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APCO Project 25
Common Air Interface Operational Description for Conventional Channels

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TELECOMMUNICATIONS INDUSTRY ASSOCIATION

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Foreword

This foreword is not part of this document.

This Telecommunications Systems Bulletin (TSB) is being promulgated and will be maintained by the TR-8.15 Common Air Interface Subcommittee as part of the effort of TR-8 Private Radio Technical Standards committee under the sponsorship of the Telecommunications Industry Association.

While not finished, TR-8.15 believes that an urgent need exists for and that this document accurately portrays a significant amount of technical information regarding emerging digital technologies for the Land Mobile Service, especially APCO/NASTD/FED Project 25. Therefore TR-8 has chosen to recommend it for publication as a TSB and thereby expedite its expected benefits to the industry.

Generally, the Project 25 Common Air Interface Operational Description for Conventional Channels and various elements thereof have been developed by TIA TR-8.15 to be consistent with the Statement of Requirements adopted by the Project 25 Steering committee. This Standards family includes and borrows heavily from the combined work of various industry and government agency representatives organized under the TIA Project 25 Ad Hoc Interface Committee.

This document presumes that APCO/NASTD/FED will establish an overall Project 25 System standard or specification. It further presumes that TIA will set standards based upon the APCO/NASTD/FED Project 25 standards or specifications.

This TSB provides the Common Air Interface Operational Description as a supplement to the APCO Project 25 Recommended Common Air Interface which is one of the interfaces to be defined under the Project 25 system. While all reasonable efforts have been made to ensure the accuracy of this document, it should be understood that significant work remains in fully developing the Project 25 family of standards and that this document will be updated as necessary to ensure an accurate representation of Project 25 systems as other implementation requirements become available.

The reader's attention is called to the possibility that compliance with the APCO/NASTD/FED Project 25 Standard or any TIA standard for equipment conforming to the APCO/NASTD/FED Project 25 Standard may require the use of one or more inventions covered by patent rights. By publication of those standards, if any, no position is taken with respect to the validity of those claims or any patent rights in connection therewith. The patent holders so far identified have, however filed statements of willingness to grant licenses under those rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such licenses. Details may be obtained from the publisher.

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Table of Contents

List of Figures

List of Tables

Terminology

ACK	Acknowledgment response for delivery confirmation of a data packet
ARQ	Automatic Retry Request to retry corrupted data packets
BR	Base Radio, a reference designating a base station
CRC	Cyclic Redundancy Checksum to detect errors in data
CRC-9	9-bit CRC used in each block of a confirmed data packet
FMF	Full Message Flag indicates the first copy of a data packet
FSSP	Frame Sync Seek Period, time allowed to detect a frame sync
IMBE	Improved Multi-Band Excitation, the voice coder for the Common Air Int.
LC	Link Control, a code word embedded in a voice message
LDU	Logical Link Data Unit. There are two different LDUs for voice.
MFID	Manufacturer's Identifier, to mark message with non-standard formats
MR	Mobile Radio, a reference designating a mobile or portable radio
NAC	Network Access Code encoded into a message to mute interference
NID	Network ID code word, includes the NAC information
OSI	Open Systems Interface, a standard communication system definition
PTT	Push-To-Talk switch, activated for radio to transmit voice
RFC	Radio Frequency Controller, to control a base station
RFG	Radio Frequency Gateway, a device to port data into a radio system
SAP	Service Access Point identifier, an address for a service using data
TGID	Talk Group Identifier, to identify a talk group in a voice call

1. Introduction

This supplement to the *Common Air Interface* [reference 1] describes some simple operational procedures for conventional systems using voice or data. These operational procedures are sufficient for basic operation of conventional radio systems. They are not intended to describe operation of trunked systems or data systems, both of which have additional operating procedures defined elsewhere. This is intended to be interpreted with the *Common Air Interface* and is not intended to be understood by itself.

The basic procedures defined in this document include those for transmitting and receiving digital voice on a radio channel, and those for transmitting and receiving data packets on a radio channel. The procedures for voice are contained in Sections 5 and 6, while the procedures for data are contained in Sections 8 and 9. The formats for these messages are defined in reference 1, and this document defines simple procedures for their use.

In order to describe the transmission of voice or data, it is necessary to define some simple addressing concepts for subscriber radios and radio repeaters, and also to define simple operating procedures for repeaters. These topics are covered in Sections 2, 3, 4, and 7.

1.1 Scope

This supplement defines sample operational procedures for basic conventional radio systems. A conventional radio system is one that does not include any controlling entity in the infrastructure to assign radio channels. It is different from a trunking system which includes some means of assigning radios to channels, i.e. a trunking controller. The sample operational procedures defined in this supplement are, in the whole, not mandatory requirements. However, some of the procedures are mandatory for this supplement, and others may be specified as mandatory for other portions of the APCO-25 set of standards even though they are not specified as mandatory here.

A basic conventional radio system is one which meets the minimum requirements for this supplement. Additional functions or features may be added to a basic system as they are required. The operation of these additional functions is not discussed in this supplement, but it is expected that they will be compatible with the basic operation as described here. Basic procedures covered in this supplement are further restricted to the lower 2 OSI layers of the radio system. Operation of the encryption function, vocoder function, or user data applications is not explicitly defined here. Operation of trunking control is also not included.

There are several different types of conventional radio system, depending on whether or not a repeater is used. These are diagrammed Figure 1-1.

For the purposes of this document, basic conventional systems can be classed as either repeater systems or direct systems. Repeater systems make use of a full duplex base station that is configured so that all of the signals that are received are re-transmitted. Direct systems simply transmit directly from one unit to another without the assistance of any intervening repeater. Radio units in a system consist of mobile or portable units, and base stations. The mobile or portable units are represented as MR elements. The base station is represented as a BR element in Figure 1-1. The communication paths are represented as arrows. They are intended to show a simplex (i.e. one direction only) path. Generally, the radios may be capable of operating half duplex, which is to say that they can transmit or receive, but not both at the same time. The repeater is always full duplex. Full duplex operation for portables or mobiles is not discussed for a basic conventional system.

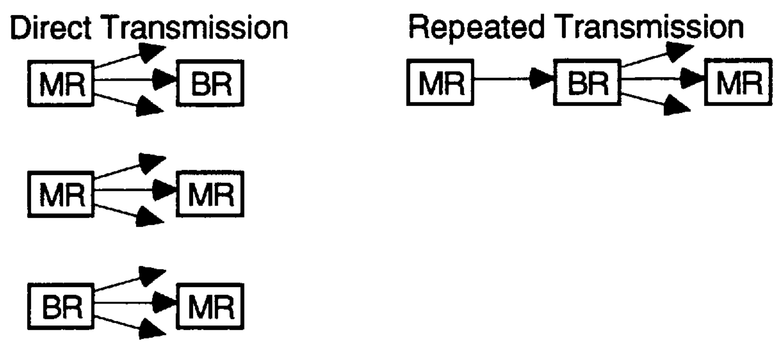

Figure 1-1 Conventional System Diagrams

Addressing for the mobiles, portables, and base stations is covered in Sections 2 and 3. Section 2 contains some mandatory requirements. Mobile, portables, and base stations also generate Status Symbols, and this subject is covered in Section 4 with some mandatory requirements.

From the stand point of the originating unit, the message is broadcast to all other radio units that are within range of the signal. Those units that are within range may choose to unmute and listen to the signal, or remain muted. The procedures for the originating unit and destination units are covered in Sections 5, 6, 8, and 9. Sections 5, 8, and 9 contain some mandatory requirements. For the purposes of direct systems, either an MR or a BR can be the origination or destination unit. Three representative cases are given in Figure 1-1. Multiple arrows from the originating unit are intended to show communication paths to multiple destination units, of which only a single destination unit is shown.

For repeater systems, the base station is the repeater, and mobile / portable units are the origination and destination units. Multiple destination units can listen to the repeater transmission, but only the repeater is configured to listen to the originating unit. The operation of the repeater is a special case of operation of the units in direct mode, and some aspects of its operation are defined in Sections 2 and 7, with both sections containing mandatory requirements.

The procedures for data transmission and reception are given in Sections 8 and 9. Portions of the procedures are mandatory for interoperability with the Common Air Interface, and these portions are indicated in those sections.

1.2 Revision History

February 8, 1993, P25.930208.1.0, contained basic operating procedures.
April 8, 1993, P25.930208.1.1, revised so that it is no longer an appendix.
September 17, 1993, P25.930208.1.2, revised to include data operation.
November 10, 1993, P25.930208.1.3, revised data operation and scope.
December 13, 1993, P25.930208.1.4, revised to indicate normative sections.

1.3 References

The following documents are referred to by this document. The versions and dates in these references are the latest available on the date of this document.

1. *APCO Project 25 Recommended Common Air Interface*, April 1994, TSB 102.BAAA.
2. *APCO Project 25 DES Encryption Protocol*, April 1994, IS 102.AAAA.
3. *APCO Project 25 Vocoder Description*, July 1993, IS 102.BABA.

2. Unit Addressing

A basic conventional radio system consists of a set of radio units and / or repeaters which can communicate with each other. Those radio units which can terminate voice or data messages in the system will be called subscriber units in the system. This definition of subscribers will exclude repeaters for the purposes of basic conventional systems. Subscriber units can be addressed with a 24 bit unit address or with a 16-bit talk group address. A system containing five subscribers is shown in the Figure 2-1.

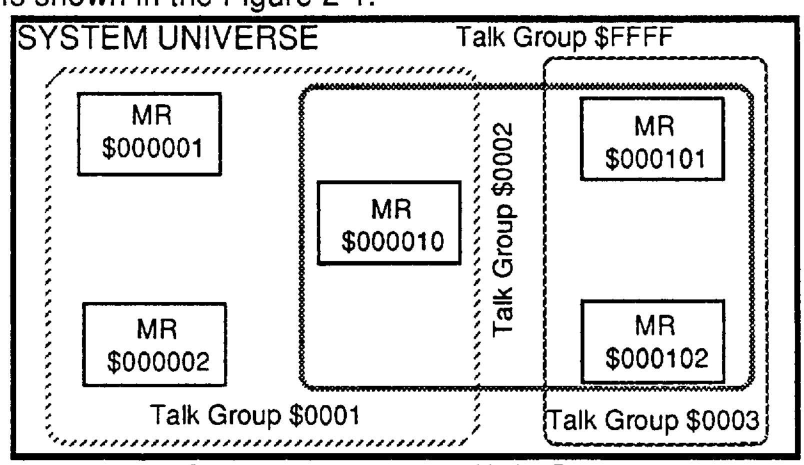

Figure 2-1 Example of Unit and Talk Group Addresses

In the example of Figure 2-1 every subscriber unit is a member of one or more talk groups. The talk group addresses are represented as 4-digit hexadecimal numbers. Each subscriber has a unit address which is represented as a 6 digit hexadecimal number in the figure. The special talk group address $FFFF contains all of the system units. The other talk groups each contain a subset of the units, that is defined so that communications between members of the talk group is useful and convenient. Any subscriber unit can be a member of any talk group, and any talk group can contain any number of subscriber units.

The address of the unit and talk group may be displayed for use by the radio operators. When the address is displayed, it shall be displayed with decimal digits 0, 1, 2,... 9. The binary value that is transmitted with the Common Air Interface is converted to decimal with standard binary to decimal conversion. Using the hexadecimal equivalents, several example addresses are given below:

hexadecimal	decimal display
$000 001	000 0001
$000 002	000 0002
$000 003	000 0003
...	...
$000 00A	000 0010
$000 00B	000 0011
...	...
$000 00F	000 0015
$000 010	000 0016
...	...
$989 67F	999 9999

The talk group addresses are also converted for display purposes in the same way. The range of talk group addresses normally spans 00001 .. 65534, with decimal value 65535 reserved to signify the group with all units. The talk group 00000 is used to signify a talk group with no members. The talk group 00001 is used as a default for systems which are not explicitly partitioning the system into different talk groups. The default talk group can be programmed into radios at the time of manufacture for convenience.

3. Repeater Addressing

Repeaters are not considered to be a subscriber unit in basic conventional systems, and consequently do not possess a unit address. They can still be addressed with the Network Access Code in the Common Air Interface. This addressing allows multiple repeaters to occupy the same channel, and remain separate and distinct. The Network Access Code (NAC) allows a large system coverage area to be serviced by separate repeaters, and it also allows multiple repeaters to service multiple systems with overlapping coverage areas. These cases are depicted in figures 3-1 and 3-2.

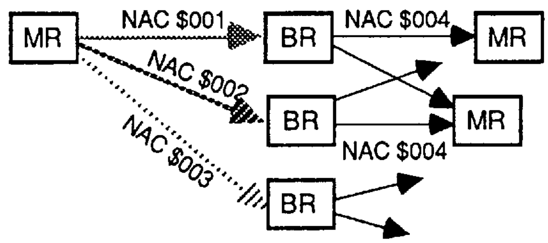

Figure 3-1 Separated Repeaters Servicing a Wide Area

Figure 3-1 shows three repeaters with each repeater using a different NAC on the inbound path and the same NAC on the outbound path. A subscriber unit may select the NAC based on its proximity to a repeater. For example, within the coverage area of the top repeater, it would use the NAC value $001. The repeater then re-transmits the message with the NAC value $004. The subscriber receivers are programmed to receive the NAC value $004, and in the figure both destination subscribers could receive the message. If the originating unit selected the second repeater, then it might reach a different set of subscribers in a different coverage area. In the figure, only one of the subscribers is reached. The third repeater reaches none of the subscribers shown.

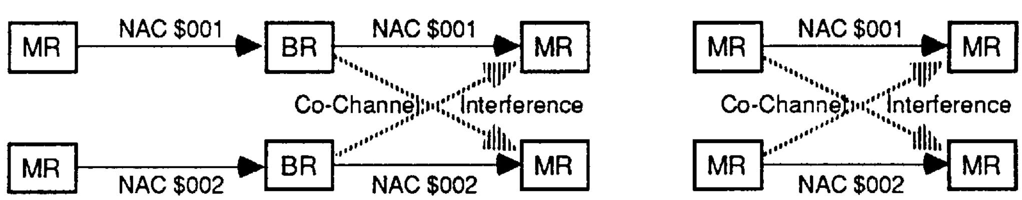

Figure 3-2 Co-Channel User Examples

Two examples showing co-channel interference are in figure 3-2. In the situation on the left two repeaters are shown sharing a channel, in this case the outbound channel. The subscribers can be programmed to accept messages with the NAC code specified for their system and reject co-channel interference from the other system. So long as both repeaters do not transmit simultaneously, the users in each system can share the channel. The situation on the right is very similar except that the channel is shared by subscribers operating in the direct mode.

4. Status Symbols

The channel status symbols allow a repeater to indicate the status of the inbound channel to subscribers that are waiting for the channel to become available so that they can send a data message. The status symbols are asserted by a repeater on both voice and data messages, and indicate inbound activity for both voice and data calls. An example for data is shown in figure 4-1.

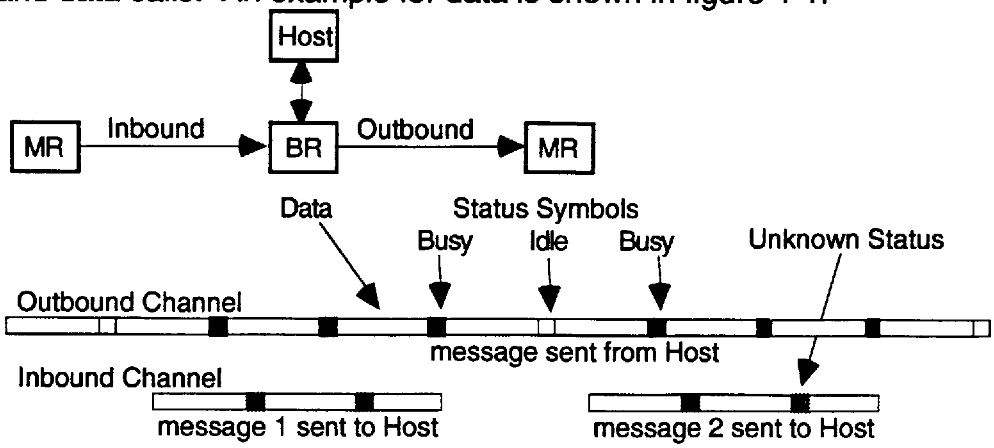

Figure 4-1 Channel Status Example

In the example, a repeater is sending a message, or a combination of messages, from a host computer device to a subscriber unit. During the transmission, the inbound channel may be free. If the repeater does not detect the presence of an inbound message, then it sets the embedded status symbol value to Idle. Any subscriber that is waiting to send in a message to the host simply waits until the status symbol indicates an Idle condition before it transmits. Once the repeater detects the presence of an inbound message, it sets the status symbol to a Busy value. This then inhibits other subscribers from transmitting until the inbound message is completed. After the message is completed the repeater clears the status symbol value on the outbound channel to the Idle value so that other subscribers can send messages.

The subscribers also embed status symbols in their messages. However, because they are not repeaters, they are unable to indicate the status of any inbound channel. Consequently, they shall set the value of the status symbol to signify an Unknown status. The channel status symbol has 4 possible values. There is one value for Busy, one for Idle, and two values to indicate Unknown status. When the subscriber sends a message on a direct channel, it shall use the Unknown value for direct mode operation. When the subscriber sends a message inbound to a repeater, it shall use the Unknown value for repeater operation.

5. Voice Transmit Operation

The operation of the subscriber transmitter for voice messages consists of 3 main cases, with several options and variations of each case. The 3 main cases consist of Routine Group Calls, Emergency Group Calls, and Individual Calls. The controls on a radio to initiate these different calls will be defined before the call operation is defined.

The subscriber transmitter may have several controls which affect the transmit operations. These controls are sufficient for a subscriber unit to support all of the call types defined here. These controls are as follows.

PTT Switch -- The Push-To-Talk switch is activated when the operator wishes to transmit and released when a transmission is finished.

Channel Selector -- The Channel Selector is a switch or control that allows the operator of the radio to select a radio's mode of operation. The operational parameters that are selected for the transmitter include the following items.

1. Transmit frequency
2. Transmit Network Access Code
3. Talk Group
4. Other parameters for setting the vocoder and encryption functions. For example, the encryption key may be selected.

Emergency Switch -- The Emergency switch is asserted by the radio operator for emergency calling. Once this switch is asserted, the emergency condition remains asserted until it is cleared by a different means, such as turning the radio off.

Numeric Keypad / Display -- This allows the radio operator to set numeric parameters, such as the number for a subscriber ID. This is most useful for individual calls.

The different types of calls described here are defined as follows.

Routine Group Call -- This is a transmission that is intended to a group of users in the radio system. It is the type of call that is made most often during normal radio operation. Typically, these calls are made when the PTT switch is asserted unless some other special condition exists.

Emergency Group Call -- This is a transmission that is intended to a group of users in a radio system, during an emergency condition. The definition of an emergency condition depends on the system's operators, but it typically signifies an exceptional condition with more urgency for the listeners to the call. These calls are typically made after the Emergency switch is asserted.

Individual Call -- This is a transmission which is addressed to a specific individual. The individual subscriber's address to which the call is directed is called the destination address. These calls are made after the destination address is entered into the radio.

The procedures for each of these calls in the transmitter are based on the procedure for the routine group call. Consequently, that call is described first, and then the other calls are described.

ROUTINE GROUP CALL PROCEDURE

1. PTT. The radio operator asserts the PTT switch.
2. Key up. The radio selects the channel parameters as determined by the Channel Selector switch. The radio follows the procedure given in Section 8.1 to key up the transmitter unless either:
   (a) the selected channel is for direct transmission, or
   (b) the procedure is optionally bypassed.

   If the procedure is bypassed, then the radio simply keys the transmitter on the transmit frequency. The radio also activates the voice encoder as described in reference 3. The radio also activates the encryption function as defined in reference 2.
3. Header Data Unit. The radio transmits the Header Data Unit with the following selected information fields.
   Network Access Code is determined by the Channel Selector switch.
   Manufacturer's ID is set to indicate a standard transmission.
   Message Indicator, Algorithm ID, and Key ID are determined by the encryption function.
   Talk Group ID is determined by the Channel Selector switch.
4. Format selection. The following voice message parameters are set.
   Network Access Code is determined by the Channel Selector switch.
   Manufacturer's ID is set to indicate a standard transmission.
   Emergency bit is set to indicate routine operation.
   Talk Group ID is determined by the Channel Selector switch.
   Source ID is set to the unit ID of the radio.
   Message Indicator, Algorithm ID, and Key ID are determined by the encryption function.
5. Transmit. The voice link data units, LDU1 and LDU2, are sent with the message parameters set in step 4. The information contents of the Link Control word are encrypted if specified by the encryption function. Link Control shall only be encrypted if the IMBE frames are also encrypted. The allowed conditions for encrypting voice fields are given in Table 5-1. If encryption of LC is selected, then the LC format value is set to indicate a group call with encrypted LC. If encryption of LC is not selected, then the LC format value is set to indicate a group call with unencrypted LC. The transmission is sustained until the PTT switch is released.
6. Terminate transmission. The transmission terminates when the PTT switch is released, or some other event forces a dekey, and the transmission has reached the end of an LDU. Then the radio terminates the voice encoder. Then the radio sends a terminator data unit. A subscriber always sends the simple terminator, consisting of a frame synchronization and Network ID word. After termination the radio notifies the encryption function to terminate, as defined in the encryption protocol.
7. Dekey. The radio dekeys the transmitter.

Table 5-1 Encrypted Voice Message Conditions

Fields Encrypted IMBE	LSD	LC	Conditions
x	x	x	Transmission of unencrypted messages is allowed. LC should use unencrypted formats.
x	x	√	NOT ALLOWED.
x	√	x	NOT ALLOWED.
x	√	√	NOT ALLOWED.
√	x	x	NOT ALLOWED.
√	x	√	NOT ALLOWED.
√	√	x	Encrypted voice + LSD with unencrypted LC is allowed. LC should use unencrypted formats.
√	√	√	Transmission of totally encrypted messages is allowed. LC should use encrypted formats.

√ = encrypted field   x = unencrypted field
IMBE = voice information   LSD = Low Speed Data
LC = Link Control

EMERGENCY GROUP CALL PROCEDURE

1. Emergency switch. The radio operator asserts the emergency switch. This sets the emergency condition until it is cleared by some other action such as turning the radio off.
2. Group Calls. Activation of the PTT switch now initiates calls that are very much like the routine group call described above. The only difference in procedure is that the emergency bit is asserted to indicate the emergency condition in step 4. Group calls can be made repeatedly, and each group call will indicate the emergency condition.
3. Emergency termination. The emergency condition is cleared by turning the radio off. When the radio is turned on, the emergency condition is cleared and routine group calls are made after a PTT assertion. In addition to this method another method may also be available.

INDIVIDUAL CALL PROCEDURE

1. Select Called Party. The unit ID of the individual to be called is entered into the radio via a keypad or some other device. This becomes the destination ID of the call.
2. Make the call. The procedure for a group call is followed, with the following exceptions.
    1. The talk group ID in the Header Data Unit is cleared to the null talk group (0000).
    2. The Link Control field is formatted with the individual call format containing the source ID and destination ID of the call.

6. Voice Receive Operation

The operation of the subscriber receiver for voice messages consists of 3 main cases, with variations that depend on the transmitter's operation. The 3 main cases are called Squelch conditions in this document. They are Monitor, Normal Squelch, and Selective Squelch.

As in the case of the transmitter, the receiver operation will be affected by the channel selector switch. This switch will select:

1. Receive frequency
2. Receiver Network Access Code
3. Talk Group
4. Other parameters for setting the vocoder and encryption functions. The encryption function operation is particularly significant to the receiver. This is covered in the encryption protocol description.

An additional radio control which affects a receiver is a Monitor switch. This allows the operator of the radio to disable any selective squelch of the receiver so that the operator will hear any signs of voice activity. This is useful for avoiding collisions on the channel between voice users.

The different types of squelch operation described here are defined as follows.

Monitor -- This enables the receiver to unmute on any recognizable voice signal. Selective muting based on the network access code, talk group ID, or unit addresses is not performed. This is analogous to monitor mode in analog receivers. This is normally activated with the Monitor switch.

Normal Squelch -- This enables the receiver to unmute on any voice signal which has the correct network access code. Voice messages from co-channel users which are using different access codes will be muted.

Selective Squelch -- This mutes all voice traffic except that which is explicitly addressed to the unit. Messages which contain the talk group or unit address of the receiver, as well as the network access code, will be received.

The details of the procedure in the receiver for implementing these different squelch options are not covered here. This is because the receivers must be designed to tolerate fading and interference while decoding the message, and the solution to this problem is likely to vary from one design to another. In general, however, the receiver is supposed to unmute if any of several attributes are decoded in the voice message. These attributes include the Network Access Code (NAC), the Manufacturer's ID (MFID), the encryption information, the Talk Group ID (TGID), and the Destination ID. The conditions for unmuting are given in Table 6-1 for the three squelch settings.

Table 6-1 Receiver Unmute Conditions

Attribute	Monitor	Normal Squelch	Selective Squelch
NAC	Don't Care	= Receiver NAC	= Receiver NAC
MFID	= standard	= standard	= standard
TGID or Dest. ID	Don't Care	Don't Care	= Receiver TGID or = unit ID
Encryption	Don't Care	Decryption is possible	Decryption is possible

The output of the receiver in the monitor mode when decryption is impossible is undefined. In general, it cannot be recognizable audio.

7. Repeater Operation

There are two different configurations for repeaters. In this document they are called the Simple configuration and Fixed Network configuration. These configurations are diagrammed in Figure 7-1. Each configuration also treats voice and data messages slightly differently.

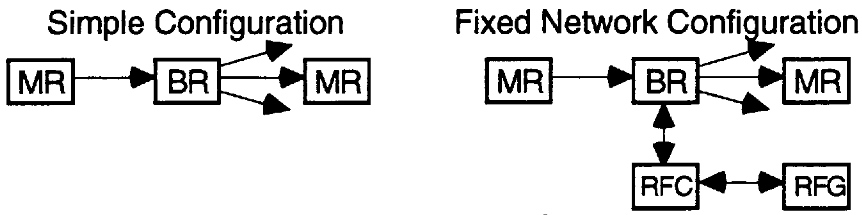

Figure 7-1 Repeater Configurations

The operation of a repeater in the simple configuration is obvious. The inbound message is received, copied to the transmitter, and transmitted. The information content of the message is unchanged. The information content of voice messages includes the coded voice and data, encryption information, and the link control information which includes the group and individual addressing. The information content of data messages includes the contents of all of the blocks of the message. The number of blocks in the data message is enumerated in the header block as defined in reference 1.

In the fixed network configuration, the repeater copies inbound voice messages to the outbound path and also to the fixed network, typically to a console device. Inbound data messages are only copied to the RFC and RFG where further processing takes place. Data messages originating in the RFG are sent on the outbound path. Voice messages originating in the fixed network are also sent on the outbound path. This allows the repeater to transmit and receive independent data messages, and voice messages, at the same time.

A voice or data message also includes status symbols and a Network Access Code (NAC), which are not, in general, copied from the receiver to the transmitter. Instead the repeater substitutes its transmit NAC in place of the received NAC, and it substitutes status information about the inbound channel for outbound status symbols. This is true of repeaters in either configuration, but the option to substitute NAC codes is usually only exercised for simple configurations, in systems as shown in Figure 3-1.

Outbound status symbols from a repeater are set to the Busy state while the repeater's receiver is receiving an inbound message. They are set to an Idle state when the receiver is not receiving an inbound message. This circumstance is only likely to happen for a repeater in the fixed network configuration. In these systems, the outbound and inbound channels are independent and it is possible to send data packets on the inbound channel while a host computer or console is sending an outbound voice or data message.

Status symbols, in general, can be slotted. The operation of slotting simply means that not every status symbol is asserted to be Busy or Idle. Instead, the Busy or Idle indication comes at the end of a slot boundary, and the intervening status symbols on microslot boundaries are set to an Unknown value. A slot consists of N microslots. In the simplest possible case N=1, but this document does not constrain the value of N. Slotting is shown in Figure 7-2.

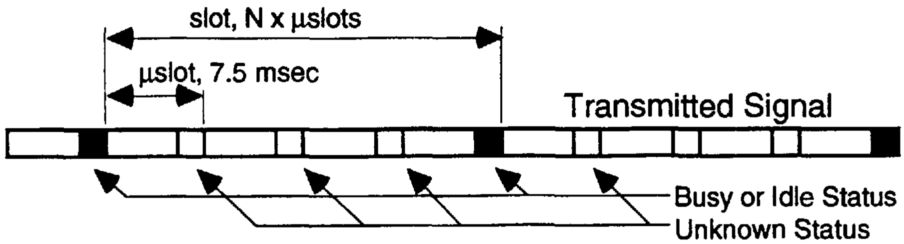

Figure 7-2 Slotted Status Symbols
N=4 is shown

The repeater asserts the status symbol at a slot boundary according to activity on the inbound channel. The activity indication may be determined by the detection of the Frame Synchronization sequence defined in the Common Air Interface. In some cases this detection may be further qualified by the detection of the Network Access Code in the NID word following the Frame Sync. The case for qualification with the NAC is presented in Section 3 and is shown in Figure 3-1 where more than one repeater shares a channel and is accessed by the specific code. Qualification with the NAC may also be done to reject co-channel interference as shown in Figure 3-2. When the repeater's receiver has detected activity, it shall assert a Busy indication on the next status symbol on the next slot boundary. This is shown in Figure 7-3.

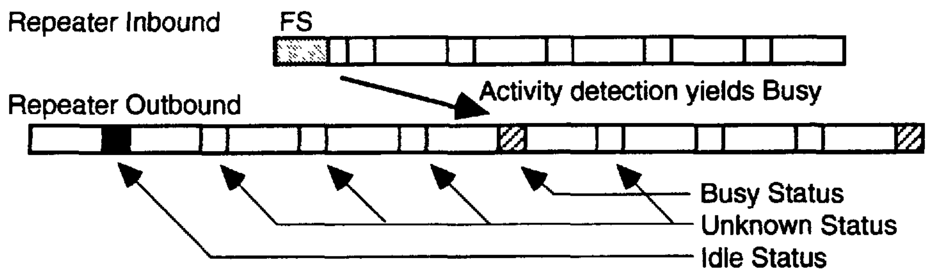

Figure 7-3 Assertion of a Status Symbol

Fixed network repeaters may or may not qualify the Frame Sync detect with a NAC, but the most common configuration is likely to be a simple Frame Sync detect. This is because the Frame Sync detect is faster, and allows the repeater to operate with a shorter slot duration.

The choice of slot time is not specified in this document. It is dependent on the operating parameters of the repeater or radio system.

8. Packet Data Transmit Operation

The direct and repeater systems described in section 1.1 are sufficient for basic voice systems, and some basic data systems. The systems, as shown, require that data messages contain both a source and a destination ID so that messages can be acknowledged properly. This form of addressing for data packets will be called symmetrical addressing. It requires an additional block after the header to include the second address.

A very useful data system that is slightly more complex allows a repeater to be connected to a host computer via an RF Gateway (RFG) function. Within the RF system there is usually an RF Controller function (RFC) which queues data packets for transmission and acknowledges the receipt of inbound packets. The RFC may perform other functions as well, but these are the principle ones that are important for data operation. This type of system is shown in figure 8-1.

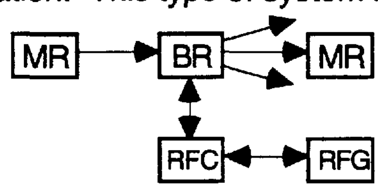

Figure 8-1 Data System with Asymmetrical Addressing

This system always directs inbound data packets from the subscriber units to the RFC and RFG. The outbound packets go from the RFG to the RFC and then to the subscriber units. This type of system only requires an originating address on inbound packets and a destination address on outbound packets. This single address is contained within the header block of the data packet. An additional block for addressing is not required. This will be called asymmetrical addressing for data packets.

The transmission of a data packet follows a polite procedure which minimizes collisions on the radio channel. This procedure waits until the channel is available before transmitting the data packet. The channel is available if either of two conditions is true.

1. **Idle Status Symbol** is detected. In this case, the receiver is listening to a repeater system's outbound channel and the repeater has signaled that the inbound channel is idle. Idle Status Symbols are never sent in direct systems.
2. **No channel activity** is detected. In this case, the receiver is unable to hear any activity on the radio channel. This works in either direct or repeater systems.

The process that the MR determines the inbound channel status and accesses the channel is illustrated by the state diagram in Figure 8-2. The MR should always assume that the inbound channel state is Unknown until it has determined otherwise.

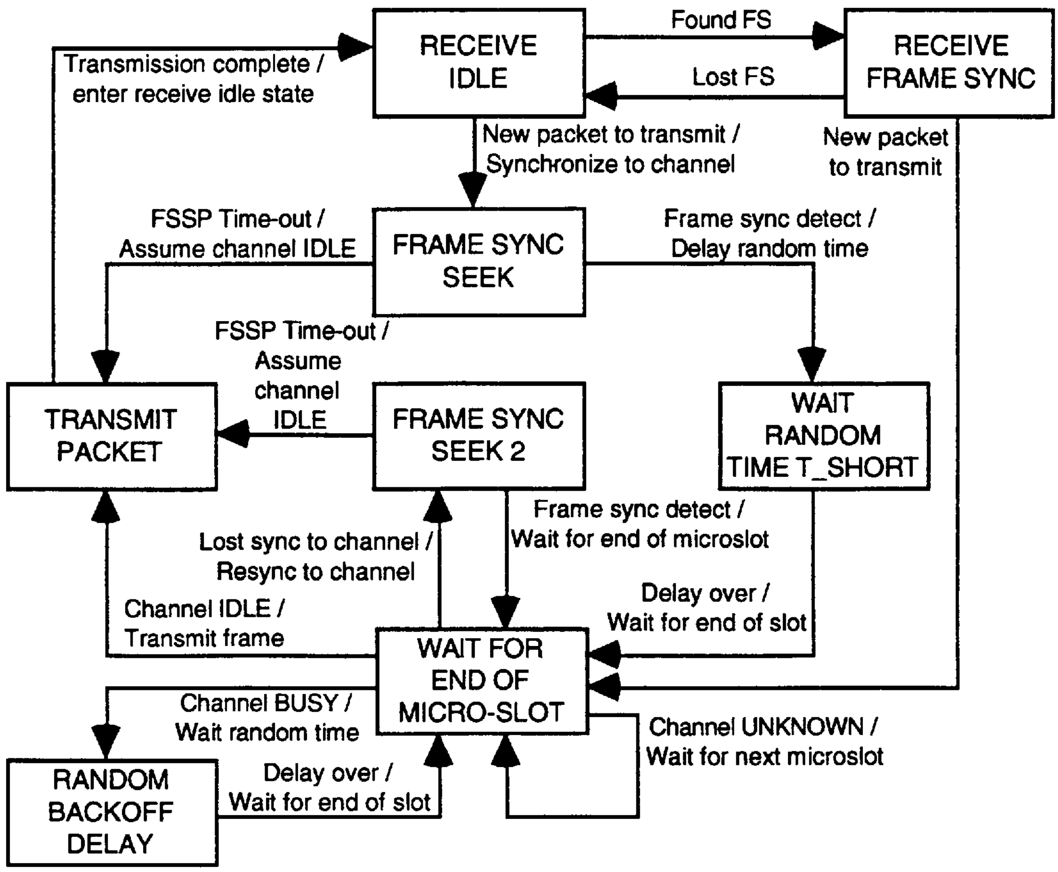

Figure 8-2 Channel Access State Diagram

8.1 MR Channel Access Procedure

MR transmit procedures are implemented to organize inbound transmissions in a manner which expedites the completion of data communications transactions in progress and reduces the potential for collisions between contending MRs. These procedures are described below, with reference to Figure 8-2.

1. While the MR is in the RECEIVE IDLE state and it has nothing to transmit, it shall respond to the arrival of a Frame Sync pattern by going to the RECEIVE SYNC state. In the RECEIVE SYNC state the receiver shall decode the NID and header block of each packet in order to recognize the NAC and its own address. After receiving any messages, if there are no further Frame Sync patterns then the receiver shall go to the RECEIVE IDLE state. Generally, an idle receiver will oscillate between these two states until the radio has a message to transmit. At that point in time it will go to either the FRAME SEEK SYNC state or the WAIT FOR END OF MICRO-SLOT state.

2. In the FRAME SYNC SEEK state, the MR tries to locate a Frame Sync sequence on the outbound channel so that it can determine the location of the channel status symbols. The MR shall respond to the arrival of a Frame

Sync sequence by waiting a random delay time, uniformly distributed between 0 and T_SHORT before it can respond to the channel status symbols. This delay serves to reduce the collision potential with other MRs which have generated packets to be sent since the last outbound message was transmitted. If no Frame Sync is detected for the Frame Sync Seek Period (FSSP) time limit, then the receiver shall go directly to the TRANSMIT PACKET state and begin transmission. The FSSP time limit is set to be at least as long as the longest possible time interval between Frame Sync patterns on the channel.

3. Upon entering the WAIT FOR END OF MICROSLOT state the MR shall delay until the end of the current microslot. The channel status symbol at this boundary will be either IDLE, BUSY, or UNKNOWN. If it is IDLE then the MR may go to the TRANSMIT FRAME state and begin transmission. If it is BUSY then the MR shall enter the RANDOM BACKOFF DELAY state and wait. If it is UNKNOWN then the MR shall return to the WAIT FOR END OF MICROSLOT state. If the end of the outbound transmission occurs and the MR looses sync with the outbound signal for some reason, then it shall go to the FRAME SYNC SEEK 2 state and wait for another Frame Sync sequence to reacquire synchronization with the outbound channel.

4. Upon entering the RANDOM BACKOFF DELAY state, the MR shall delay a random time uniformly distributed between 0 and T_LONG (if the packet is not a response), or 0 and T_ACK (if the packet is a response). After the delay is over the MR returns to the WAIT FOR END OF MICROSLOT state. The random delay redistributes the subsequent accesses of multiple contending MRs into the future to reduce collision potential and prevent them from accessing the channel in lock-step. Note that the maximum delay is shorter for responses than for data messages, which gives them priority access to the inbound channel.

5. In the event that the BR is not transmitting, so no Frame Sync sequences are being sent, the MR operating in the FRAME SYNC SEEK or FRAME SYNC SEEK 2 states will not locate a Frame Sync sequence. After a time-out period of FSSP seconds, if it knows that the channel is not continuously keyed, the MR may assume that the system is not busy and go directly to the TRANSMIT FRAME state.

Table 8-1 lists the parameters for the channel access procedure. These are recommended default values. Different systems may be tuned to operate with different values to improve performance. The FSSP time out value is set equal to the transmit time for a confirmed delivery data packet with 512 octets of data. Some systems may choose to shorten or lengthen this time if the system applications impose different constraints on packet sizes.

Table 8-1 Channel Access Procedure Parameters

Name	Description	Value
FSSP	Frame Sync Seek Period	728 msec
	Channel Access Delay spreads	
T_ACK	- for responses after a BUSY	250 msec
T_LONG	- for all data packets after BUSY	500 msec
T_SHORT	- after first frame sync	50 msec

8.2 Sequence Numbering

In confirmed mode the Common Air Interface is a stop-and-wait protocol. The response packet is the event which causes the next data packet to be sent. The response packet generally indicates an acknowledgment (ACK) or a negative acknowledgment (NACK) of the reception of the packet.

The RFC as well as the MR maintains a pair of sequence number variables, V(S) and V(R). A subscriber only needs to maintain one pair unless it is intended to sustain multiple simultaneous sessions with different subscribers. The RFC must maintain one pair for each subscriber in service. These variables are necessary for each MR that is addressed with a Logical Link ID. V(S) stores the value of N(S) that was used on the last transmitted packet. V(R) stores the value of N(S) from the last packet to be received. V(S) and V(R) are incremented modulo 8, and are represented as a 3-bit number.

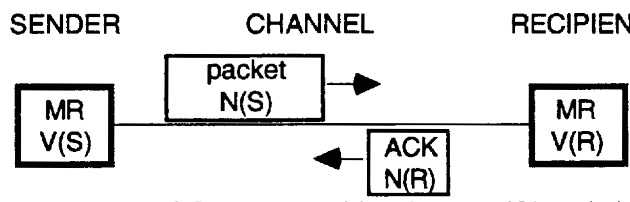

Figure 8-3 Context of Sequence Numbers V(S), V(R), and N(S)

At an instant in time when there are no packets being transmitted, V(S) and V(R) have the following exact interpretations:

V(S) = N(S) of the last unique packet that was transmitted.

V(S) shall be incremented when a new packet is ready to be transmitted over the Common Air Interface.

If the packet is delivered successfully but the ACK is lost, V(S) will be incremented anyway on the next packet. V(S) does not depend on the receipt of an ACK to be incremented.

If all retry attempts fail to deliver a packet, then V(S) of the next new packet that is delivered may be out of sequence, since V(S) is incremented with each new packet. This is an indication to the recipient that one or more packets have been lost. The protocol will not automatically recover the lost packets, but it will adjust the recipient's V(R) as necessary.

V(R) = N(S) of the last packet received successfully.

When the recipient receives each packet, it shall compare N(S) in the packet with its V(R). There are three possible conditions:

N(S) = V(R) + 1 (mod 8). This is the normal case. The recipient shall deliver the packet, increment V(R), and acknowledge the packet.

N(S) = V(R). This may be a duplicate. The recipient shall compare the message CRC of this packet with the message CRC of the last packet that was successfully received. If they match, it shall acknowledge the packet with an ACK, discard it, and leave V(R) unchanged. If the CRCs do not match, the recipient shall acknowledge the packet, deliver it to the appropriate port or service, and leave V(R) unchanged. Without the CRC check, a packet would be incorrectly reduced as a duplicate if 7 packets were lost ahead of it.

N(S) = anything else. Packets have been lost. The recipient ignores the lost packets. It shall assign its V(R) to equal N(S) of the received packet. This will allow duplicate reduction to work correctly on the next packet.

At any instant in time when there are no packets being transmitted, the sender's V(S) should equal the recipient's V(R) variable.

8.3 Resynchronization of Sequence Numbers

A resynchronization of sequence numbers affects both the sender's and recipient's V(S) and V(R). The initiator of a resync initializes its V(S) and V(R) to zero. The initiator then sends a special packet with the resync bit set. The N(S) value of the packet with the resync bit set is zero.

The recipient assigns its V(R) and V(S) to zero when it receives the packet with the resync bit asserted. It also responds with an acknowledgment. When the initiator receives the acknowledgment, it can then begin sending packets in the usual way.

8.4 Fragments

The Common Air Interface uses fragment sequence numbers to support the chaining of packets together into longer logical messages. The high order bit of the Fragment Sequence Number Field (FSNF) is the "last-in-chain" flag. The sequence number formed by the last three bits is initialized to zero for the first fragment of a logical message. This number is incremented before each new fragment is sent, and after 7 wraps back to 1. A message that will fit entirely into a single packet is sent as an "only-in-chain" message. The last-in-chain bit is set and the sequence number field is assigned to zero to specify an only-in-chain message.

Fragment Sequence Number Field (FSNF) values:

1 000 Only-in-chain
0 000 First-in-chain
0 nnn Middle-in-chain (nnn = 1, 2, 3, 4, 5, 6, 7, 1, 2,...)
1 nnn Last-in-chain

The recipient of a logical message fragmented in this way can use the FSNF to determine if a packet has been lost in transmission.

8.5 Procedure to Send a Confirmed Delivery Packet

This is a procedure to send a data packet with selective retries for confirmed delivery. It is used when a new data packet is ready to be transmitted over the Common Air Interface. It is exited when the retries have been exhausted, or the packet has been successfully acknowledged. This procedure applies to packets which originate in MR radios as well as packets which originate in the fixed network (RFC or RFG). The procedure is diagrammed in Figure 8-4.

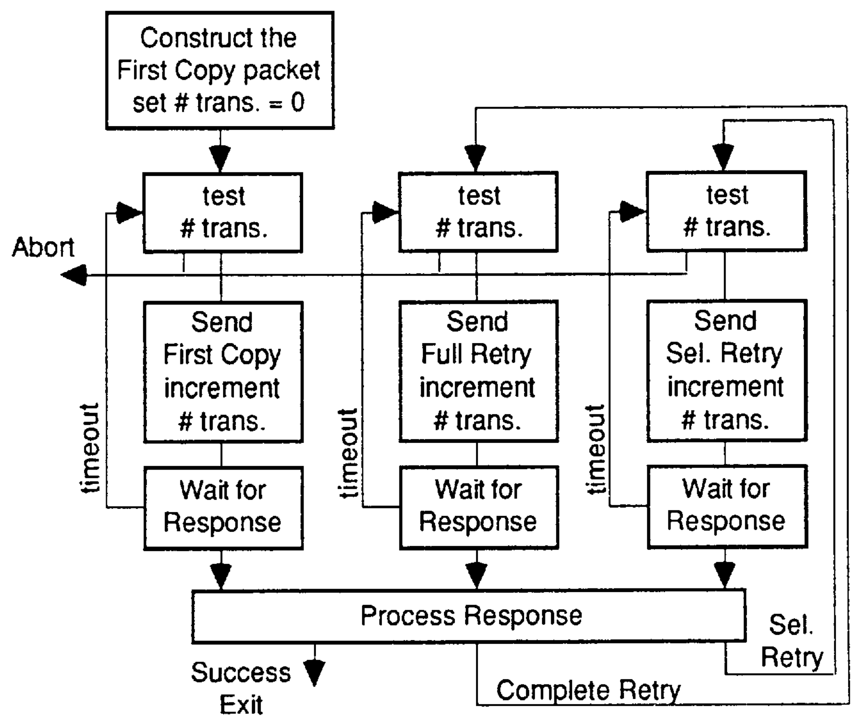

Figure 8-4 Confirmed Delivery Packet Transmission State Diagram

Suggested limit constants:

max_pads	15 pad octets
timeout limit to wait for response	2 seconds
max_number_of_transmissions	4 transmissions

1. Construct the First Copy of the packet.
   1.1 Set Sequence Numbers.
      Increment V(S) modulo 8. Set N(S) ← V(S), Sync bit ← 0. If this is a fragment in a chain then increment the fragment number, otherwise set FSNF ← %1000.
   1.2 Compute the length of the message.
      Let L = number of information octets in the packet. For encrypted messages, L is increased by the encryption overhead defined in the relevant encryption protocol, e.g. reference 2 for DES encryption.
      Set blocks_to_follow ← (L + 4 + max_pads)/16 where the division result is truncated to the nearest integer.
      Set pad_count ← blocks_to_follow x 16 – L – 4.
      Set the Full Message Flag (FMF) ← 1.
   1.3 Format the Header Block and compute the Header CRC.
      Format the header block according to the formats for confirmed delivery data packets in the Common Air Interface. Compute the header CRC from the contents of the header block, as defined in the Common Air Interface.
   1.4 Encrypt the packet.
      Using the Encryption Protocol, encrypt the information in the data packet. See reference 2 for DES encryption.
   1.5 Compute the Message CRC.
      Compute the 32-bit message CRC as defined in the Common Air Interface. This CRC computation includes the pad octets. The message with the 4-octet CRC should be an integer multiple of 16 in length.
   1.6 Break the message into blocks.
      Separate the message into blocks of 16 octets each. For each block of 16 octets add a Serial Number and a 9-bit CRC-9. The Serial Numbers are consecutive, starting at 0 and increasing to blocks_to_follow – 1. The CRC-9 values for each block are computed as defined in the Common Air Interface. For each block of the message a retry flag shall be maintained. Initialize the flags to indicate retries (see steps 4 and 5).
   1.7 Initialize number_of_transmissions ← 0.
2. Transmit the First Copy of the packet.
   2.1 Transmit.
      If the number_of_transmissions ≥ max_number_of_transmissions, then abort the procedure. Otherwise, the blocks of the entire message, including the header block, shall be transmitted according to the definition in the Common Air Interface.
      Increment number_of_transmissions.
   2.2 Wait for a Response.
      Wait for a valid response from the recipient of the packet. The format for the response packet is given in the Common Air Interface. The response must include the proper ID in the Logical Link ID as well as meaningful values for Class, Type and Status. Meaningful values are tabulated in Table 8-2. Other Response packet values are treated as not meaningful. If no meaningful

response packet is received before a timeout interval, then return to step 2.1. Otherwise proceed to step 3.

Table 8-2 Meaningful Class, Type and Status in Response

Class	Type	Status	Meaning
%00	%001	N(R)	ACK -- All blocks successfully received
%01	%001	N(R)	NACK -- Packet error, Data CRC failure
%10	%000	N(R)	ACK -- Selective Retry for some blocks

note: a meaningful value for N(R) is equal to N(S)

3. Process the Response.
   The response packet shall be processed according to Table 8-3.

Table 8-3 Response Disposition

Response Type	Disposition
All blocks successfully received	Exit the procedure
Packet error, Data CRC failure	Go to step 4
Selective Retry for some blocks	Go to step 5

4. Retry the entire packet.
   4.1 Transmit.
   Set the FMF ← 0 (this is a retry, not the first try). Set blocks_to_follow to the value of the full packet. Recompute the CRC for the header block.
   If the number_of_transmissions ≥ max_number_of_transmissions, then abort the procedure. Otherwise, the blocks of the entire message, including the header block, shall be transmitted according to the definition in the Common Air Interface.
   Increment number_of_transmissions.
   4.2 Wait for Response.
   Wait for a valid response as in step 2.2. If a wait timer expires then return to step 4.1. If a valid response is received then go to step 3.
5. Selective retry of parts of the packet.
   5.1 Determine the data blocks to selectively retry.
   Read the data portion of the response packet. If the data CRC has failed then proceed to step 5.2. Otherwise, mark the blocks of the message which are to be retried from the flags in the response packet data, as defined in the Common Air Interface.
   5.2 Selective Retransmission of the packet.
   Set the FMF ← 0 (this is a retry, not the first try). Set the blocks_to_follow to indicate the number of data blocks being retried. Recompute the CRC for the header block.
   If the number_of_transmissions ≥ max_number_of_transmissions, then abort the procedure. Otherwise, the blocks of the message that are marked to be retried, and the header block, shall be transmitted as defined in the Common Air Interface.
   Increment number_of_transmissions.
   5.3 Wait for Response.
   Wait for a valid response as in step 2.2. If a wait timer expires then return to step 5.2. If a valid response is received then go to step 3.

9. Packet Data Receive Operation

Data packets are received when the addressing on the packet is directed to the receiver. The address includes the NAC and a destination unit ID. If both of these qualify the packet, then the packet is accepted by the receiver and further processing by encryption functions and other applications is allowed.

The processing of unconfirmed delivery data packets is not defined any further in this document. These data packets are directed to the service indicated in the Service Access Point identifier (SAP) in the data packet.

9.1 Procedure for Receipt of a Confirmed Data Packet

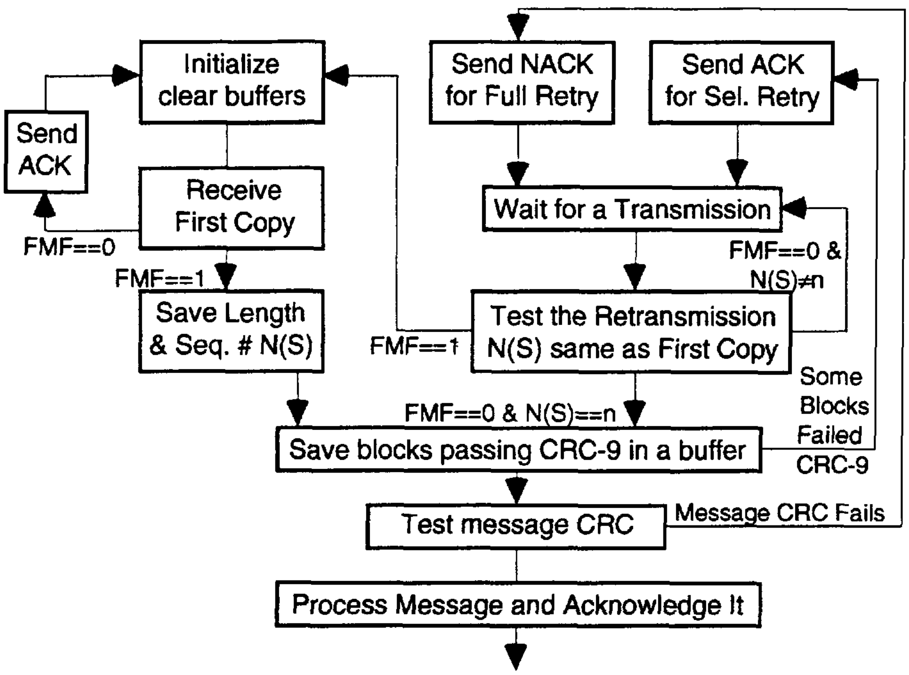

Figure 9-1 Confirmed Delivery Packet Reception State Diagram

This is a procedure to follow upon receipt of a data packet which requires confirmation. It is entered when a new data packet is received over the Common Air Interface. The procedure is diagrammed in Figure 9-1 and described in this Section. A new data packet is "received" when

the Frame Sync and Network ID are decoded,
the Data Unit ID in the NID indicates a data format, and
the Header Block in the data format has been decoded and
it has successfully passed the Header CRC comparison.

After this, the receiver can decode the blocks_to_follow field and receive the remainder of the packet.

1. Initialize.
   Clear a buffer which stores blocks of a packet. The receiver will wait indefinitely in this state until a packet arrives.
2. Receive a First Copy of a packet.
   If FMF = 1 then continue on to step 3.
   If FMF = 0 then a partial retry is received, without a valid First Copy. This can happen if the ACK for a packet is lost and the originator of the packet retries automatically. The receiver shall acknowledge receipt of the packet but discard the contents and return to step 1.
3. Save the Length and Sequence Number parameters.
   Save the blocks_to_follow and pad_octet_count values from the header block. Set n ← N(S), in order to distinguish this packet from others that may be transmitted later. Go to step 8.
4. Selective Retry.
   Send an ACK with Class = %10, Type = %000, Status = N(S), and with the flags set and cleared to indicate which blocks to retry, according to the Common Air Interface; then go on to step 6.
5. Complete Retry.
   Send a NACK with Class = %01, Type = %001, Status = N(S), and with no flags (i.e. blocks_to_follow = 0), according to the Common Air Interface; and continue on to step 6.
6. Wait for a Transmission.
   Wait for the sender to transmit another copy of the message. The receiver may wait indefinitely in this state. Once another transmission is received proceed with step 7.
7. Test the Retransmission.
   At this point the receiver has to distinguish three different cases.
   Case 1. FMF=1. In this case a new First Copy packet has been received. The receiver should start over with step 1 and then go to step 2. This can occur if the last retransmission of a packet fails to be received, and the originator starts over with a new packet.
   Case 2. FMF=0 and N(S)≠n. In this case a retransmission of a different packet has been received. The receiver may ignore the transmission and return to step 6 to wait some more.
   Case 3. FMF=0 and N(S)=n. In this case an expected retransmission has been received. The receiver proceeds to step 8.
8. Save blocks passing the CRC-9 parity check.
   For each block in the packet, if the CRC-9 passes, then update the buffered message block according to the serial number in the block and mark the block as received so that selective retries will not be requested. If not all of the blocks have passed the CRC-9 parity check, then go back to step 4. Otherwise proceed to step 9.
9. Test the Message CRC.
   Now the 32-bit message CRC is tested. If this parity check fails, then the receiver requests a complete retransmission by going to step 5. If the parity check passes then finish up in step 10.
10. Process the Message and Send an Acknowledgment.
    At this point the packet has passed all the CRC checks. Send an ACK with Class = %00, Type = %001, and Status = N(S). Test the packet

sequence number, N(S), against V(R). If N(S) = V(R) and the message CRC = last_message_CRC, then the packet is a duplicate and should be discarded. Otherwise the packet is accepted and the receiver shall send it to the Service Access Point (SAP) indicated in the header block. If an encrypted service is selected, then the packet will be decrypted at this point. Set V(R) ← N(S), and last_message_CRC ← CRC of this message.

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