6 APCO-25

Unlike D-STAR, which is a digital standard devised by and for Amateur Radio, APCO-25 was developed specifically for local, state and federal public safety communications. "APCO" is the Association of Public-Safety Communications Officials, originally an association of police communication technicians, but now a private organization. APCO has a technical standards group responsible for planning the future needs of police (and more recently public-safety) users. It was through this group that a standard for advanced narrow-band digital communications (voice or data) was developed. This standard is known as APCO Project 25, APCO-25, or simply P25.

The overall purpose of the APCO-25 standard is to make it possible for governments to shift from analog to digital communications with the least difficulty possible. This means placing a great deal of emphasis on *backward compatibility* (P25 radios include analog operation and newer P25 technology doesn't render older technology instantly obsolete) and *interoperability* (the ability for all P25 radios to communicate with each other).

In the public safety world, interoperability is a key selling point. The chaotic communications experience in New York City during the September 11, 2001 terrorist attack and in 2005 during Hurricane Katrina demonstrated the critical importance of interoperability. During both disasters there were numerous instances where radio communication between various groups was impossible because each group was using mutually incompatible equipment.

APCO-25 is comprised of a "Suite of Standards" that specifies eight open interfaces between the various components of a land mobile radio system.

- **Common Air Interface** (CAI) standard specifies the type and content of signals transmitted by compliant radios. One radio using CAI should be able to communicate with any other CAI radio, regardless of manufacturer. There is a detailed explanation of the Common Air Interface in Appendix C of this book.
- **Subscriber Data Peripheral Interface** standard specifies the port through which mobiles and portables can connect to laptops or data networks
- **Fixed Station Interface** standard specifies a set of mandatory messages supporting digital voice, data, encryption and telephone interconnect necessary for communication between a Fixed Station and P25 RF Subsystem
- **Console Subsystem Interface** standard specifies the basic messaging to interface a console subsystem to a P25 RF Subsystem
- **Network Management** Interface standard specifies a single network management scheme which will allow all network elements of the RF subsystem to be managed
- **Data Network Interface** standard specifies the RF Subsystem's connections to computers, data networks, or external data sources
- **Telephone Interconnect Interface** standard specifies the interface to Public Switched Telephone Network (PSTN) supporting both analog and ISDN telephone interfaces.
- **Inter RF Subsystem Interface** (ISSI) standard specifies the interface between RF subsystems which will allow them to be connected into wide area networks.

You'll find more details about the APCO-25 standard on the Web at **www.apcointl.org/frequency/project25/index.html**.

APCO-25 "PHASES"

The APCO-25 rollout was planned in "phases." Phase 1 radio systems operate in 12.5 kHz analog, digital or mixed mode. Phase 1 radios use continuous 4-level FM (C4FM) modulation for digital transmissions at 4800 baud and 2 bits per symbol, which yields 9600 bits per second total throughput. It is interesting to note that receivers designed for the C4FM standard can also demodulate the compatible quadrature phase shift keying (CQPSK) standard. The parameters of the CQPSK signal were chosen to yield the same signal deviation at symbol time as C4FM while using only 6.25 kHz of bandwidth. This is to pave the way for Phase 2, which we'll discuss in a moment.

In a typical Phase 1 radio, the analog signal from the microphone is compressed and digitized by an Improved Multi-Band Excitation, or *IMBE*, vocoder. This is a proprietary device licensed by Digital Voice Systems Corporation. The IMBE vocoder converts the voice signal from the microphone into digital data at a rate of 4400 bps. An additional 2400 bps worth of signaling information is added, along with 2800 bps of forward error correction to protect the bits during transmission. The combined channel rate for IMBE in P25 radios is 9600 bps. **Figure 6-1** shows a block diagram of a typical P25 transceiver.

P25 radios are able to operate in analog mode with older analog radios and in digital mode with other P25 radios. If an agency wants to mix old analog radios with P25 radios, the system must use a control channel that both types of radios can understand. That means a trunked radio system.

Phase 1 is the current phase in use at the time this course was written and is likely to be in force for a number of years to come. Phase 2 is still under development. Phase 2 will use the AMBE vocoder, the same one used in D-STAR equipment (this does *not* mean that Phase 2 APCO-25 and D-STAR will be interoperable, however). Phase 2 also involves console interfacing between repeaters and other subsystems, and man-machine interfaces for console operators that would facilitate centralized training, equipment transitions and personnel movement.

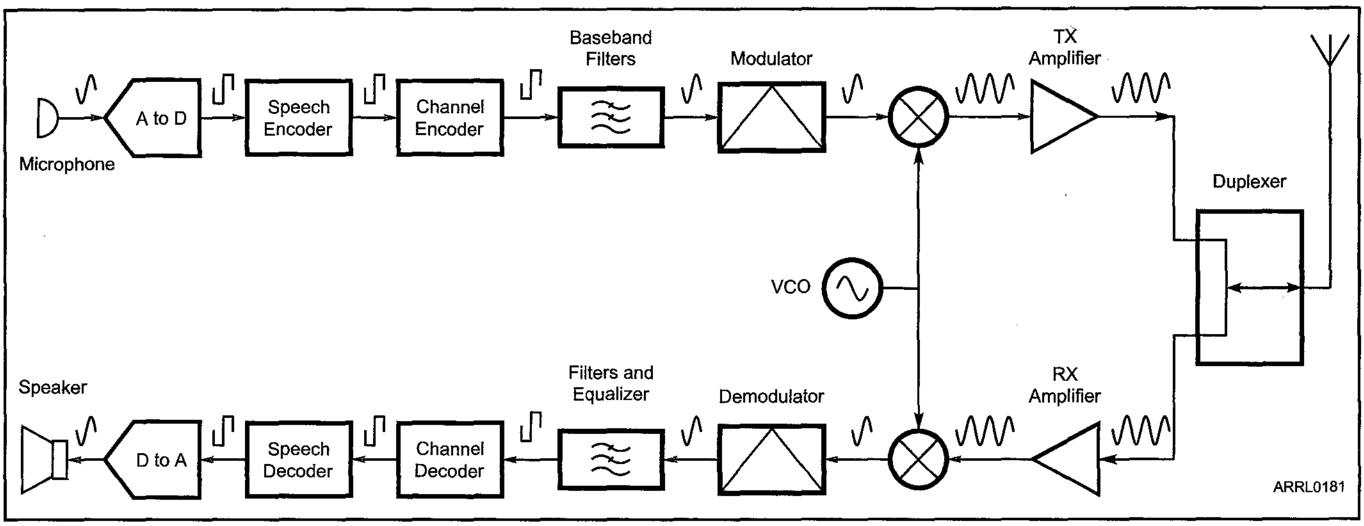
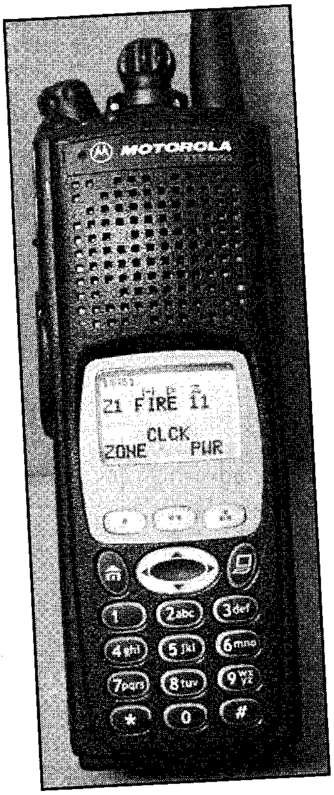


Figure 6-1—Block diagram of a typical P25 transceiver.

OPERATING APCO-25

APCO-25 transceivers vary substantially from one manufacturer to another, but there are some common elements. For example, there are 3 methods to send a voice message, with several options and variations of each case.

- **Routine Group Call:** This is the most common type of call and is intended for a group of users within the system. This type of call is typically initiated by pressing the Push-To-Talk switch.
- **Emergency Group Call:** This type of call is similar to a Routine Group Call, but is used during an emergency condition. An emergency condition is defined by the radio system users. This type of call is typically initiated by pressing the **EMERGENCY** switch, which is prominent on every APCO-25 compliant radio.
- **Individual Call:** This type of call is addressed to a specific individual. The caller enters the subscribers Unit ID and this is used as the Destination ID by the radio making the call. This type of call is made after the Destination ID is entered into the radio. For ham



A Motorola handheld P25 transceiver.

application, the Unit and Destination IDs can be call signs.

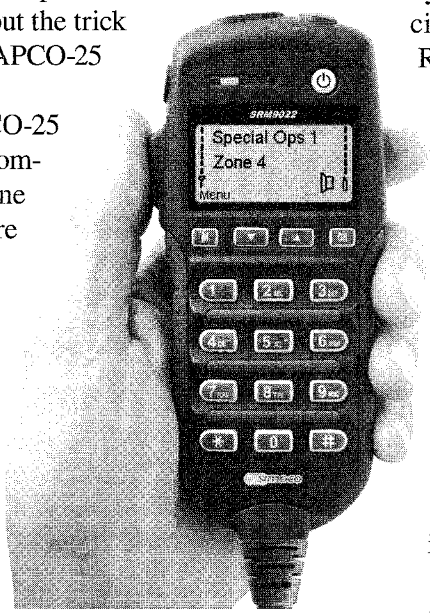
In addition to data capability, APCO-25 radios and repeater systems also support various control messages. These control messages use packet data to transfer discrete information. For example...

- **Emergency Alarm:** Activated by a user to inform the dispatcher that an emergency is taking place.
- **Call Alert:** Sends a data packet to another user identifying the source of the Call Alert and requesting the destination station to contact the source. Call Alert is typically used if the destination user did not respond to a voice message from the source.
- **Radio Check:** Used to determine if a specific user is currently available on the radio system. A response to the Radio Check is required, or the system will assume the user is not available.
- **Radio Inhibit (Radio Uninhibit):** Used to deny all calls between the inhibited user. Uninhibit cancels the inhibit status of the user.
- **Status Update and Status Request:** Status Update is used by a user to indicate his or her current status. Status Request is used by a user to request the current status of a another user.
- **Message:** A Message may be sent by a user to the system or to a specific user.
- **Telephone Interconnect Dialing:** If a telephone connection is available through the system, the user can place a call, or someone outside the system can call the user.
- **Radio Unit Monitor:** A form of remote control that will key a user's radio upon request from a central dispatcher so that he or she can listen to activity at the user location.

APCO-25 AND AMATEUR RADIO

At the time this book was written, no one was making APCO-25 transceivers specifically for the Amateur Radio market, but that hasn't stopped some hams from exploring this mode. Because APCO-25 is an open, published standard, it *is* legal for Amateur Radio, but the trick is finding the means to adapt commercial APCO-25 gear to ham purposes.

The present-day Amateur Radio APCO-25 world looks a lot like the analog FM community in the early 1970s. Back then, none of the Amateur Radio manufacturers were making FM transceivers or repeaters. Hams were forced to modify existing commercial FM gear, which typically consisted of transceivers that had seen duty in police cruisers, taxi cabs and so on. Many of the FM "gurus" in those days were individuals who were employed by two-way radio service shops. These hams had easy access not only to test equipment, but also to the knowledge of how to modify commercial transceivers for ham applications. They built the first Amateur Radio FM repeaters by repurposing commercial two-way radio transmitters and receivers.



Mobile P25 rigs are often supplied with sophisticated microphone units that display user ID, GPS location data and short text messages.

Amateur Radio APCO-25 enthusiasts today are treading the same path taken by analog FM pioneers more than 30 years ago. They are modifying commercial APCO-25 equipment for Amateur Radio and setting up APCO-25 repeater systems. Thanks to online sites such as eBay, it is relatively easy to track down surplus APCO-25 transceivers. Manufactured in both handheld and mobile configurations, these rigs are available for either VHF or UHF.

Modifying commercial APCO-25 radios has become a software hacking game. Since most functions of these radios are software defined, you can change their operating characteristics (including frequencies) with a computer and a compatible interface.

The first step is to obtain the programming software, which can be different for every brand. Some manufacturers provide programming software if you purchase the radio as new equipment.

A MA/COM APCO-25 mobile transceiver.

Others are highly restrictive and will not provide their software under any conditions. Motorola, a popular brand among amateur P25 users, uses different programs for every transceiver model. The programming software must be purchased from them at a cost of $250 to $300. To reprogram the Motorola transceivers (as well as many other brands), you may need a hardware device that is sometimes referred to as a Radio Interface Box, or RIB.

The downside of using surplus commercial equipment is that it can be expensive. At the time of this writing, used handheld APCO-25 transceivers were selling for as much as $700 at eBay and other sites. Modified APCO-25 repeaters can cost several thousand dollars.

The cost hurdle hasn't deterred hams from setting up APCO-25 networks. There are more than a dozen amateur APCO-25 repeater system in operation throughout the United States. Many of these repeaters operate in mixed mode—analog and digital. Others are digital only. The ability to operated in mixed modes is one of the strengths of Amateur Radio APCO-25. An APCO-25 repeater, for instance, can support digital voice and data with APCO-25 transceivers, but can still relay analog FM traffic.

More ham-related programming information is available at the following Web sites, although it applies specifically to Motorola transceivers:

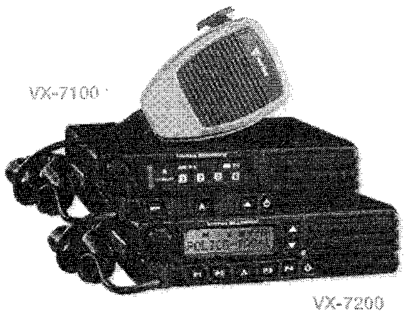
- **www.batlabs.com/newbie.html**
- **www.batlabs.com/flash.html**

AMATEUR APCO-25 IN EMERGENCY APPLICATIONS

APCO-25 transceivers can operate in either analog or digital voice modes. APCO-25 rigs also support selective calling and are capable of sending data within a networked environment.

APCO-25 has potential for use in Amateur Radio emergency communications, although that potential has yet to be tested. Some manufacturers are marketing rapid deployment APCO-25 repeaters, which can be used to set up networks at a moment's notice. Many of these are designed to use solar power.

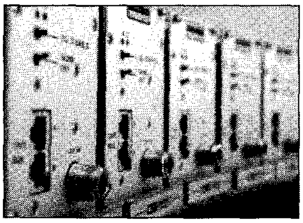
Two Vertex (Yaesu) APCO-25 radios.



With a network of portable repeaters in the disaster zone, and possibly long-distance VHF/UHF data links to the nearest Internet access point, an Amateur Radio implementation of APCO-25 may provide excellent service.

APPENDIX C

Reprinted with permission from Daniels Electronics from
P25 Radio Systems Training Guide



ANATOMY OF THE COMMON AIR INTERFACE

VOICE

The P25 standard requires the use of the IMBE™ Vocoder to encode speech (tone and audio level) into a digital bit stream. The IMBE™ digital bit stream is broken ino voice frames where each voice frame is 88 bits in length (representing 20 ms of speech). The voice frames are protected with error correction codes which add 56 parity check bits resulting in an overall voice frame size of 144 bits. The voice frames are grouped into Logical Link Data Units (LDU1 and LDU2) that contain 9 voice frames each. Each Logical Link Data Unit is 180 ms in length and can be consecutively grouped into Superframes of 360 ms. The superframes are repeated continuously throughout the voice message after a Header Data Unit has been sent. Additional information (encryption, Link Control information and Low Speed Data) is interleaved throughout the voice message.

The voice message structure for a P25 CAI voice transmission is shown in Figure 4-1. The voice message begins with a Header Data Unit (to properly initialize any encryption and link control functions for the message), and then continues with Logical Link Data Units or LDUs. The LDUs alternate until the end of the voice message. The end of the message is marked with a Terminator Data Unit. The Terminator Data Unit can follow any of the other voice data units.

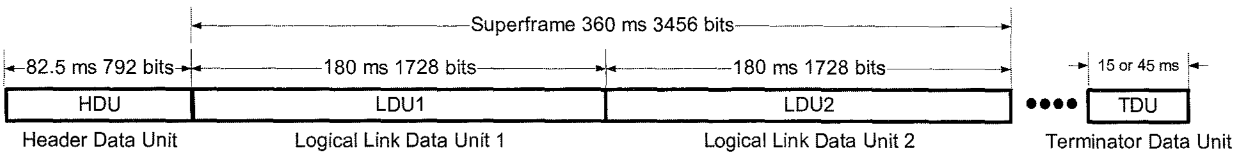


Figure 4-1: P25 Voice Message Structure

DATA

Data messages are transmitted over the P25 CAI using a packet technique. The data information is broken into fragments, packets and blocks are then error coded and sent as a single packet called a Packet Data Unit. The Packet Data Unit can be of varying lengths and includes a header block that contains the length of the data message.

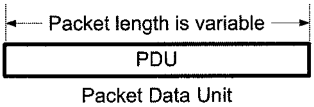
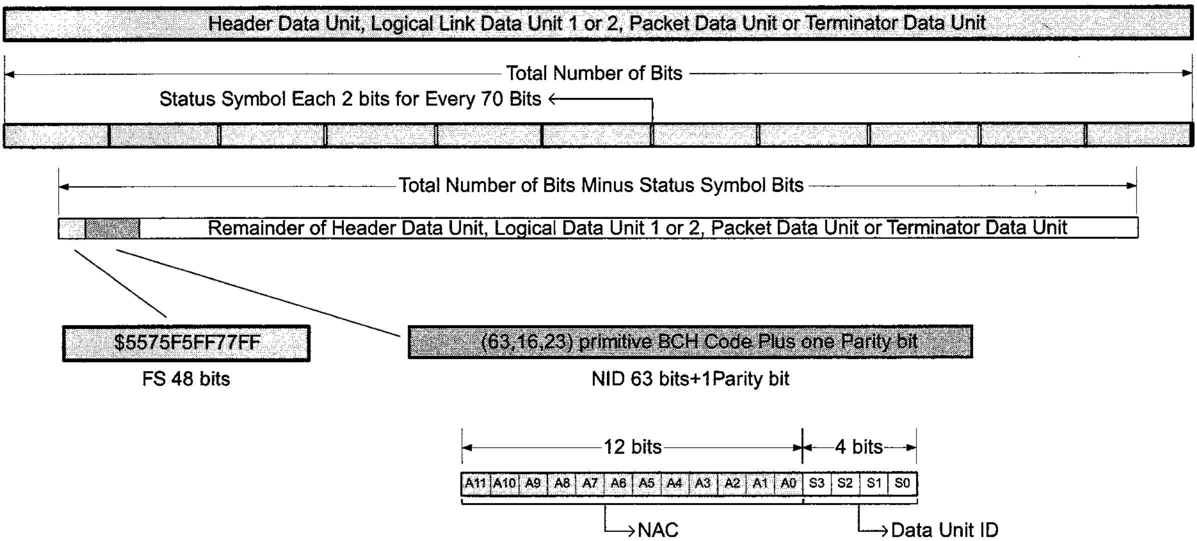


Figure 4-2: P25 Data Message Structure

FRAME SYNCHRONIZATION AND NETWORK IDENTIFIER

Each data unit (Header Data Unit, Logical Link Data Unit 1, Logical Link Data Unit 2, Packet Data Unit and Terminator Data Unit) begins with a Frame Synchronization (FS) and Network Identifier (NID).



Data Unit ID	P	Data Unit Usage
0000	0	Header Data Unit
0011	0	Terminator without subsequent Link Control
0101	1	Logical Link Data Unit 1
1010	1	Logical Link Data Unit 2
1100	0	Packet Data Unit
1111	0	Terminator with subsequent Link Control

The codes for the 6 different data units are shown.
The other 10 data units not shown are reserved for use in trunking or other systems.
The P bit is the last (64-th) parity bit in the code word.

Figure 4-3: Frame Synchronization and Network Identifier

STATUS SYMBOLS

Throughout all of the data units (Header Data Unit, Logical Link Data Unit 1, Logical Link Data Unit 2, Packet Data Unit and Terminator Data Unit) the 2 bit status symbols are interleaved so that there is one status symbol for every 70 bits of information.

Status Symbol	Meaning	Usage
01	Inbound Channel is Busy	Repeater
00	Unknown, use for talk-around	Subscriber
10	Unknown, use for inbound or outbound	Repeater or Subscriber
11	Inbound Channel is Idle	Repeater

HEADER DATA UNIT

A diagram of the header data unit is given in Figure 4-4. The Header Data Unit is composed of the FS (48 bits), NID (64 bits), and the header code word (648 bits). Ten null bits are added to the end of the header code word resulting in 770 bits. Eleven status symbols are also interleaved throughout the Header Data Unit yielding 792 bits total. The Header Data Unit takes 82.5 ms to transmit at 9.6 kbps (the standard bit rate of the P25 CAI).

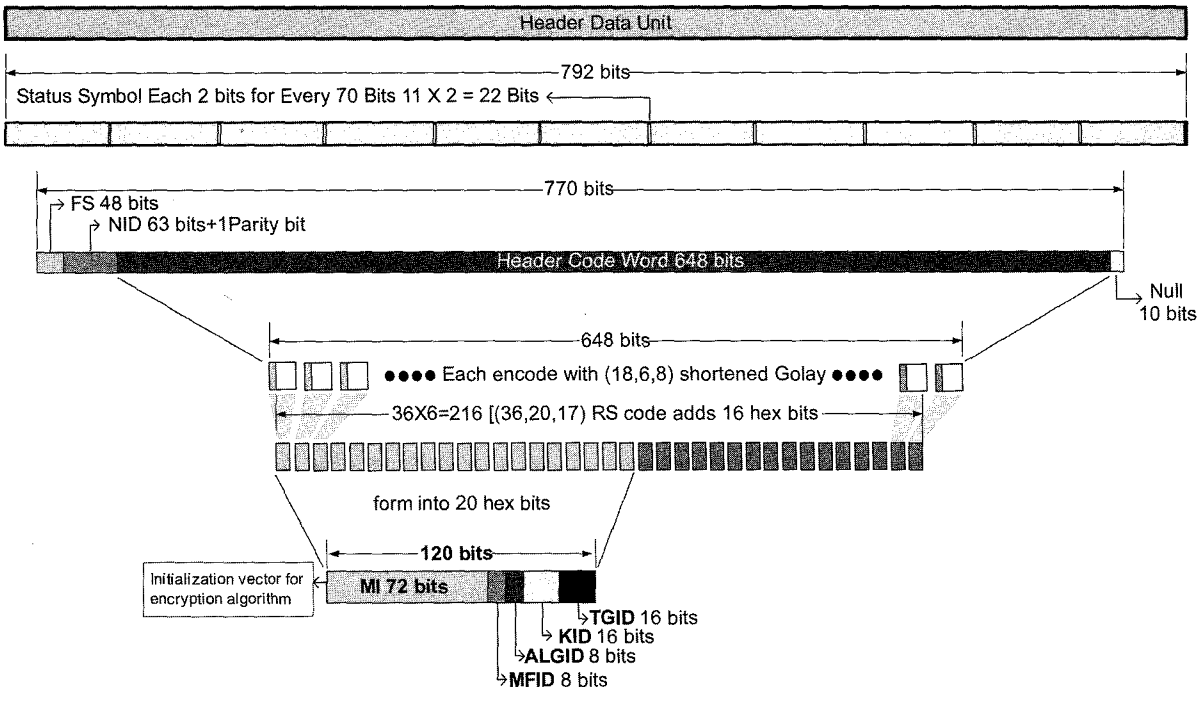


Figure 4-4: Header Data Unit

The Header Code Word field includes a **Message Indicator** (MI), and **Algorithm ID** (ALGID) for the encryption algorithm, and the **Key ID** (KID) for the encryption key as well as the **Manufacturer's ID** (MFID) and **Talk-group ID** (TGID). These information fields total 120 bits.

The information fields are separated into 20 symbols of 6 bits each (these are called hex bits). The symbols or hex bits are encoded with a (36,20,17) Reed-Solomon code to yield 36 hex bits. The 36 hex bits are then encoded with a (18,6,8) shortened Golay code to yield 648 bits total.

VOICE CODE WORDS

The IMBE™ vocoder converts speech into a digital bit stream where the bit stream is broken into voice frames of 88 bits in length for every 20 ms of speech. This corresponds to a continuous average vocoder bit rate of 4.4 kbps. Voice frames consist of 8 information vectors, labelled u_0, u_1, ... u_7.

Voice frames are encoded into a 144 bit voice code word as follows:

The voice frame bits are rated according to their effect on audio quality and are then protected using Golay and Hamming codes. The 48 most important bits (u_0 through u_3) are error protected with four (23,12,7) Golay code words. The next 33 most significant bits (u_4 through u_6) are error protected with three (15,11,3) Hamming code words. The last 7 least significant bits (u_7) are not error protected. Construction of the IMBE™digital bit stream into voice code words is given in Figure 4-5.

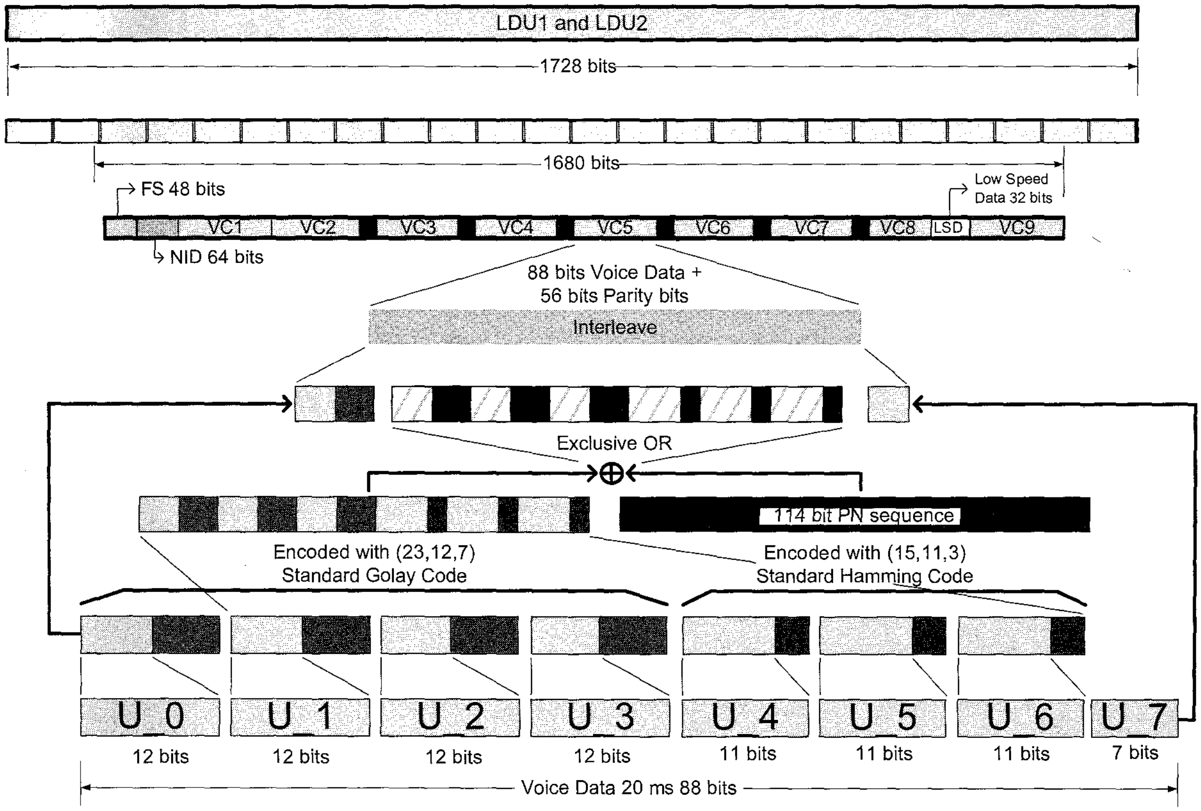


Figure 4-5: Voice Code Word

After the voice data has been error protected using the Golay and Hamming codes, a 114 bit pseudo random sequence (PN sequence) is generated from the 12 bits of u_0. The error protected voice data in u_1 through u_6 is then bit-wise exclusive-ored with the PN sequence. This information is then interleaved throughout the voice frame to resist fades.

LOGICAL LINK DATA UNIT 1

A diagram of Logical Link Data Unit 1 (LDU1) is given in Figure 4-6. LDU1 is the first half of a superframe. LDU1 is composed of the FS (48 bits), NID (64 bits), nine voice code words, numbered VC1 through VC9 (1296 bits), Link Control Word (240 bits) and Low Speed Data (32 bits). Twenty-Four Status Symbols are also interleaved throughout LDU1 yielding 1728 bits total. LDU1 takes 180 ms to transmit at 9.6 kbps (the standard bit rate of the P25 CAI).

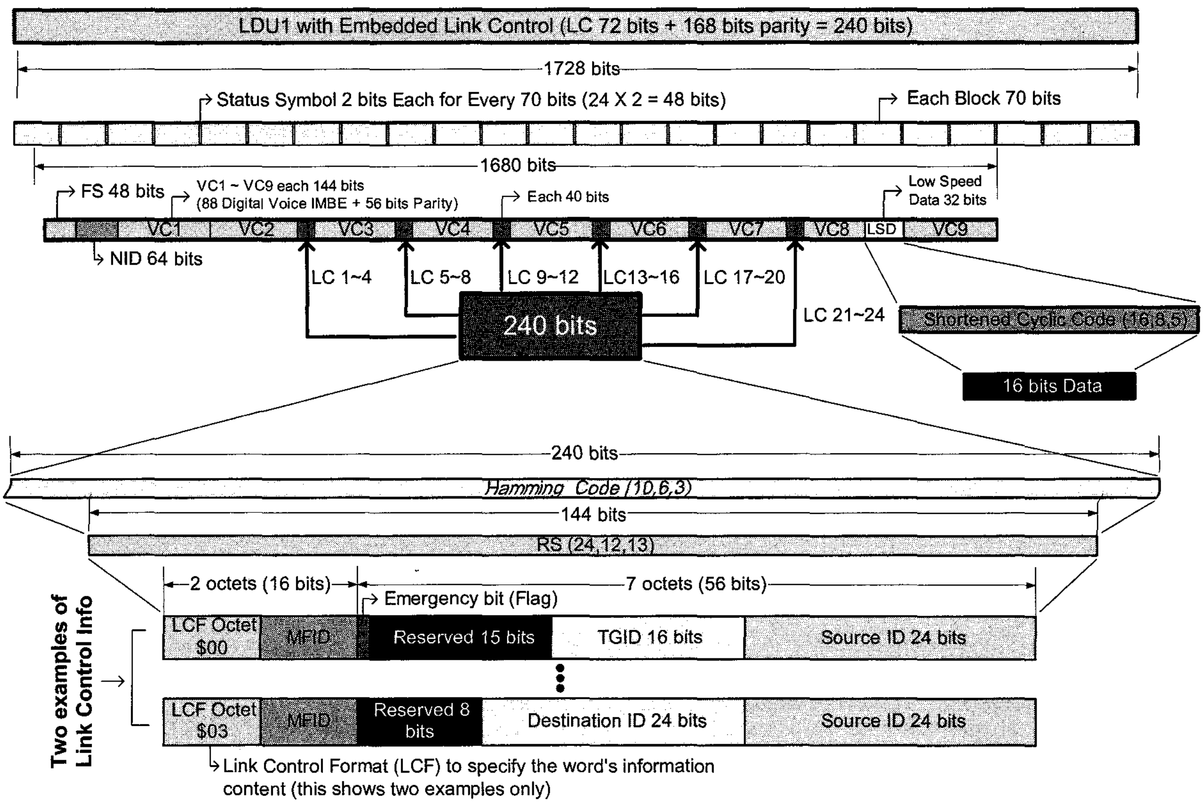


Figure 4-6: Logical Data Unit 1

The Link Control Word field may include a **Talk-group ID** (TGID), a **Source ID**, a **Destination ID**, an **Emergency** indicator, a **Manufacturer's ID** (MFID) and any other necessary call ID information. The Link Control Word uses a variable format since there is too much information for a fixed field format. The type of format is identified by the **Link Control Format** (LCF). The LCF specifies the the content of the Link Control Word's information. Two format examples are diagrammed in Figure 4-6. All of the information fields (including the LCF) total 72 bits.

The Link Control Word is constructed by serializing the information into 12 hex bits and then encoding them with a (24,12,13) RS code to yield 24 hex bits. The 24 hex bits are then encoded with a (10,6,3) shortened Hamming code to yield 240 bits total. The 240 bits of Link Control (LC) information is then inserted in between the voice code words (VC2 to VC8) in blocks of 40 bits (LC 1-4 is a block of 40 bits, etc.).

LOGICAL LINK DATA UNIT 2

A diagram of Logical Link Data Unit 2 (LDU2) is given in Figure 4-7. LDU2 is the second half of a superframe. LDU2 is composed of the FS (48 bits), NID (64 bits), nine voice code words, numbered VC10 through VC18 (1296 bits), Encryption Sync Word (240 bits) and Low Speed Data (32 bits). Twenty-Four Status Symbols are also interleaved throughout LDU1 yielding 1728 bits total. LDU2 takes 180 ms to transmit at 9.6 kbps (the standard bit rate of the P25 CAI).

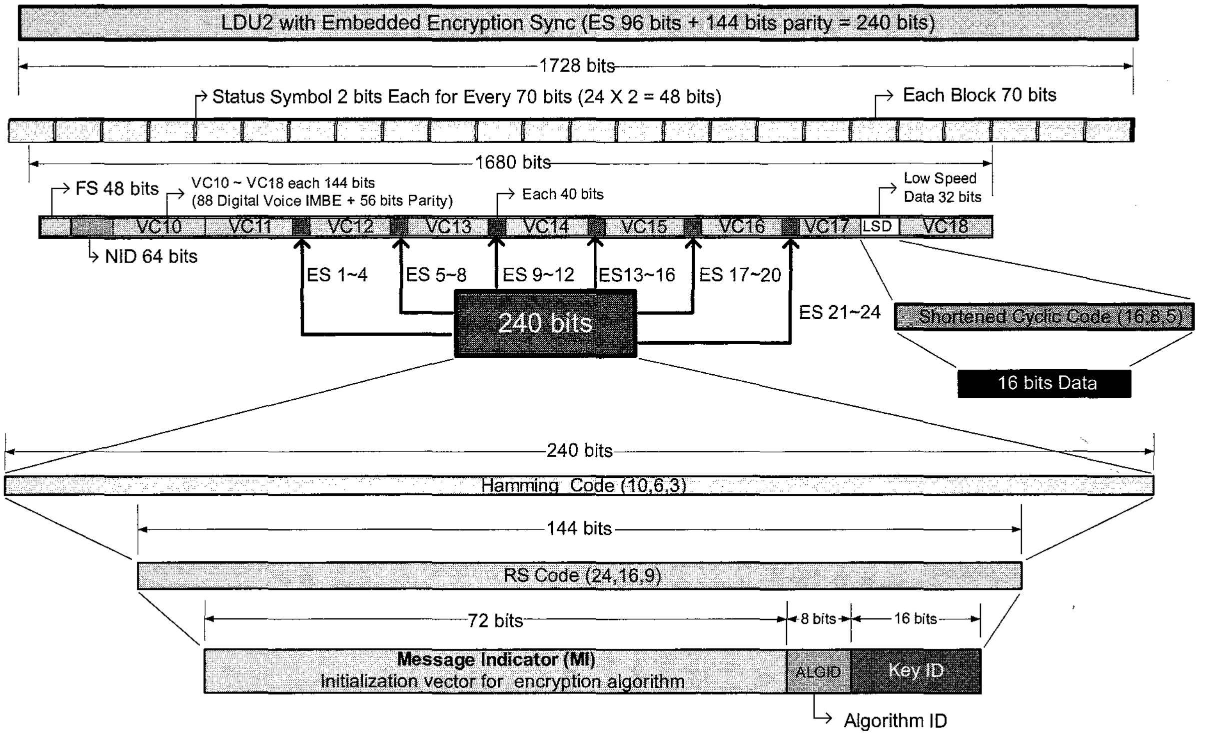


Figure 4-7: Logical Data Unit 2

The Encryption Sync Word field includes the **Message Indicator** (MI), **Algorithm ID** (ALGID) for the encryption algorithm, and the **Key ID** (KID) for the encryption key. This information may be used to support a multi-key encryption system, but is also used for single key and clear messages.

The Encryption Sync Word is constructed by serializing the information into 16 hex bits and then encoding them with a (24,16,9) RS code to yield 24 hex bits. The 24 hex bits are then encoded with a (10,6,3) shortened Hamming code to yield 240 bits total. The 240 bits of Encryption Sync (ES) information is then inserted in between the voice code words (VC11 to VC17) in blocks of 40 bits (ES 1-4 is a block of 40 bits, etc.).

LOW SPEED DATA

Low Speed Data is a serial stream of information. This information is provided for custom applications that are not defined in the CAI. Low Speed Data is comprised of 32 bits of data, 16 bits of which are inserted between VC8 and VC9 in LDU1 and 16 bits are inserted between VC17 and VC18 in LDU2. Each group of 16 bits is encoded with a (16,8,5) shortened cyclic code, creating 32 bits total in each LDU. Low Speed Data has a total capacity of 88.89 bps.

TERMINATOR DATA UNIT

Voice messages may use one of two different Terminator Data Units.. The simple Terminator Data Unit is composed of the FS (48 bits), NID (64 bits), and Null bits (28 bits). A diagram of the simple Terminator Data Unit is given in Figure 4-8.

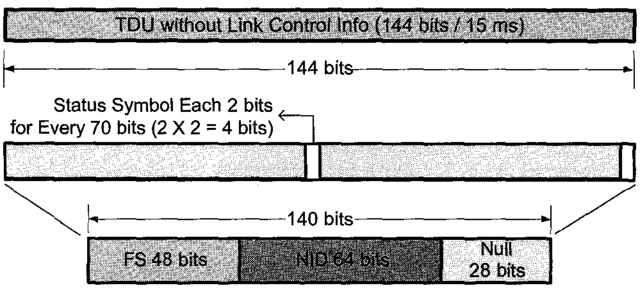


Figure 4-8: Terminator Data Unit without Link Control Info

The Terminator Data Unit can also be sent with the Link Control Word embedded in it. A diagram of the expanded Terminator Data Unit is given in Figure 4-9. The Link Control Word is the same as the Link Control Word used in LDU1, except that it is error protected with a Golay code instead of the Hamming code.

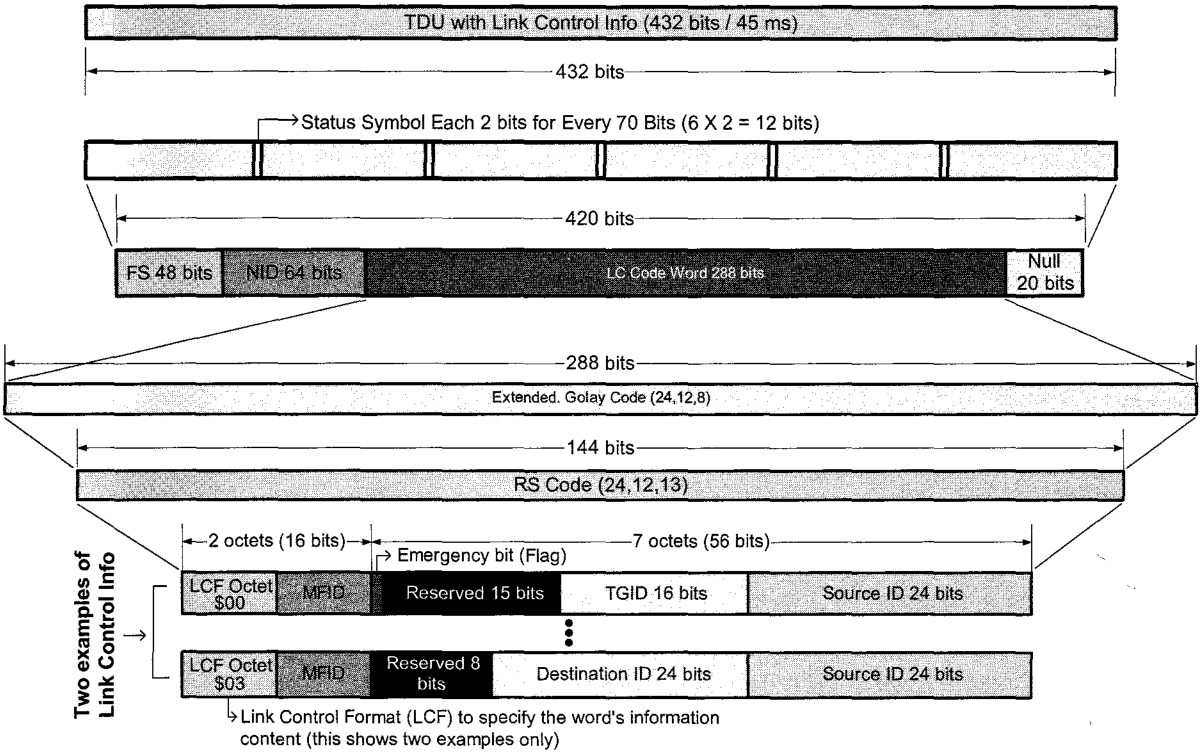


Figure 4-9: Terminator Data Unit with Link Control Info

When the voice message is finished, the transmitter continues the transmission, by encoding silence for the voice, until the Logical Link Data Unit is completed. Once the Logical Link Data Unit is completed, the transmitter then sends the Terminator Data Unit to signify the end of the message. The terminating data unit may follow either LDU1 or LDU2.

PACKET DATA UNIT

A diagram of the Packet Data Unit is given in Figure 4-10. Data Packets use two different types of data with two different structures. Confirmed or uncomfirmed delivery may be used to send data. Confirmed delivery is used when the recipient of the packet is required to send an acknowledgment of receipt. Unconfirmed delivery does not require an acknowledgment of receipt. Confirmed or unconfirmed delivery is defined in the header block.

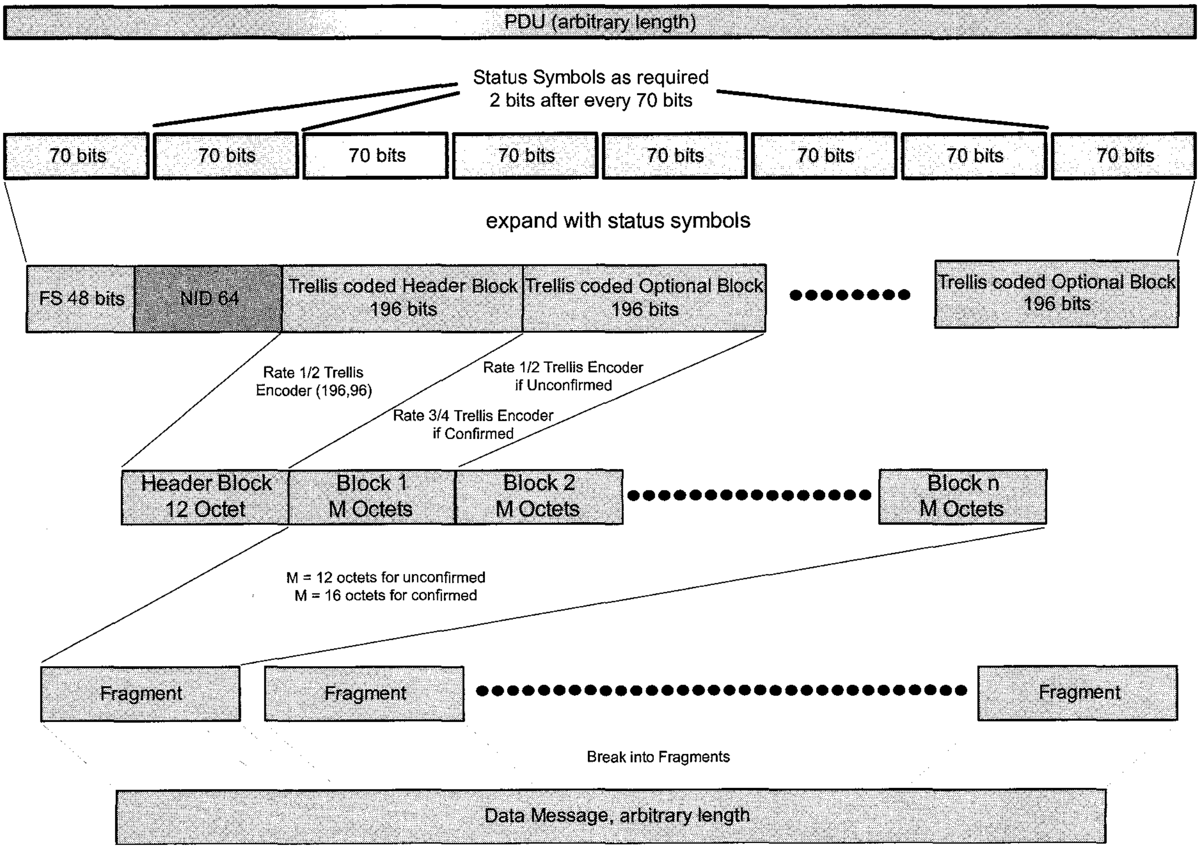


Figure 4-10: Data Packet Unit

Data is sent in variable length packets and the length of the data packet is defined in the header block. When a data packet ends, nulls are added until the next status symbol.

The data message is split into fragments, then formed into packets, and the packets are then split into a sequence of information blocks that are error protected by a Trellis code. These blocks are then transmitted as a single data packet.