AX.25, the common amateur packet radio protocol, is borrowed from the commercial packet switching protocol named X.25. This number is simply a catalog designation for this particular international standard. AX.25 is the AmateurX.25. AX.25 differs in some important details. One of these details is that X.25 has a network master to control operation. Since this was considered unacceptable for ham use, a masterless (also called peer-to-peer) version was developed for AX.25. Also, addressing was changed to meet ham legal requirements.

11.A WHAT IS A PROTOCOL?

The author's "American College Dictionary", 1957 edition, defines protocol as:

> **pro-to-col,** *n.* **1.** an original draft, minute, or record from which a document, esp. a treaty, is prepared. **2.** a supplementary international agreement. **3.** an agreement between states. **4.** an annex to a treaty giving data relating to it. **5.** the customs and regulations dealing with ceremonies and etiquette of the diplomatic corps and others at a court or capitol.

Definition 4 comes perhaps the closest to the current technical usage of this word. A useful way of thinking about it might be to think about sports. Sports protocol is what is written in the referee's rule book. But in each sport, there is also a lot tradition. In U.S. football, for example, there are the cheerleaders, the equipment, the coaches & trainers, and so forth. Most of this is not written about in rules books but is, none the less, part of the sport.

So, also, is it in amateur packet radio. AX.25 is the formal name of the protocol but there are a lot of other things which are thought of as packet radio which really are not part of the AX.25 rule book.

Actually, AX.25 defines only a very small portion packet operation. We will see how small a portion it is and how it fits with many other parts which are often not formalized or agreed on.

11.B. THE "LAYER" MODEL

There is a model (a way of visualizing) which is becoming popular in networking. It is called the ISO OSI Reference Model. ISO stands for International Standards Organization. OSI stands for Open Systems Inter-connection. Many refer to this as simply The Layer Model. It is really a framework or outline to which digital data transmission systems can be fitted. Some schemes fit this model pretty well and some, not so well. AX.25 is not too bad as long as it is recognized that it fits only a small part of the model. There is a diagram which is usually used to illustrate this model. It is shown in Figure 11-1.

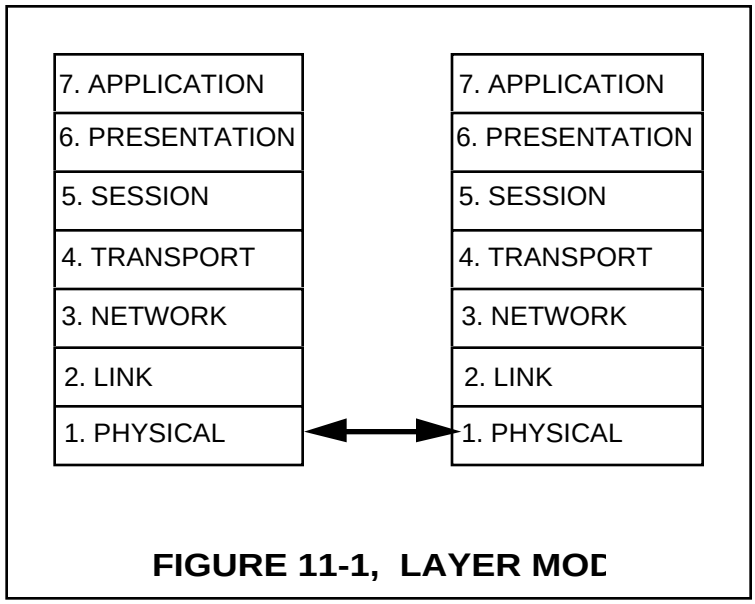

FIGURE 11-1, LAYER MOD

The layer model is important because it defines a way of organizing the computer programs which do packet radio (a TNC is, after all, just a special-purpose computer). When the programs or processes are organized this way, we start to see that:

(a) a Physical Layer does not "care" what the "bits" represent; it simply provides a mechanical means for moving those bits from one place to another.

(b) a Link Layer does not "care" how the bits are moved. It simply constructs the packet and hands it to the Physical Layer for movement.

(c) The Network Layer does not care how links are established. It tells the Link Layer to make a connection. It has a standard message format which it hands to the Link Layer for sending.

(d) Each higher layer, where it is implemented, simply passes the message to the next lower layer, expecting that that layer will move it. And that layer, passes it to the next, expecting the same, until it reaches the Physical Layer where it finally gets moved. The same happen in the opposite order at the receiving end.

11.C. A LAYER MODEL STORY

In several earlier chapters, primitive telephone systems where used to simplify the ideas of connections and routing. Here, we will use another metaphor - a pair of mythical, not-too-long-ago, armies - the Grey Army and the Light-Black Force (that's right, they are difficult to tell apart). These armies have been at war for some time for control of the region where they live. Lets zoom in on one portion of each army, the Grey Message Corps and the Light-Black Dispatch Service. Please accept my apologies about the male-only characters in this little story but in this time not-too-long-ago, almost all soldiers were male!

11.C.1 Runner-Privates: These armies (being somewhat long ago) used runners (Privates, of course) to carry messages between units. Now, these runners really do not care what the message is. They care, thought, about some pretty fundamental things, like - is it small enough? - does it have far go? - is it very heavy? In this, the two armies are really no different.

11.C.2 Command-Post Corporals: In both armies, Corporals are in charge of getting messages moved between command-posts. Corporals in adjacent command-posts have to agree on how messages are to be exchanged.

The Grey Message Corps has chosen a rather elaborate system of message pouches. They have agreed that green pouches are to be used to make initial contact between neighboring command-posts. Red pouches are to be used to end contact. White pouches are for general messages. Yellow ones are sent back to the post which sent a pouch when a white (information) pouch arrives so badly damaged that a new

one is needed to replace the original. The pouches have a handy place on the outside for writing where it is from and where it is going to. The white (information) ones also have handy numbers so that the destination can tell if any have been lost. The Corporals, of course, are responsible for writing the destination and origin information on the labels on the outside of each pouch.

The Light-Black Dispatch Service, on the other hand, has chosen to make it as simple as possible for the Corporals. There are no fancy colored pouches here! There are just some nondescript beige ones which have a label for the origin and destination. The Light-Blacks have decided that they will just send messages without all of the business of making and terminating communications.

We now have the two foundation layers for a pair of mythical communication systems. The Greys use theirs like this: The Corporal in command-post Charlie is told by his Sargent that he had better start sending plans (for tomorrow's action) to their neighbors to the north, command-post Bravo. The Corporal gets out a green pouch, and writes on the outside "to Bravo from Charlie" and gives it to a runner. The runner, having been told to go north to find command-post Bravo, sets out. But part-way there, he steps on a land-mine and is never heard from again. The Corporal at command-post Bravo does not even know that anything has happened except for the dull thud off to the south when a land-mine went off. The Corporal at command-post Charlie waits for a reply and, when none arrives, decides that it is necessary to try again. So he gets out another green pouch, addresses it again, and sends off a new runner. This runner makes it to command-post Bravo and hands it to the Corporal there. This Corporal does not have to look in the pouch; he sees that it is green, that it is addressed to his command-post, and that it is from command-post Charlie. He gets out a brown pouch (agreeing to begin exchanging messages) and addresses it to command-post Charlie from Bravo. A runner carries the pouch back, thus signaling that it is ok to proceed. Once this exchange is complete, the Corporals at each command-post tells his Sargent that the message can proceed.

On the other side of the line, the Light-Black Sargent of Dispatches at command-post Beta decides that it is time to send a message with tomorrow's plans to command-post Alpha. He simply gives the message to his Corporal with the instructions to send it. The Corporal places the message into a convenient beige pouch, addresses the pouch, and passes it to a runner with directions. The Corporal makes no decisions about

success or failure of the message exchange; that is the responsibility of his superior officers!

There is more than just a difference in style here. The Greys, being populists, believe in making decisions at as low a level as possible. Thus, their Corporals are given lots of responsibility. The Light-Blacks, on the other hand, are believers in centralized decision making and choose to make as simple as possible for their Corporals.

11.C.3 Command-Post Sargents: In both armies, Sargents are responsible for managing links with neighboring command-posts. Of course, how they go about it differs in the two armies.

The Greys think of the communication system among command-posts as a network. The Sargents are responsible, among other things, for determining which neighboring command-post to send a message which is really going to a location many command-posts distant. For example, command-post Charlie may have a message for command-post Zulu. The Sargent, who keeps track of such things, knows to send messages for Zulu to the neighbor Romeo, because Romeo sent out a general bulletin not long ago that it has a way to send messages to Zulu. When command-post Charlie wants to send a message to Zulu, the command-post Message Corps Sargent instructs his Corporal to send a special message to command-post Romeo. The Corporal, of course, does not care what the message is but it will request Romeo to "set up a circuit" to Zulu. When the Corporal receives this message, he first goes through the exercise of establishing communication with command-post Romeo, its neighbor to the South. This is done, if you will recall, by exchanging colored message pouches. Once communication is established, the Corporal at Bravo tells his Sargent that it is possible to proceed. The Sargent gives the "set up a circuit" message to his Corporal who places it into one of his (white) pouches and sends it off to Romeo. When it arrives successfully at Romeo, the Corporal there removes the message from the pouch and passes it to his Sargent. The Sargent says, "Hey, we can send directly to Zulu!" So he, in turn, writes a "set up a circuit" message and directs that it be sent off to Zulu. He passes it to his Corporal who goes through the same process, but this time with Zulu. Once established, a message goes back to Bravo, saying that the circuit is established. The Sargents in the three command-posts (Bravo, Romeo, and Zulu) control this circuit. The Corporals take care of the sending details and the Privates run the messages between the command-posts.

Light-Blacks, on the other hand, have a slightly different concept of their network. The Sargents keep a list of where to send messages for different destinations. In some cases, it is based on best guesses. In other cases, it is based on the last time the Sargents of the Light-Black Dispatch Corps got together for one-too-many beers. These lists are often kept on rumpled scraps of yellow sticky-pad which sometimes fall off the wall where they normally hang. So it is when the Sargent at command-post Beta finds that it is necessary to send a message to command-post Omega. He finds one of his pieces of yellow sticky-pad; it has written on it that messages for Omega should be sent to command-post Rho. He addresses the message to Omega but tells his Corporal to send it to command-post Rho. The Corporal puts the message into one of their beige pouches and sends the runner on his way. When it arrives at command-post Rho, the Corporal there passes the message to his Sargent, as every good Corporal should. The Sargent sees that the message is really addressed to command-post Omega so he gives it back to the Sargent with instructions to send it on to Omega. The Sargent does not know that this message is the same one he just received; to him, it is just another message and he sends it on its way.

11.C.4 Command-Post Lieutenants: In both armies, Lieutenants keep track of message movement reliability. They attach various checks to the messages received from their superiors. These checks are then used at the other end to verify that messages are received in the right order and without error. In principle, the checks are quite similar in the two armies. They choose to do them just a little differently but the differences are small enough that we need not examine them in detail.

What is important is that the Lieutenants receive messages from their Captains, add the error-checking to them, then pass them on to their Sargents for sending. On receiving a message, the Lieutenants remove all of the extra error-checking and pass the clean message up to their Captains. Their superiors need not know anything of message passing problems, it is all hidden from them.

11.C.5 Command-Post Captains: In both armies, Captains are responsible for managing message-passing sessions. In other words, this means that if there are messages are moving several ways at a time, the proper message gets sent toward the right destination. These captains are also responsible for handing messages from their Captains to their superiors, the Majors.

11.C.6 Command-Post Majors: In both armies, Majors deal with presentation of messages. In both cases, the messages may be rewritten on standard message forms. However, the forms are only vaguely similar in the two armies. But in each army, the forms are easily recognized.

11.C.7 Command-Post Generals: In both armies, the Generals being like Generals, the world over, are directors of action or application. In some cases, the Artillery Generals are interested in sending and receiving special messages of importance to their artillery units. So their messages have information about targets, winds, and such. The Airplane Generals are interested in things like targets, anti-aircraft batteries, and storms. The Supply Generals are interested in things like food, cots, boots, and spare bayonets. The standard messages are a little different for each and, of course, the two armies do things a bit differently. But the principle is that a General is responsible for each application.

When a General, say the General of Supply, wishes to send a message to another General of Supply, he passes it to his Major who makes sure the message has been written on the proper form. He then passes it to his Captain who begins a new session (if this is not a continuation of an existing one). He, the Captain, passes it to his Lieutenant who adds the necessary error verification. The Lieutenant then passes it to his Sargent with instructions for sending. The Sargent, as described earlier, goes through the actions appropriate for his army, to get it sent. At the other end, the message ripples back up through the chain-of-command to the General of Supply who can do something with the message.

11.C.8 Cutting through red tape: The Greys, particularly, seem burdened by lots of red-tape, especially in making and breaking communication with other command-posts. But every once in a while, a different runner arrives. This runner is from the "Grey News", the newspaper serving the the populace which supports the Greys. Being civilian, the Grey News folks want to get to the real source of the news, the General. As a concession to their supporters, the Grey Message Corps has made it possible for the inquiries from the News to bypass all of the Lieutenants, Captains, and Majors, and go directly to the General. This makes for much better local support and still allows the Grey Army to (generally) do things the way they want to.

11.C.9 Comments: These two "armies" represent the AX.25/NetRom and the TCP/IP world. If there is any question, the Greys are the NetRom folks and the Light-Blacks are the TCP/IP people. Each

command level corresponds to one of the layers in the Layer Model.

11.D. AX.25 & THE PHYSICAL LAYER

The physical layer describes the physical mechanism for getting "bits" from one place to another. THIS IS NOT PART OF AX.25! We are left to our own devices for moving those bits. But, over the years, a whole set of customs has grown up and they have come to define how those bits get transported from one place to another.

For example, the use of BELL-202 modem tones (1200Hz and 2200Hz) as the standard tones for AFSK modulation is the standard for VHF. On HF, the standard tones are 1600Hz and 800Hz. AX.25 never refers to this. Likewise, we tend to think of AFSK as standard. However, a modulation scheme called biphase is used on many of the packet satellites. Packet satellite modems are available for many of the TNCs with modem disconnect headers (see Vol 2-CH22: Connecting TNCs to Radios for other comments about modem disconnect headers). Similarly, direct FSK is commonly used at baud rates above 2400.

It is clearly up to system builders to define the physical layer characteristics for various parts of packet systems. It should also be fairly clear that that once bits get moved through a physical layer, it should make no difference to other layers how the bits were moved. Likewise, to the physical layer, it makes no difference what the bits represent.

11.E. DATAGRAMS AND VIRTUAL CIRCUITS

At lower levels, one of the biggest distinctions between AX.25 and TCP/IP is the use of datagrams as compared to virtual circuits. We should not, however, limit our investigation to TCP/IP because ROSE and TexNet (see Chapter 10) both use datagram-based communication for movement of packets between nodes or switches. Here, as elsewhere in this book, the term Net/Rom will be used to refer to Level 3 and Level 4 for AX.25; this term should be understood to apply equally to G8BPQ, TheNet, JNOS, and MSYS nodes.

11.E.1 Virtual Circuits: In a Net/Rom network, a link between nodes

(whether immediate neighbors or not) is set up and tested (by the nodes, themselves) before passage of user information proceeds. Once established, there is error-checking between the end nodes.

To clarify this a little further, suppose that a user is connected to a node named PODUNQ. She wishes to talk to a friend at a node names WAYFAR. In between, there are nodes named (in order from PODUNQ) HILTOP, BIGCTY, MOUNT, KNOLL, VALLY, & CENTRL. Because of the way this network happens to be set up, our user as PODUNQ cannot just type "C WAYFAR" and have a successful link. Instead, by experimenting, she has found that it works pretty well if she types, instead "C BIGCTY", then "C KNOLL", then "C WAYFAR".

When the connection request to BIGCTY is made, a circuit is set up from PODUNQ through HILTOP to BIGCTY. This is the first of three circuits which are generated. Until the circuit is broken (by a link failure or a disconnect request), error checking and correcting happens between PODUNQ and BIGCTY. Once the connection to BIGCTY is made, the connection request for KNOLL is acted upon by BIGCTY. It sets up a circuit from BIGCTY through MOUNT to KNOLL. This is the second circuit. Error correction now also happens between BIGCTY and KNOLL. Once the connection to KNOLL is made, the connection request for WAYFAR is acted upon by KNOLL. It sets up a circuit from KNOLL through VALLEY and through CENTRL to WAYFAR. This is the third circuit. Error correction now also happens between KNOLL and WAYFAR. Recognize that the error correction referred to in this paragraph is on top of the packet-by-packet error correction which is built into Level 2 of AX.25. The circuits of the kind referred to here are called virtual circuits. Note that there is no mention here of how one node knows which neighbor to use for a circuit to another node which is not a neighbor; that is also part of the Net/Rom protocol but does not relate in any way to the issue of circuits vs. datagrams.

11.E.2 Datagrams: In TCP/IP networks and the other networks mentioned previously, datagram message transfer occurs. Lets suppose that our previous example of nodes PODUNQ, HILTOP, BIGCTY, MOUNT, KNOLL, VALLY, CENTRL, & WAYFAR are part of a datagram network. Lets further suppose that this network is like TexNet such that users can connect to the nodes in AX.25 style but that datagrams are used between the nodes.

The first notable difference between this network and the Net/Rom one just described is the method for setting up the link between PODUNQ

and WAYFAR. The way these networks are set up means that the intermediate connections are not likely to be needed. PODUNQ simply sends off the first information packet to HILTOP. The packet is addressed immediately to HILTOP but it also contain characters which say the final destination is WAYFAR.

HILTOP sends it on to BIGCTY. To do so, it changes the immediate address of the packet to BIGCTY without changing the final destination. Each packet has not only the user information and final destination but other characters added by PODUNQ. These characters are for error correction by WAYFAR. If some packets arrive at WAYFAR damaged or some are lost, it is up to WAYFAR to request a repeat of those packets.

If one of the nodes in unable to deliver a packet to the next node in the chain, one of several things might happen, depending on how the network is designed. In some systems, the user might never know (except for missing notification of receipt from WAYFAR). In other systems, the user could be notified by the node which could not move the packet onward. It might, however, take some time.

BBS-to-BBS mail forwarding is in datagram style. Mail is forwarded from one BBS to another. It may take minutes, hours, or days to move from one to the next. The sender is never notified of this fact. Nor is the sender notified if one of the BBSs has a computer crash and the message is lost. Delivery is determined only if the addressee happens to send a reply (which our social protocol does not demand).

In datagram packet transport, the reliability depends on cooperation between the two end-points in the exchange, not on the system in between. It's not that efforts to produce a reliable transport system are useless. It is simply a recognition that no network likely to be built is perfectly reliable.

11.F. SOME EXAMPLES OF PACKET PROTOCOL

Lets now look at how some of these protocol ideas and the Layer Model, in particular, actually fit some of the things we experience as packet radio operators.

11.F.1 Operating with a TNC & Terminal: Basic packet operation with a TNC or its equivalent is probably the single most common packet radio activity. A TNC takes care of Layer 2 and part of Layer 1 of the Layer Model. The TNC defines the structure of a packet and the connection procedure to other AX.25 stations. The TNC also defines a lot of the characteristics of the modulation used by Layer 1. The radio defines whether the modulation is FSK or AFSK, & whether it is Single Side Band or Frequency Modulation.

For all practical purposes, none of the higher layers are present. The TNC simply delivers text characters to the terminal which displays the characters. The TNC receives characters from the terminal moves them directly to Layer 2.

11.F.2 Operating with a TNC & Advanced Terminal Software: Advanced terminal software such as LanLink and KaGold provide some of the features of higher Layers. The layers in between are missing, however. Still, the ability to manage sessions & move mail automatically should not be discounted.TNCs with auto-forwarding mailboxes fall into a similar category.

Use of software with file-transfer procedures (X-Modem, Y-Modem, Z-Modem, Kermit, YAPP, etc. see Chapter 14) have some of the upper layers managed within these procedures.

11.F.3 Net/Rom-type Nodes: These nodes have (at least) three modes of operation. One provides through-routing for circuits between other nodes. When operating in this way, only Layer 1, Layer 2, Layer 3, and Layer 4 are used. All 4 of these layers are implemented within the node software.

When a station is connected to a node directly as a local user, the low 2 layers are used. If the user asks for information from the node (such as a user list), the request is passed to higher layers which provide the response. Each such connection is a session.

If a local user requests a connection to another node or if a distant user connects through network links, then, at the very least, Layer 3 and Layer 4 come into play.

11.F.4 BBS with Node Shell: These stations have, perhaps, the most complete and obvious implementation of the full layer model. Layer 1 and Layer 2 provide the physical link to other local stations. Layer 3 and

Layer 4 (which rely of course, on the lower layers) provide network linking. Each connection to the bulletin board represents a session. Each session is capable of doing very close to the same thing, to all appearances simultaneously. The display of information including prompts, message lists, and the messages themselves, are all part of Layer 7, the Application Layer.

11.F.5 TCP/IP Stations: These stations, whether a user station or a BBS, have a similar layer implementation. In general, however, more of the layers are operating in the typical TCP/IP home station than they are in a standard AX.25 station. Because of the protocol differences, the software built into a standard TNC must be bypassed. Other software often present in a TNC (called "KISS") is used. This software permits the computer connected to the TNC to make the TNC do what the computer wants, rather than what the TNC wants.

11.G. PACKET PROTOCOL SUMMARY

The concept of a packet protocol is not particularly easy to explain. One way of visualizing the idea uses the ISO Layer Model. This model describes a (digital) communication system in the form of independent processes. The lowest level one is responsible for moving bits from one place to another without regard to what the bits mean. Then next layer describes how the bits are organized (in our case, into packets). The next two layers describe the methods by which stations are linked together into a network. In all, this model has 7 layers. The situation where the layering is perhaps the most obvious is in a bulletin board (BBS).

There are two common protocols used by hams for moving packets. One is AX.25 protocol which describes how connections are made, information is passed, and connections are broken. The other protocol is TCP/IP which uses a method without connections (called datagram or connectionless packets).