UHF Modem MAC Sublayer for Amateur Radio Stations

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1. Introduction

This document defines a medium access control (MAC) sublayer entity in the Open System Interconnection model for point-to-point and point-to-multi-point operation between fixed and mobile stations operating in the amateur radio service. This document defines the protocol implemented by this MAC entity.

The amateur radio service (ARS) has the following unique requirements for a MAC service and protocol:

1. The radio links can cover a wide area. Transmitter and receiver antennas mounted at a 90 foot height above average terrain (HAAT) can provide can provide communication over a 50 mile path. A station located on a mountaintop at 1500 feet HAAT has a radio horizon of 100 miles.

2. The ARS requires efficient multicast operation. A net can have over 100 stations participating that must all be able to receive transmissions from the net control station and from each other.

3. Radio communication is subject to fading that results in bursts of errors. Efficient operation requires that the error rate be minimized on each communication link.

The coverage area of ARS stations results in propagation times that approach one millisecond. Carrier-sense multiple access (CSMA) techniques are not sufficient to control medium access so some form of polling must be used. The radio channel characteristics dictate error correction but traditional ARQ techniques do not work for multicasting. Consequently, the MAC entity must incorporate forward error correction (FEC) to provide a reliable multicast service. Since all stations are not in range of each other, the net control (primary) station must have the capability of forwarding MAC protocol data units (MPDUs) to all other (secondary) stations to achieve full connectivity. FEC required long data units to work effectively but many applications will transmit short data blocks. The MAC protocol must support concatenation of short MPDUs into a longer physical service data unit (PHY-SDU).

2. MAC Service Interface

The MAC service defined in this document is designed for a network of stations that all operate on the same frequency and at the same symbol (baud) rate. The available data rates on each station may vary due to differing sets of capabilities, but all neighboring stations must have a common baud rate and compatible modulation.

The primary purpose of the MAC entity is to transfer blocks of user data called MAC service data units or MSDUs. A MSDU consists of 1 to 1,536 bytes of user data that is sent from a source address to a destination address. Addresses are six bytes in length and are formed from the ARS call signs of individual stations or the name of a multicast group. Three service primitives are used to transfer user data:

The user issues an **MA-UNITDATA.request** when it wishes to transmit a MAC service data unit (MSDU). The parameters are the destination address, source address, length and 1 to 1,536 bytes of user data.

The provider issues an **MA-UNITDATA-STATUS.indication** when the user data plus MAC protocol control information (PCI) is fully processed and the MAC entity is available for further data transmission. The single parameter is transmission status, which may have the value TRANSMITTED or LOCAL_ERROR.

The provider issues an **MA-UNITDATA.indication** when a complete MSDU has been received. The parameters are the destination address, source address, length and 1 to 1,536 bytes of user data.

3. MPDU Format

The MAC entity will concatenate multiple MAC protocol data units (MPDUs) for transmission in one PHY-SDU whenever possible. Each MPDU consists of MAC protocol control information (MPCI) and, optionally, a MAC service data unit (MSDU). Figure 1 shows an example with five MPDUs where three contain MSDUs. The maximum PHY-SDU length is 5,184 bytes.

MPDU 1		MPDU 2	MPDU3	MPDU 4		MPDU 5	
$MPCI_1$	**$MSDU_1$**	**$MPCI_2$**	**$MPCI_3$**	**$MPCI_4$**	**$MSDU_2$**	**$MPCI_5$**	**$MSDU_3$**

Figure 1. PHY-SDU with Multiple MPDUs

3.1 Data MPDU

A Data MPDU transports a complete MSDU. It consists of 21-bytes of MPCI containing the address and type fields followed by a variable-length user-data field as shown in figure 2. The MPCI fields are defined in table 1. DA, SA and L are obtained from the MAC service user while IA is generated by the MAC entity. IA is the next destination address while DA is the ultimate destination address.

0	1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	19 20	21 … 21+N
0	**IA**	**DA**	**SA**	**L**	**MSDU**

Figure 2. Data MPDU

Field	Bytes	Semantics
IA	6	Intermediate MAC Address.
DA	6	Destination MAC Address.
SA	6	Source MAC Address.
L	2	802.3 Length field.
MSDU	1-1536	User data.

Table 1. Data MPDU Fields

3.2 Token MPDU

A Token MPDU contains the address of the next secondary station to transmit as shown in figure 3 and table 4.

0	1	2	3	4	5	6	7	8	9	10	11	12	13
1	**PA**						**N**	**SA**					

Figure 3. Token MPDU

Field	Bytes	Semantics
PA	6	Primary station MAC address.
N	1	0 if token sent to PA, 1 if token sent to SA.
SA	6	Secondary station MAC Address if N = 1.

Table 4. Token MPDU Fields

3.3 RSSI MPDU

A RSSI MPDU reports the received signal strength indication (RSSI) for one or more transmitting stations at a particular receiving station as shown in figure 4 and table 5. The TA and RSSI fields are repeated N times. The C and M fields indicate the transmitter capabilities at the reporting station.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	**RA**						**C**	**M**	**N**	**TA_1**						**SNR_1**

Figure 4. RSSI MPDU with one signal report.

Field	Bytes	Semantics
RA	6	Reporting station MAC address.
C	1	Maximum number of carriers divided by 12.
M	1	Maximum number of bits per 12 carrier group.
N	1	Number of RSSI reports (0-255).
TA_N	6	Transmitter MAC address.
SNR_N	1	SNR of TA_N pilot carrier at RA in dB.

Table 5. RSSI MPDU Fields

3.4 MAC Address Format for Amateur Radio Stations

A modem implementation conformant to this standard shall use the locally administered ANSI/IEEE 802 48-bit address format and addresses shall be formatted as shown in figure 5. Source addresses must be individual addresses.

47	46	45	44	43	42	41 40 39 38 37 36	35 34 33 32 31 30	29 28 27 26 25 24	23 22 21 20 19 18	17 16 15 14 13 12	11 10 9 8 7 6	5 4 3 2 1 0
X	1	0	0	0	0	C0	C1	C2	C3	C4	C5	C6

Figure 5. ARS Subnetwork Address Format

The X bit shall be 0 for individual addresses and 1 for group addresses. Each address shall consist of exactly seven characters whose values are in fields C0 through C7. Each shall be encoded in 6-bit ASCII as shown in table 6. Allowable characters are the Latin letters A through Z (case insensitive), the decimal numbers 0 through 9 and the space character.

	Bits 5-4			
Bits 3-0	00	01	10	11
0000	(space)	**0**		**P**
0001		**1**	**A**	**Q**
0010		**2**	**B**	**R**
0011		**3**	**C**	**S**
0100		**4**	**D**	**T**
0101		**5**	**E**	**U**
0110		**6**	**F**	**V**
0111		**7**	**G**	**W**
1000		**8**	**H**	**X**
1001		**9**	**I**	**Y**
1010			**J**	**Z**
1011			**K**	
1100			**L**	
1101			**M**	
1110			**N**	
1111			**O**	

Table 6. ARS 802-style Address Character Set and Encoding.

Multicast addresses are group addresses that start with a letter or number and must consist of seven characters.

Individual addresses shall start with a letter or number and fields C0 through C5 shall be the amateur radio service (ARS) call sign assigned to the control operator. Call signs shorter than 6 characters shall be padded at the right end with spaces. The last character is an extension field. If only one modem is under control of the licensed operator or trustee, C6 shall be a space character. If more than one modem is under the control of the licensed operator or trustee, C6 shall be a non-space character.

4. Block Error Correction Code

The radio communications channel is subject to fading and/or impulse noise that may introduce errors in bursts. The error correction provided in the physical layer may be overwhelmed and bytes containing errors may be delivered to the MAC sublayer. A MAC-level block error correction code generates additional error correction information and distributes it over many symbols to allow correction of burst errors and increase the number of MAC-PDUs delivered to the user. This section describes the block error correction code.

A Reed-Solomon code with a symbol width of one byte, a block length of 255 bytes, a maximum data field width of 223 bytes and a Galois field polynomial of 100011101_2 is used. This code will correct errors in up to 16 symbols per block with an overhead of 12.6%. When 239 data bytes are available for transmission, an encoded block of 255 bytes is generated. If the end of the PHY-SDU is reached and the number of data bytes to be transmitted is less than 239 a shortened code block is generated.

5. MPDU Forwarding

When the MAC entity receives a Data MPDU it must decide whether to deliver it locally, forward it to an adjacent station or discard it. The decision is made using the information maintained in the Neighbor Table in each station. The forwarding procedure depends on the type of destination address (individual or multicast) and the type of station (primary or secondary) involved.

Normal Forwarding: If the destination address is not a multicast address, the entries in the RSSI Table for all destination addresses are examined. If the destination addresses is the local station address, the user data is delivered to the local user at the MAC SAP. If the destination address is in the Neighbor table, the MPDU is forwarded by setting the IA field to the destination address and transmitting the modified MPDU when this station has the permission to transmit token. If the destination address is not in the Neighbor Table, the MPDU is forwarded by setting the IA field to the primary station address and transmitting the modified MPDU when this station has the permission to transmit token. If this is the primary station, the MPDU is discarded.

Multicast Forwarding: If the destination address is a multicast address and this is a secondary station, the MPDU is forwarded by setting the IA field to the primary station address and transmitting the MPDU when this station has the permission to transmit token. If the destination address is a multicast address and this is the primary station, the MPDU is forwarded by setting the IA field to the destination address and transmitting the modified MPDU when this station has the permission to transmit token.

Each MAC entity make decisions on the modulation method and number of carriers to use when transmitting to adjacent stations. It uses SNR data from the Neighbor Table entries for the adjacent stations that are to receive the PHY-SDU to select the modulation type and number of carriers to be used. The lowest SNR value is used to make the decision. The modulation type and number of carriers are selected based on the required SNR defined the physical layer standard. The MAC entity then checks the maximum allowed by the adjacent stations that are to receive this PHY-SDU. If the number of carriers selected is not supported by any one of these adjacent stations, the number of carriers is set to the maximum supported by all these stations and the modulation type is re-evaluated. The modulation type is then examined for each of these adjacent stations and if it is not supported, the number of bits per carrier is set to the minimum supported by all of these stations. The PHY-SDU is transmitted when the station receives permission in a Token MPDU.

6. Medium Access Control

Access control is achieved via a token-passing mechanism. One station is the primary station that periodically transmits a token MPDU to selected secondary stations. The token MPDU is usually contained in a PHY-SDU that includes data transmissions to secondary stations. This token confers the right to transmit to the specified secondary station.

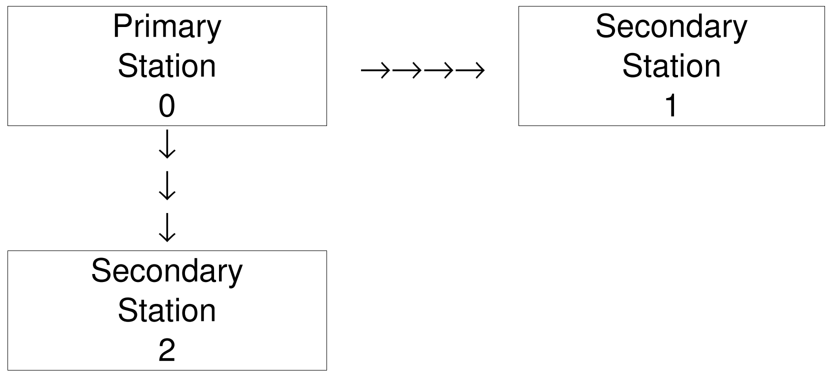

Figure 6. Token Passing

The primary station transmits the token periodically to poll the secondary stations whose addresses are stored in its RSSI Table. After transmitting the token, the primary station monitors the channel status via PHY-CCA.indications. If the medium is idle for more than two maximum length PHY-PDU times, the token is assumed to be lost and the primary station polls the next secondary station in the Neighbor Table.

Alternate primary stations (which may otherwise be secondary stations) may be configured. Each alternate primary station resets the ALT_PRI timer when it is passed the token. If the ALT_PRI timer ever expires, that station becomes the primary. The timer values for the first, second and third primaries are 0, 2^{20} (1,048,576), and 2^{21} (2,097,152) symbol periods.

7. RSSI Distribution

The Neighbor Table in the MAC MIB must be constantly refreshed with information on the communications paths between stations. The primary station polls all secondary stations by periodically transmitting an RSSI MPDU that contains the secondary station's pilot carrier amplitude at the primary station. Each secondary station broadcasts the received pilot carrier SNR by taking its idle time RSSI and the pilot carrier RSSI and calculating the SNR of the pilot carriers of all adjacent (i.e. heard) stations. The SNR information is then broadcast in an RSSI MPDU. Secondary stations that do not respond to this poll 4 times in a row are deleted from the primary station's Neighbor Table. The polling interval is every 2^{16} (65,536) symbol periods.

MAC Address	SNR	C	M
3ABC78	15	6	3
1465A7	23	12	6
A7779B	11	3	3

Figure 7. Neighbor Table

The Neighbor Table also contains the transmitting capabilities of each neighboring station. C is an unsigned number from 0 to 255 giving the maximum number of carriers that the station can transmit divided by 4. M is an unsigned number from 0 to 15 giving the maximum number of bits per carrier that the station can transmit.

8. MAC Protocol

This section describes the actions taken by this MAC sublayer entity in response to stimulus from the underlying physical service access point (PHY-SAP) and the user connected to the MAC service access point (MSAP).

8.1 PHY-CCA.indication

When a PHY-CCA.indication with a value of BUSY is received transmission of MPDUs is inhibited. When a PHY-CCA.indication with a value of IDLE is received, the background noise level is stored.

8.2 PHY-RXSTART.indication

When a PHY-RXSTART.indication is received, the MAC receiver entity prepares to receive and decode bytes and stores the pilot carrier RSSI.

8.3 PHY-DATA.indication

When a PHY-DATA.indication is received the data byte is transferred to the FEC decoder logic. The output is monitored for incoming MPDUs. If there are uncorrectable errors in an MPDU, the received MPDU is discarded. Otherwise, Data MPDUs are forwarded according to the process described in section 5. Each correctly decoded MPDU with the address of the local station results in a MAC-DATA.indication. RSSI MPDUs are used to update the Neighbor Table and, if received at a secondary station, cause an RSSI MPDU to be queued for transmission to the primary station.

8.4 PHY-RXEND.indication

When a PHY-RXEND.indication is received, the MAC entity discards any partial MPDU and checks for a Token MPDU. The primary station address is set by the Token MPDU. If the token specifies the local station as the secondary station with permission to transmit, CCA is checked and transmission of any accumulated MPDUs begins. A token MPDU is always sent to the primary station as part of the PHY-SDU.

8.5 MAC-DATA.request

When a MAC-UNITDATA.request is received, the MPDU is formatted and stored. The total PHY-SDU size, in bytes, is then calculated and this information is stored until the station receives permission to transmit.

8.6 Receipt of Token MMPDU

If the token MMPDU contains the local station address the MAC transmitter entity checks the channel status, waits for a value of IDLE, and issues a PHY-TXSTART.request with the appropriate carrier and modulation parameters.

8.6 PHY-TXSTART.confirm

When a PHY-TXSTART.confirm is received, the MAC entity issues the first PHY-DATA.request.

8.7 PHY-DATA.confirm

When a PHY-DATA.confirm is received, the MAC entity checks for more bytes to transmit. If so, the MAC entity issues a PHY-DATA.request. A MAC-UNITDATA-STATUS.indication is issued as transmission of each Data MMPDU completes. When all are transmitted a PHY-TXEND.request is issued.

8.8 PHY-TXEND.confirm

When a PHY-TXEND.confirm is received the receiver is enabled.