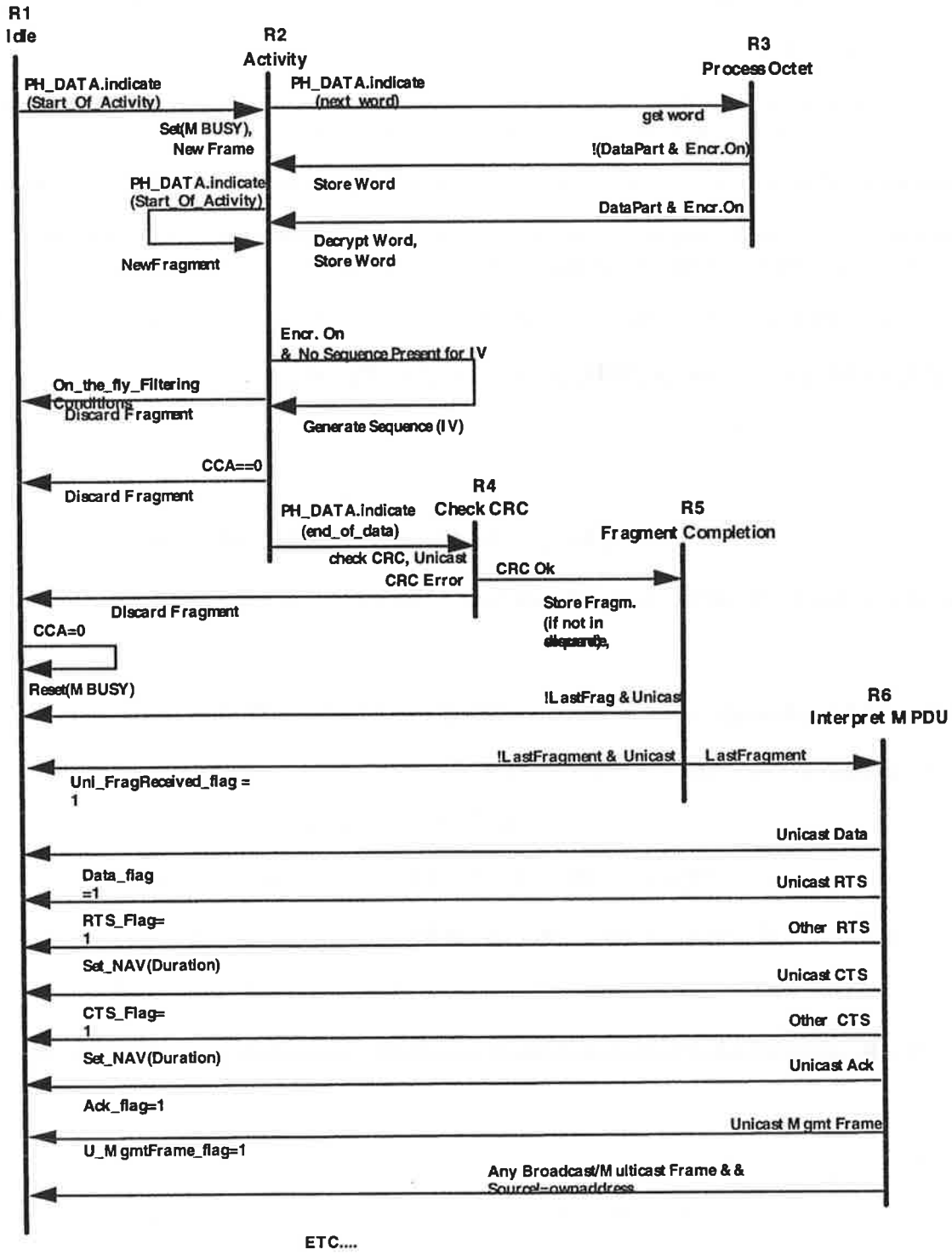


Figure 6-xx(6): MAC Control State Machine

6.7.6.1. Notes to the MAC Control State Machine

State C0, Idle: The control state machine shall enter this state upon initialization and after any of the following conditions: receipt of ACK after a successful transmission, exceeding the maximum retry count during transmission, after a backoff interval has been computed, after transmitting a CTS and after transmitting an ACK. In this state, the backoff interval shall be counted down while the media is free. While in a backoff interval, transmit requests shall be postponed.
C00a, No_Data: This transition shall be taken when the RTS timer expires due to not receiving a data frame that corresponds to the RTS frame or due to the receipt of a CFACK frame signalling the end of a contention-free period. The NAV shall be reset and the RTS_timeout shall be reset.
C00b, RTS_timeout_and_busy: This transition shall be taken when the RTS timer expires and the PHY indicates activity on the medium. The RTS timeout condition shall be reset.
C00c, Backoff_done: This transition shall be taken when the backoff interval expires. The Backoff flag shall be reset.
C00d, Can't_respond_to_RTS: This transition shall be taken when a valid RTS frame addressed to this station has been received and a response is not possible because the media is not free.
C01, Start_transmit_handshake: This transition shall be taken when the MAC is requested to transmit with the full RTS, CTS handshake, the MAC is not in a backoff interval and the media is free for longer than DIFS.
C03, Start_transmit_unitdata: This transition shall be taken when the MAC is requested to transmit a unitdata frame, a multicast frame or a broadcast frame, the media is free longer than DIFS and the MAC is not in a backoff interval.
C05, Send_CTS: This transition shall be taken when a valid RTS frame addressed to this station is received and the media is free longer than SIFS.
C06, Send_ACK: This transition shall be taken when a valid data frame addressed to this station is received.
C07, Media_busy: This transition shall be taken when a transmit data request is received and the media is busy.

State C1, Transmit RTS: In this state , a valid RTS frame addressed to the destination shall be formed and passed to the Transmit state machine. The Tx_req shall be set.
C12, Wait_for_CTS: This transition shall be taken when the transmission of the RTS frame is complete. The Rx_flag and frame type flags shall be reset.

State C2, CTS Wait: This state shall be entered after an RTS frame has been transmitted. The CTS timeout timer shall be initialized and started.
C23, Send_data: This transition shall be taken when a valid CTS frame that matched the MPDUID of the previously transmitted RTS has been received. The CTS timer and CTS_timeout shall be reset.
C27, No_CTS: This transition shall be taken when the CTS timer expires or the Rx_flag is set and the frame type is not CTS_frame.

State C3, Transmit Data: In this state, the MAC data frame shall be formed and the Tx_request shall be set.
C30, Multicast_sent: This transition shall be taken when the transmission of a broadcast or multicast frame is complete and the frame is not to be forwarded by an access point.
C34, Wait_for_ACK: This transition shall be taken when the transmission of the data frame is complete and the frame was not a multicast or broadcast frame sent to an AP. The ACK timer shall be initialized and started. The Rx_flag and frame type flags shall be reset.

State C4, ACK Wait: This state shall be entered while waiting for an ACK response to a transmitted data frame.
C40, End_transmit_handshake: This transition shall be taken when a valid ACK frame that matches the MPDUID of the previously transmitted RTS has been received. Retry_cnt and the frame type flags shall be reset and CW set to CWmin. The ACK timer shall be reset. The NAV shall be reset.
C47, No_ACK: This transition shall be taken when the ACK timer expires or the Rx_flag is set and the frame type is not ACK_frame. The NAV shall be reset.

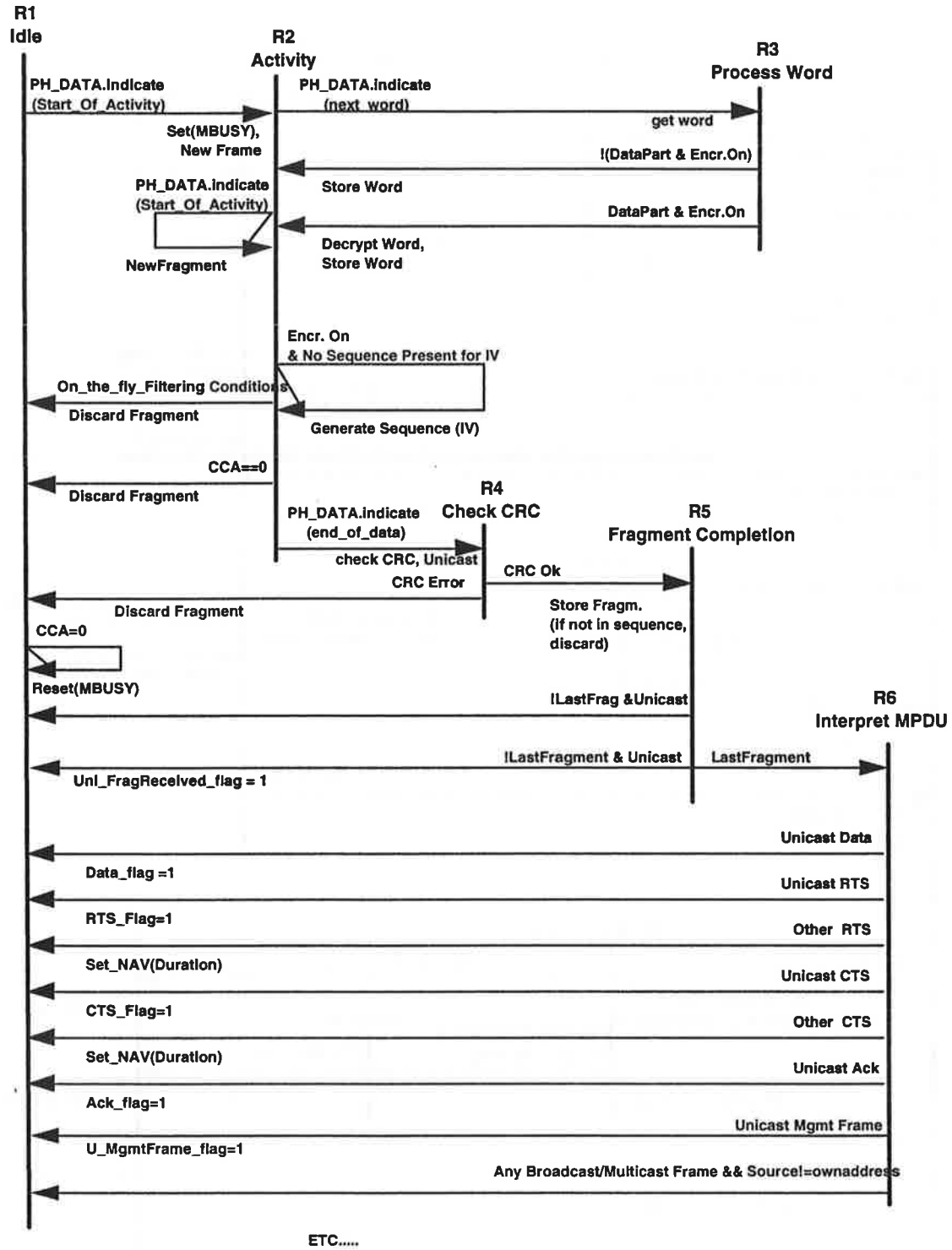
State C5, Transmit CTS: In this state, the control state machine shall respond to an RTS frame directed to this station. A CTS frame shall be formed and passed to the Transmit state machine. The Tx_req shall be set.
C50, CTS_complete: This transition shall be taken when the CTS frame has been transmitted.

State C6, Transmit ACK: In this state, the control state machine shall respond to the successful receipt of a data frame. An ACK frame shall be formed and passed to the Transmit state machine. The Tx_req shall be set.
C60, ACK_complete: This transition shall be taken when the transmission of the ACK frame is complete. The NAV shall be reset.

State C7, Transmit Failed: In this state, the control state machine shall react to a failure in the handshake required for data transmission or to a request to transmit while the medium is not free.
C70, Transmission_failure: This transition shall be taken when the maximum number of retry attempts has been exhausted. Tx_failed shall be set. Retry_cnt shall be reset. CW shall be set to CWmin.
C78, Try_again: This transition shall be taken when the maximum number of retry attempts has not been exhausted. The Retry_cnt shall be incremented.

State C8, Select Backoff: In this state a backoff interval shall be calculated by multiplying a random number uniformly distributed between zero and one by the product of the contention window parameter (CW) and the slot time.
C80, Wait_for_Backoff: This transition shall be taken when the backoff interval is computed. The CW shall be doubled and limited by CWmax. The backoff flag shall be set.

6.7.7. MAC Management (M) State Machine Definition


R1
Idle
R2
Activity
R3
Process Word
PH_DATA.Indicate
(Start_Of_Activity)
PH_DATA.Indicate
(next_word)
get word
Set(MBUSY),
New Frame
!(DataPart & Encr.On)
PH_DATA.Indicate
(Start_Of_Activity)
Store Word
DataPart & Encr.On
NewFragment
Decrypt Word,
Store Word
Encr. On
& No Sequence Present for IV
On_the_fly_Filtering Conditions
Discard Fragment
Generate Sequence (IV)
CCA==0
Discard Fragment
R4
Check CRC
R5
Fragment Completion
PH_DATA.Indicate
(end_of_data)
check CRC, Unicast
CRC Error
CRC Ok
Discard Fragment
Store Fragm.
(if not in sequence,
discard)
CCA=0
Reset(MBUSY)
!LastFrag &Unicast
R6
Interpret MPDU
!LastFragment & Unicast
LastFragment
Unl_FragReceived_flag = 1
Unicast Data
Data_flag =1
Unicast RTS
RTS_Flag=1
Other RTS
Set_NAV(Duration)
Unicast CTS
CTS_Flag=1
Other CTS
Set_NAV(Duration)
Unicast Ack
Ack_flag=1
Unicast Mgmt Frame
U_MgmtFrame_flag=1
Any Broadcast/Multicast Frame && Source!=ownaddress
ETC.....

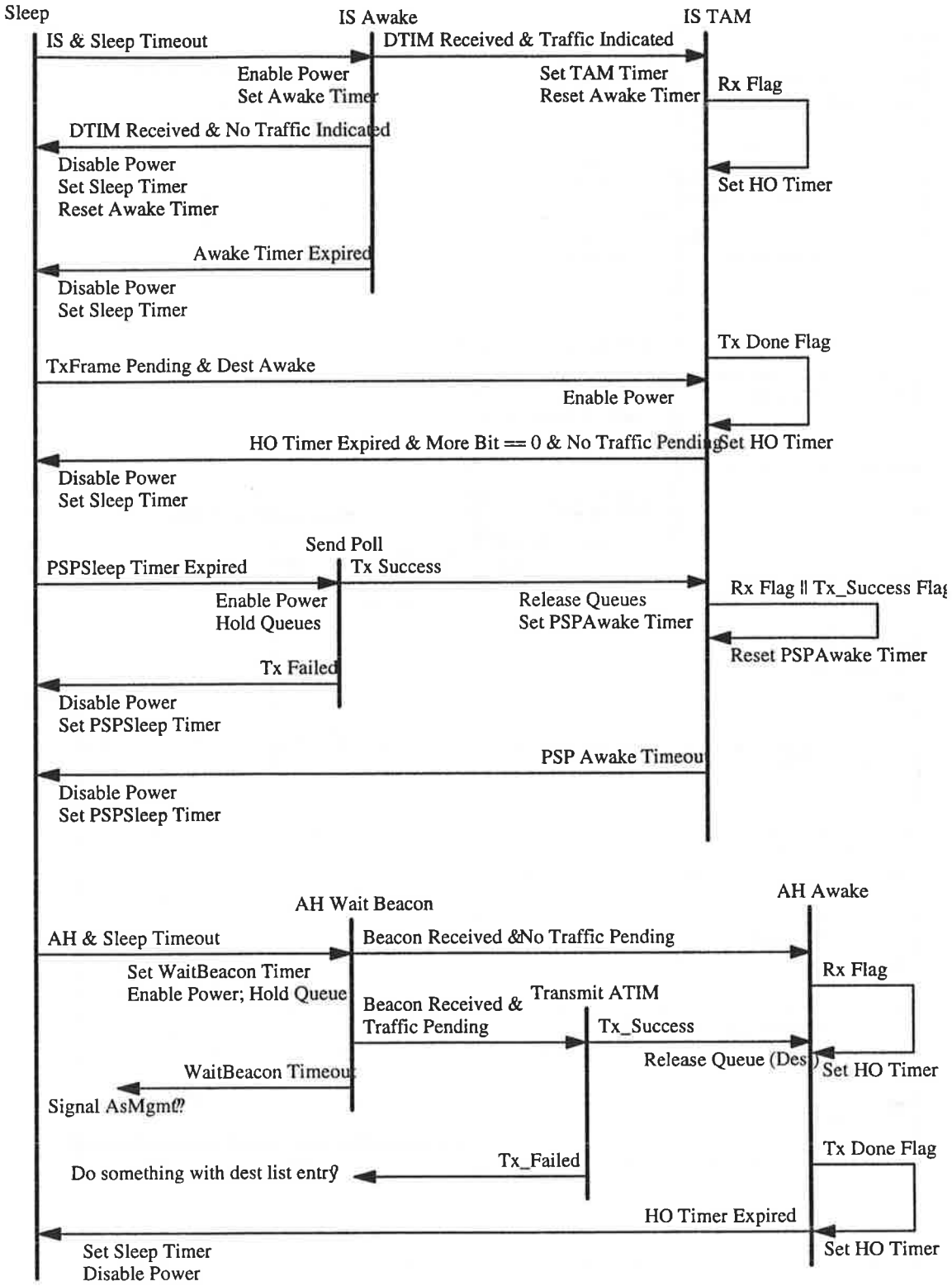


Figure 6-xx(7): MAC Management State Machine

6.7.7.1. Notes to the MAC Management State Machine

6.7.8. Transmitter (T) State Machine Definition

The transmitter state machine is a simple "data pump" which transfers the MPDU contents to the PHY while calculating the CRC value, transfers the CRC value after the end of the MPDU payload is reached, then ends the transmission and returns to its idle state awaiting the next transfer indication from the MAC control state machine. The CRC generation must be done in the MAC state machine in order to accomodate the transmission of Beacon and Probe Response frames, where the contents of the timestamp field in the MPDU are not known until immediately prior to transfer to the PHY.

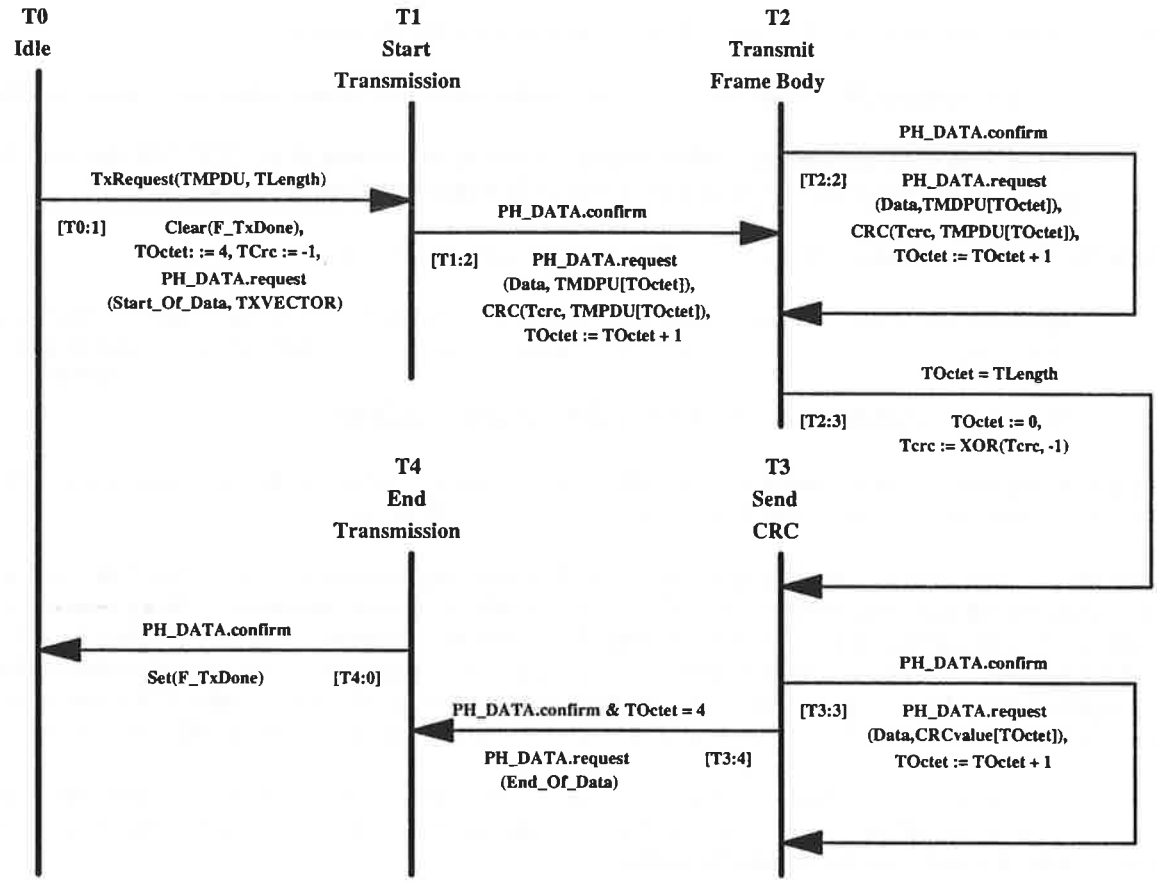


Figure 6-xx(8): Transmitter State Machine

6.7.8.1. Notes to the Transmitter State Machine

State T0, Idle: The MAC transmitter shall enter this state upon initialization or after a transmission is concluded.

> **T[0,1] Start PHY transmitter:** When a transmit request is received this transition shall be taken to initialize the local variables and CRC generator, and to inform the PHY to begin a transmission. The TXVECTOR shall be generated using the Tlength value and the values of MIB or global variables for any other information needed in the TXVECTOR of the present PHY.

State T1, Start Transmission: Waits for the PHY to confirm the start of data so the MPDU transfer can begin.

T[1,2] Send first octet: When the PHY confirms the start of data, this transition is taken to send the first octet of the MPDU to the PHY and start CRC accumulation.

State T2, Transmit Frame Body: The state machine enters this state when the PHY confirms the first octet transmitted.

T[2,2] Send next octet: This transition to self is taken to send each successive octet in the MPDU, prior to the CRC field, to the PHY, and to accumulate the updated CRC value.

T[2,3] End of MPDU payload: This transition is taken when the last octet of the MPDU payload has been transferred to the PHY. The accumulated CRC value is one's complemented in preparation for transmission.

State T3, Send CRC: Sends the 4 octets of the CRC field after the MPDU payload.

T[3,3] Send next CRC octet: This transition to self is taken to send each successive octet in the CRC field.

T[3,4] Stop PHY transmitter: When the PHY confirms the last octet of the CRC field, this transition is taken to indicate the end of the MPDU and initiate the PHY transmitter shutdown sequence.

State T4: End Transmission: Waits for the PHY to confirm the end of data.

T[4,0] Return to idle: When the PHY confirms the end of data, this transition is taken to indicate completion of the transmission to the MAC control state machine and suspend operation of the transmitter state machine.

6.7.8.2. Known Limitations of the Transmitter State Machine

The transmitter state machine assumes that the PHY always returns a confirmation for each request, and provides no recovery mechanism for a case where the PHY does not return a confirmation.

When sending Beacon and Probe Response frames it will be necessary to obtain the value of the TSF timer at a precise time during the transfer of the MPDU to the PHY. The TSF value cannot be sampled an arbitrary time earlier in the Management state machine and queued with the rest of the frame for subsequent transmission. Once the reference point for the TSF value is defined, it will be necessary to add a special case state transition, active only when the frame type and subtype in the MPDU indicate a Beacon or Probe Response frame, to obtain the current TSF value, or to update a previously saved copy of the TSF value, immediately prior to transferring the first of the TSF's 8 octets to the PHY.

There is no mechanism by which the MAC control or management state machines can abort a transmission in progress (which may not be a problem, because such an abort does not appear to be necessary, and because such an abort would cause an invalid frame to be placed onto the medium).

6.7.9. Receiver (R) State Machine Definition

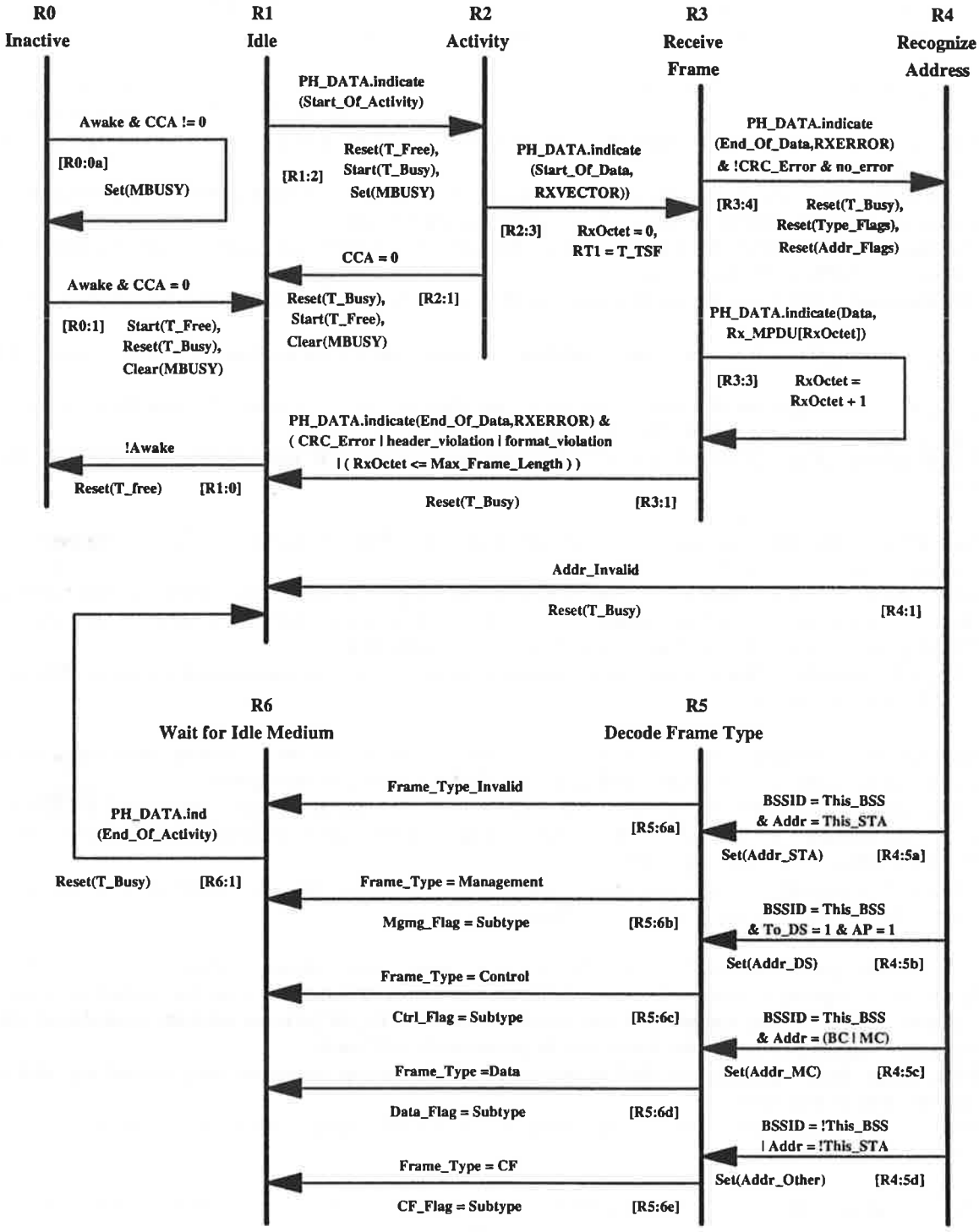


Figure 6-xx(9): Receiver State Machine

6.7.9.1. Notes to the Receiver State Machine

State R0, Inactive: This state shall be entered whenever the MAC receiver is initialized. In this state the receiver awaits the receipt of the start delimiter.

R01, Start_Receive: If a start delimiter is received from the PHY, a transition to state R1 shall occur. The address

recognized flag and error detected flag shall be cleared. The CRC accumulator shall be cleared in preparation for receiving a frame. My_addr and the frame type flags shall be cleared.

State R1, Idle: This state shall be entered when a valid start delimiter is detected. In this state the incoming frame shall be checked for valid format, correct CRC, valid network identifier and correct MPDU_ID as appropriate for the frame type. Based upon the frame type received, the appropriate exit shall be chosen. If the frame is uniquely addressed to this station, My_addr shall be set.
R10, Frame_error: If there is an error in the frame format or the frame contains a CRC error, this transition shall be taken to return the receiver to the Idle state. The error flag shall be set.
R12, Received_RTS: When the frame is valid and the frame type is RTS, this transition shall be taken. Original_ID shall be set to MPDU_ID. Rx_flag shall be set.
R13, Received_CTS: When the frame is valid and the frame type is CTS, this transition shall be taken.. Rx_flag shall be set.
R14a, Received_Data: When the frame is valid and the frame type is Data, this transition shall be taken.. Rx_flag shall be set.
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.
R15, Received_ACK: When the frame is valid and the frame type is ACK, this transition shall be taken.. Rx_flag shall be set.

State R2, Activity: This state shall be entered when a valid RTS frame is received. In this state the actions appropriate to receipt of an RTS frame shall be taken.
R20a, Other_RTS: This transition shall be taken when the RTS receipt actions are complete and My_addr is not set. The NAV shall be updated with the value in the Length field of the frame plus the value of RTS_time_offset. The RTS_flag shall be reset. The RTS timer shall be initialized and started.
R20b, RTS_complete: This transition shall be taken when the RTS receipt actions are complete and My_addr is set. The RTS_flag shall be set.

State R3, Receive Frame: This state shall be entered when a valid CTS frame is received. In this state the actions appropriate to receipt of a CTS frame shall be taken. The CTS timer shall be stopped.
R30a, Other_CTS: This transition shall be taken when the CTS receipt actions are complete and the MPDU_ID is not equal to the Original_ID. The NAV shall be updated with the value in the Length field of the frame plus the value of CTS_time_offset. The CTS_flag shall be reset.
R30b, CTS_complete: This transition shall be taken when the CTS receipt actions are complete and the MPDU_ID is equal to the Original_ID. The CTS_flag shall be set.

State R4, Recognize Address: This state shall be entered when a valid Data or Unitdata frame is received. In this state the actions appropriate to receipt of a Data or Unitdata frame shall be taken. If the destination address received is contained in the set of this station's destination addresses and the To_AP bit is not set in the control field, the address recognized flag shall be set and the frame shall be passed to the LLC entity.
R40a, Other_Data: This transition shall be taken when the data receipt actions are complete and My_addr is not set. The data_flag shall be reset.
R40b, Data_complete: This transition shall be taken when the data receipt actions are complete and My_addr is set. The data_flag shall be set.

State R5, ACK Received: This state shall be entered when a valid ACK frame is received. In this state, the actions appropriate to the receipt of an ACK frame shall be taken.
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.
R50b, ACK_complete: This transition shall be taken when the ACK receipt actions are complete and the MDPU_ID is equal to the Original_ID. The ACK_flag shall be set.

State R6, CFACK Received: This state shall be entered when a valid CFACK frame is received.
R60, CFACK_complete: This transition shall be taken when the CFACK receipt actions are complete. The NAV shall be reset. The CFACK_flag shall be set.