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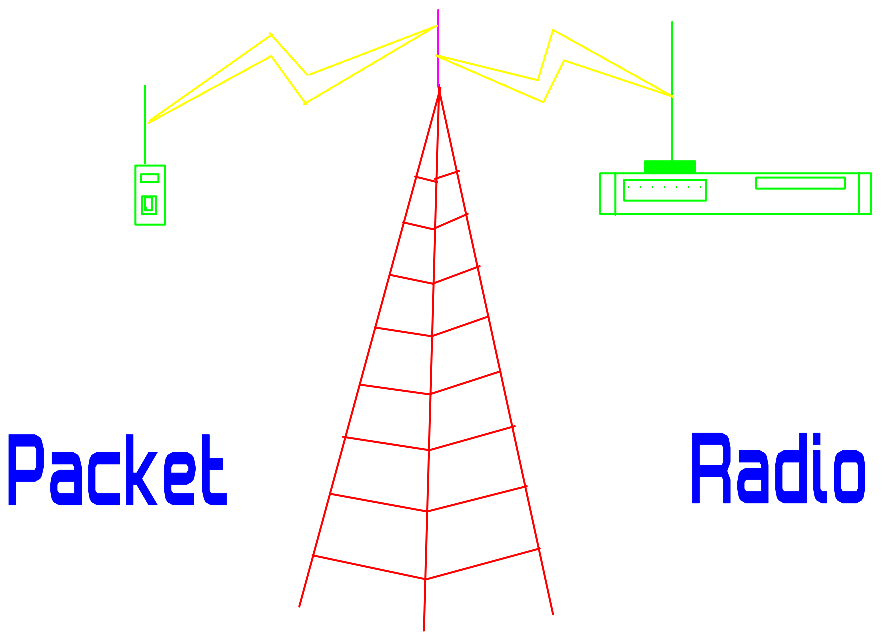

Amateur Packet Radio

A Complete Tutorial

Evie Cooper

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First Edition, January 27, 2026

Note: This is the initial version of this document, so it is likely to have all manner of errors.

Preface

I have tried to compose this to be as turnkey as possible, but I will have inevitably made mistakes somewhere. If you find any, please email me at ***wec@bam.moe***!

AI statement: no generative AI was used in the composition of this work.

This document was formatted on an IBM System/390 Multiprise 3000 mainframe running z/VM 4.4 with BookMaster 1.4.

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An Introduction to Packet Radio

Packet radio is a very advanced world, and I assure you that this guide only barely does the protocol family justice. Amateur packet radio has a rich history of protocol development and asserting an influence on later network protocol stacks, and played a pivotal development in the popularization of the Internet Protocol with hobbyists.

Original Packet Radio

In the past, computer networks were not nearly as commonplace, accessible, or affordable-to-construct as they are today. Before the modern era, the ARPAnet was inaccessible to anyone that wasn't a government employee, contractor, or university student in the US; while that did exist, the world was dotted by numerable *corporate networks* that used strange protocols, unusual hardware, and were of no interest to the casual hobbyist. Where the ARPAnet required the blessing of the US government and enterprise networks required strange mainframes, communications controllers the size of refrigerators, and things like that, the amateur radio operators of the late 1970s and early 1980s looked on to things their peers had developed *but seemed so out-of-touch.*

An important milestone in the development of computing networking was Professor Norman Abramson at the University of Hawaii's project: **ALOHAnet.** The Hawaiian Islands were separated by oceans, and it was not affordable for a group of universities to lay cables into the ocean to connect their sites; as such, Dr. Abramson sought a wireless approach. He figured that since a single radio station could cover a sizable portion of the Islands, couldn't the same approach work for a wireless computer network?

The development of ALOHAnet resulted in a 9600 baud UHF packet radio system that had reasonably been perfected by 1975, and the Aloha medium-multiple-access protocol had inspired many descendent technologies.[1]

In the San Francisco Bay, DARPA worked with SRI International to construct a network called PRNET; this was the aptly-named **Packet Radio NETwork.** These researchers worked from 1973 to 1976 to run the APRAnet NCP protocol (which preceded the current Internet Protocol, but is *radically* different) wirelessly. Rather than using a more primitive FSK modem design like the ALOHAnet project did, PRNET used direct-sequence-spread-spectrum modems that included a forward error correction algorithm -- this resulted in 100 kbps and 400 kbps radio channels filling the air. Most pivotally, the PRNET project demonstrated the first *internetworking* wherein the APRAnet, PRNET, and SATNET (a satellite communications network) were interlinked.[2]

Ham Packet Radio

Amateur packet radio started in Montreal, Quebec in May 1978: VE2PY (Robert Rouleau), VE2BQS (Norm Pearl), and VE2EHP (Jacques Orsali) acquired special authorization from the Canadian government (an “Amateur Radio Digital Operator's Certificate”) to transmit ASCII-encoded data on the 1.25-meter amateur band with custom equipment. On the other side of the continent, VE7APU (Doug Lockhart) and his group, the Vancouver Area Digital Communications Group) began to produce proper modems that were much more capable than the earlier Montreal Amateur Radio Club work. These devices became known as ***Terminal Node Controllers.***

South of Canada in the United States, the FCC permitted ASCII transmissions in 1980; shortly after that in December 1980, KA6M (Hank Magnuski) had erected the first packet repeater on 2 meters. Since the old NCP

[1] An interesting offshoot of the Aloha protocol was, of all things, *Ethernet*; the designers called it “Aloha in a wire” and were not far-off -- both systems used the same CSMA medium access control technique.

[2] The site of the first internetworking was a GMC Value-Van that Don Cone had filled with radio equipment and computer equipment (which was a DEC PDP-11/03 LSI-11 minicomputer); on November 22, 1977, the Internet was born.

protocol had yet to be replaced, Hank scored a very valuable victory: the *entirety* of the **44.0.0.0/8** network was allocated for amateur radio, and became known as AMPRnet.[3]

Two years later (in January 1983), NCP was replaced with TCP, and RFC 790 listed it amongst several other networks.[4]

1982 was a pivotal year for packet radio. The Pacific Packet Radio Society (California), the Tuscon Amateur Packet Radio Corporation (TAPR, Arizona), and the Amateur Radio Research and Development Corporation (AMRAD, Washington, D.C.) were hot on the trails of developing consumer hardware for this new craze.

All of these incompatible TNCs meant that, though everyone used Bell 202 modems, nobody could interlink with each other. Everyone claimed to use a modified “Vancouver Protocol” (based on the work of VADCG), but nobody really was. In 1982, several meetings were held, consisting of many of the big names in packet radio of the day. They realized they needed a standard, and they eventually came up with the “Amateur Radio Protocol.”

This protocol was based on the extremely popular X.25 protocol, and was named AX.25 (more information on it will be presented after this chapter). It was WB4JFI (Terry Fox), who was the head of the ARRL's *Ad-Hoc Committee on Amateur Radio Digital Communication* who signed off on the standard after it had been decided; this occurred on October 26, 1984.

AX.25 was a massive improvement over the existing VADCG protocols. For one, it could handle 128 connections at the same time -- on the eve of AX.25's standardization, it was estimated that were no more than 200 hams using packet radio in the entirety of the US and Canada combined! One of the early TNCs that was responsible for settling this issue was produced by a company called “Bill Ashby and Sons”; that company built a simple board based off of the Vancouver protocol hardware and software, and made it available. Richcraft Engineering, ran by W4UCH, came up with an ingenious idea: use the CP/M microcomputer OS to implement a software-based packet radio stack. This greatly simplified part complexity, and removed the need to use actual modem parts (often called “HDLC controllers” because they were lifted straight from wireline X.25 modem hardware). After that, GLB Electronics came onto the scene with something that would become extremely familiar to anyone that finds old TNCs at hamfests: they designed a simple and cheap Z80-based microcomputer that drove the audio interface much in the same way that the Richcraft board did; this was the PK-1, and it was the first popular software-only TNC.

The TAPR was a strange bunch, and consisted of not more than 20 amateurs. On a weekend, they all met in the University of Arizona's Computer Science building, and pitched an interesting project idea: “could we develop a cheap packet radio system that was capable of transmitting microcomputer software via the airwaves?”

Interestingly, many of the TAPR engineers worked for Motorola, who was just down the street; the efforts of that club were shown to the world in 1982 at the First American Radio Relay League Computer Networking Conference. Drawing on the successes of the past, they launched a very good and high-quality TNC kit in July 1983; whereas the earlier attempts were somewhat shoddy in their design and just as bad in their manufacturing, the TAPR kits felt *almost professional* -- the quality of their kits readily rivalled commercial radio vendors (as in, companies that made radio hardware for the non-amateur “real world” market). The first run of this TNC was at 9:12 PM PST on June 25, 1982; blazing away on 146.55 MHz, KD2S (Den Connors) and Lyle Johnson (WA7GXD) held the first contact using Heath H-89 serial terminals.

In 1984, the TAPR TNC-1 board took the world by storm. It wasn't for lack of trying, though; the production of the boards was very troubled. In December 1982, just as they were getting ready to launch the aforementioned board,

[3] In keeping with the ARPANET theme.

[4] Interestingly enough, the now-ubiquitous **10.0.0.0/8** network was a direct mapping of the ARPANET address space -- the Internet has had several major addressing scheme overhauls throughout its history!

the TAPR guys were having nonstop solder problems on their circuit board assembly line. This resulted in a mad dash to fix the productions, but the group was successful -- the board took the world by storm.

As soon as these became commonplace, all manner of bulletin board systems (BBSes) began to pop up. One of the first BBSes put up on the East Coast was by AI2Q (Alex Mendelsohn), and was powered by a Xerox 820 desktop computer running CP/M. Digipeaters quickly cropped up, bringing the footprint of these BBSes to hundreds of mile in a matter of weeks. Since the packet radio stack ran on that Xerox 820, NW2X (Howie Goldstein) had a bright idea during his time as a student at the Florida Institute of Technology: use the surplus and obsolete Xerox 820 motherboards to greatly evolve the function of those TAPR TNC-1 boards!

The TNC-2 was announced at the 1985 Dayton Hamvention, to amazing acclaim. This was based on the same idea as the early Z80 soft-TNC pioneers, but greatly upgraded after many had experimented with the TNC-1 and Xerox 820 combination system. The TNC-2 contained a Z80, some RAM, a ROM chip, and a modem interface; this was quickly licensed out to several companies, who began manufacturing them all over the world. By the early 90s, TNC-2 devices were ubiquitous. Packet radio had hit it big, arguably much bigger than it is today.

Now, it is up to you to breathe life back into this amazing forgotten world in an age of an uncertain Internet future.

Bringing it Together

Before proceeding, I recommend you familiarize yourself with some key terms heard in packet radio:

- Packet Radio: a collection of hardware and software that performs network communications via radio
- TNC (Terminal Node Controller): a box or program that connects a computer or terminal to a radio and performs the modulation/demodulation tasks required to generate a baseband signal containing data
- Node: a host on a packet radio network, usually capable of receiving inbound connections
- BBS (Bulletin Board System): a special kind of node that stores messages (and sometimes forwards them off to other nodes)

For 99% of packet radio installations, the TNC will connect to a VHF/UHF FM radio through its ***audio interface;*** it also likely has the ability to ***key the radio*** -- since accurate transmit/receive timings are paramount for packet radio, **you cannot use your radio's VOX control for bidirectional packet** (and you should not use it for unidirectional packet either, honestly)!

Audio filtering and high-speed packet

For most people using a Baofeng HT or mobile radio, the highest speed you will be able to attain is 2400 baud (with 1200 baud being the most common, for things like APRS). This is not because packet radio has not evolved (in fact, there are megabaud packet radio systems), but because the radio applies an audio filter on both the microphone input and the audio output.

The audio input is filtered to cut off any audio below 300 Hz (this is to prevent bass tones from tripping a repeater's PL tone decoder, which may stop you from being able to transmit into the repeater for the duration of your transmission) and above 4 KHz (to conserve FM bandwidth); likewise, the audio output is filtered to remove anything above 4 KHz and below 300 Hz (to prevent screws backing out due to constant PL tone bass vibrations on the speaker, or so I'm told).

As such, in order to go faster (such as up to 9600 baud, the most-desired speed), one must do away with these filters. This is done by **tapping the discriminator** and **directly driving the modulator.** This can be done by examining the schematic for your radio, but many VHF/UHF mobiles made through the late 1990s to today contain a port at the back that has a 9600 baud packet output; note that it is paramount that you check the manual to determine what the output level is (too low of an output level results in poor reception) and ensure you do not overdrive the modulator input (doing so could put your transmissions out-of-spec).

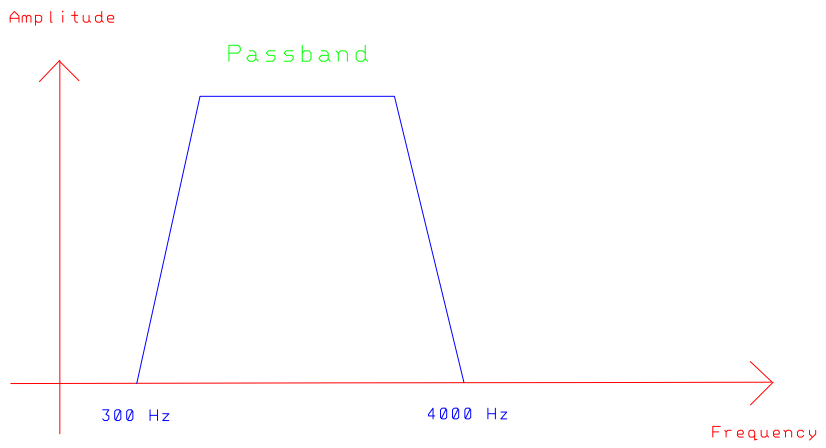

Figure 1. VHF/UHF LMR audio frequency range

Surveying the Landscape: Protocols and Stacks

When discussing packet radio, it helps to have an understanding of the numerable protocols found on the air:

- AX.25
- KISS
- NET/ROM
- ROSE
- TCP/IP
- APRS

Before we get carried away, it is a good idea to familiarize oneself with these protocols:

AX.25 (and KISS)

The primary network protocol of amateur packet radio is ***AX.25.***, and it is a ***link layer protocol.*** This is a protocol derived from the earlier (but once extremely popular) *X.25* protocol family, a stack of protocols that provided:

- A relatively simple protocol family that could be implemented anywhere from large mainframe computers to small boxes that attached to terminals
- Packet-switched networking, wherein "virtual circuits" would be propped up like TCP sockets are today on the TCP/IP protocol family[5]
- Congestion control, retransmission, and other such features for reliable communications on network links of uncertain reliability

*If you are passingly-familiar with **TCP**, you may realize that these X.25 features share significant overlap with TCP features -- TCP was intended to emulate the X.25 PLP (packet layer protocol) over IP.*

Addressing Scheme: AX.25 provides a very simple service: a virtual circuit, between two callsigns (which includes the SSID). This means that AX.25 addresses use ham radio callsigns, so **`WA4XYZ-6`** and **`N4ABC`** are valid.

The suffix after the dash is called the ***SSID***, i.e. the Service Set Identifier. This allows you to have 16 different AX.25 addresses with one callsign; by convention, you would not write**`N4ABC-0`**, but would instead write **`N4ABC`** without the suffix.

The fundamental unit of AX.25 communication is the ***frame.*** This contains the destination callsign, source callsign, protocol number, and a control byte; the control byte selects the frame type (shown below), and the protocol number identifies the packet contents (also listed below).

Operating Modes: AX.25 has two operating modes: disconnected and connected. In the disconnected mode, the following frame types may be sent:

- **`SABM`** (Set Asynchronous Balanced Mode), used to initiate a connection
- **`DISC`** (Disconnect), to disconnect any stale connections
- **`XID`** (Exchange Identification), sometimes used to exchange station protocol capabilities

[5] Keep that ***virtual circuit*** term in mind as you read this, as it is critical to understanding AX.25

- **`UA`** (Unnumbered Acknowledge), to acknowledge an SABM or DISC frame
- **`UI`** (Unnumbered Information), a frame that contains a bit of information blasted verbatim without being contained within a virtual circuit

When station 1 sends an SABM frame to station 2, station 2 will hopefully reply with a UA frame -- if this does happen, the two stations will now be "connected." In this state, the following frames can be sent:

- **`I`** (Information), a frame that contains the virtual circuit "payload"; this is transmitted alongside a send and receive sequence number (which is used to ensure the packets are arriving)
- **`RR`** (Receiver Ready), to inform the recipient of the packet that it got it and to inform the transmitting station to proceed sending more
- **`REJ`** (Reject), if one side receives an I-frame with an invalid **`N(S)`** value (i.e. send sequence number)
- **`RNR`** (Receiver Not Ready), if the receiving station is unable to process packets for whatever reason (perhaps it is out of computational resources)

Packet Format: As you may imagine, UI frames are often used for beacons or to carry additional network protocols. Now, examine the following diagram of an AX.25 frame:

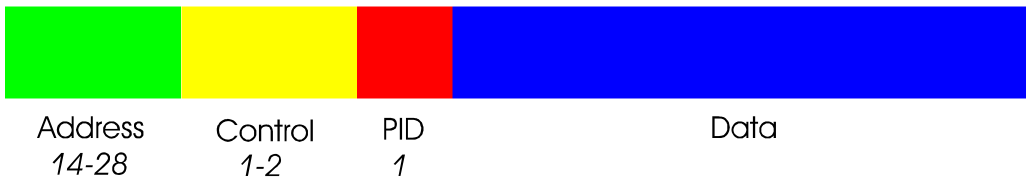

Figure 2. AX.25 frame structure

Note that the image here is good for either a numbered or unnumbered frame (that is, connected-mode or unconnected-mode). It is a good idea to break down the packet structure for additional clarity:

- Address: the address field here is variable-length (as shown, 14 to 28 bytes) since this can accommodate a plain source/destination pair or ***up to two digipeaters****. A digipeater is a packet repeater system, usually simplex; you can only have two digipeaters along a path!*
- Control: this conveys the field type, seen in the above list; it may span two bytes -- this is necessary to accommodate the sequence numbers (which run ***0 to 7*** so 4 bits; **`N(R)`** and**`N(S)`** fit nicely in one byte together)
- PID (Protocol ID): this specifies the protocol contained within the packet. The current registered values are as follows:
  - 0x01: ISO 8208 (X.25 Packet Layer Protocol)[6]
  - 0x06: VJ-compressed TCP/IP[7]
  - 0x07: VJ-compressed TCP/IP (for an uncompressed frame)
  - 0x08: Segmentation fragment
  - 0xC3: TEXNET Datagram Protocol
  - 0xC4: Link Quality Protocol (LQP)
  - 0xCA: AppleTalk

[6] See the section on ROSE for more information on this.

[7] This is the same compression algorithm used for "IP Header Compression" on PPP networks.

– 0xCB: AARP (AppleTalk)

– 0xCC: IPv4

– 0xCD: ARP (ARPA)

– 0xCE: FlexNet

– 0xCF: NET/ROM

– 0xF0: no layer-3 protocol; the payload is raw text

– 0xFF: escape character for a two-byte protocol field

The “no layer-3” AX.25 operating mode is used for connections from a packet terminal to a BBS or packet radio command-line shell node.

In an unconnected state, you can send and receive UI-frames by using some specific command that the TNC or packet stack provides; there is no acknowlegement. In a connected state, I-frames are sent instead and both sides expect to exchange those RR frames. The window size controls how many packets each side can exchange before a RR frame must be sent. Finding a good window size is crucial to reliable network links! As mentioned above, the sequence numbers run **0 to 7**, and so does the range for possible window size values.

A Bigger Window?

There is a mechanism to get more than 8 packets in a window, and it is called ***modulo-128***; it lengthens the size of the control field to three bytes (with byte 1 being the frame type, byte 2 being the modulo-8 window size, and byte 2 and 3 together being the modulo-128 window size). Most packet radio stacks support this, but no real TNCs do as far as I am aware.

From Packet to Transmission: The next step of transmission occurs if you are driving your packet TNC from a PC running the AX.25 network stack code on a PC.[8] Before being sent to the TNC, the packet needs to be wrapped in a ***KISS*** frame. KISS, short for Keep It Simple Stupid, is a protocol that is very reminiscent of the UNIX SLIP (Serial Line IP) protocol. The AX.25 frame is wrapped in **0xC0** bytes, and any of those bytes encountered in the packet are escaped with a double-byte escape. Examine the following diagram of a KISS frame:

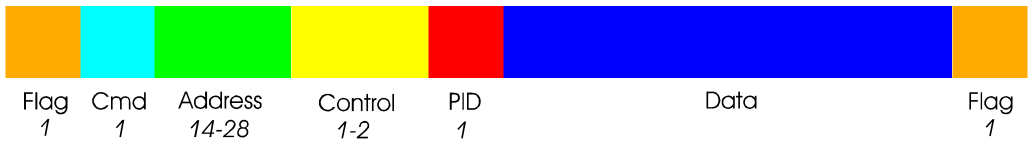

Figure 3. KISS + AX.25 frame structure

Now, just before transmission (this is done in the TNC), the AX.25 frames are stripped of their KISS framing and wrapped into an ***HDLC*** frame, just like X.25. HDLC (High-level Data Link Control) is the equivalent of the Ethernet MAC protocol for X.25 networks -- it provides a very simple link layer protocol that X.25 rode on top of. AX.25 is similar, except it replaces most of the fields of an HDLC frame; AX.25 encapsulated into HDLC only adds the frame mark byte (which is always **0x7E**) and a frame check sequence (the standard HDLC CRC algorithm computes this) at the end.

Examine the following diagram to see an HDLC-encapsulated AX.25 frame:

[8] Most TNCs from the 1980s and 1990s have a ROM that provides a simple command-line interface to AX.25 no-layer-3 connections (that is, simple textual connections) without the aid of a PC.

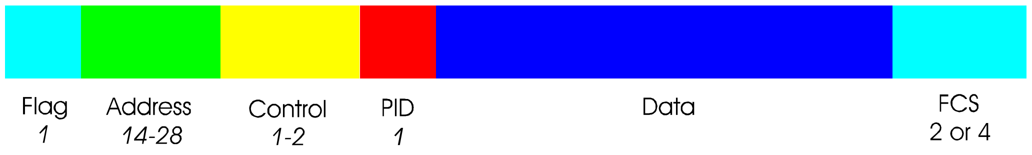

Figure 4. HDLC + AX.25 frame structure

Two link-layer protocols?

This is a common question heard when discussing non-TCP/IP protocols; a number of non-Ethernet-based protocols have what one might would describe as more than one link-layer protocol! X.25 is a network-layer protocol, and it used HDLC over *synchronous-serial links* (similar to KISS). Now, when the AX.25 frame is sent to the TNC, it is wrapped in a KISS encapsulation; when that packet arrives at the TNC from the host computer, the TNC's firmware will strip the KISS encapsulation off, re-frame it into HDLC *instead* instead of KISS, then proceed with the packet encoding and modulation.

Once the packet has arrived at the TNC and has been re-framed in HDLC framing, it will be encoded using some kind of serial data encoding algorithm (like NRZ, NRZI, or Manchester coding), modulated, and the audio stream will be sent to the radio for transmission.

For the TNCs that use 6PACK framing, the TNC directly speaks an HDLC-like protocol (and the attached computer is much more aware of the status of the RF channel). The 6PACK protocol results in the TNC telling the host computer whenever it is receiving data, and the host computer can trigger (in much more detail) partial transmissions.

What's the point of 6PACK?

6PACK is an alternate framing method (i.e. “line discipline”) to KISS that allows for multi-dropped TNCs (multiple TNCs on a serial port daisy chain). TNCs that provide this function are rare in the modern era, but it was once provided by swapping out the ROM chips in the TNC.

NET/ROM

When AX.25's limit of two digipeater hops started to become an issue in the late 80s (as packet networks were exploding in popularity by this time), a solution needed to be found, and found fast! This originally came in the form of a ROM chip (made by Software 2000) that replaced the factory ROM in a TNC-2 compatible TNC (such as the ubiquitous ones made by MFJ), and was called “the Net ROM.” Soon thereafter, the protocol it spoke became known as **NET/ROM.**

NET/ROM alleviates the two-hop constraint by allowing nodes to set up virtual circuits between themselves, then packets could pass through many nodes simply by passing through those virtual circuit tunnels. Since AX.25 has a limitation of one virtual circuit tunnel per callsign pair per protocol number, it is highly recommended that you use a different SSID for your “basic AX.25 connections” and your NET/ROM node.[9]

[9] In an ideal world, you could use the same callsign for both base AX.25 (i.e. no-L3 connections to a node or BBS) and NET/ROM, but due to a practical limit in the old NET/ROM TNC firmware of the past (and apparently in some modern packet radio stacks), you must use different SSIDs -- this is because the node lumps all packets from one node to another under the same umbrella, regardless of the protocol ID number.

Once the NET/ROM tunnels have been established, the same frame types are used as AX.25 used; to start a connection, **SABM** and**UA** frames are used, then I-frames and **RR** frames throughout the duration of the session!

Addressing Scheme: Rather than relying on callsigns explicitly, NET/ROM often uses *node name aliases.* For instance, your BBS could be named**NYBBS**, and your own node could be named **WECNOD**. In order to build up a collection of nodes and adjacency, NET/ROM nodes emit node broadcasts on a fixed timer (which is inevitably changeable by the user); once adjacent nodes receive these packets, the virtual circuit tunnels open and NET/ROM packets may pass.

Some packet radio stacks (namely XRouter) refer to a NET/ROM connection as a "layer 4" connection; by a contrast, a no-L3 connection would be a "layer 2" connection.[10]

So, what are all these layers?

Network stacks are divvied up into "layers," and this notation is used to conceptualize network protocol families. To provide you with a visual overview, please see the below image.

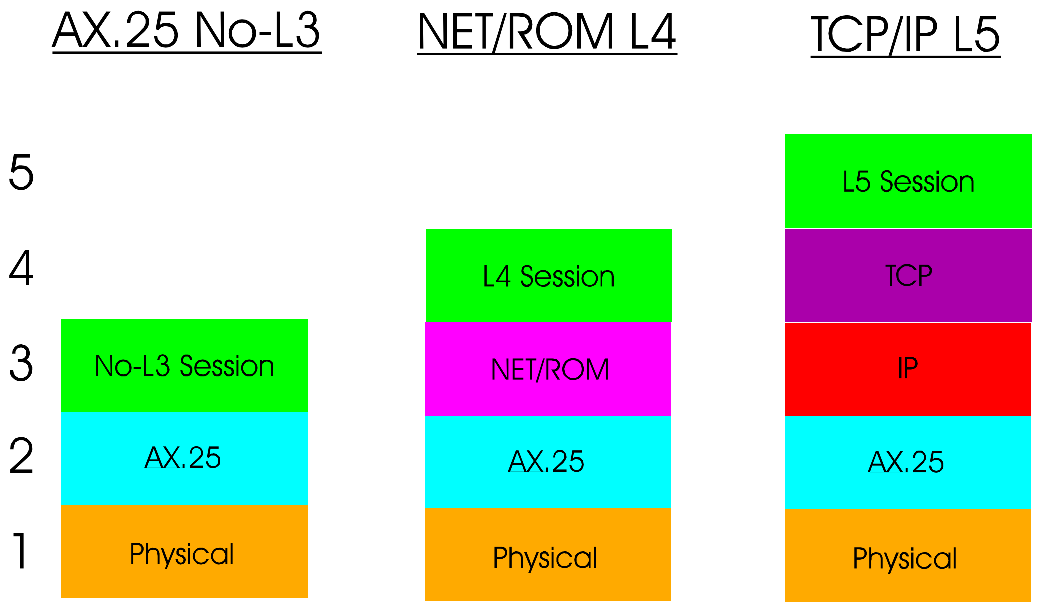

Figure 5. Packet radio protocol layers

Routing and Quality: NET/ROM, as mentioned before, uses node names to build up its routing table. As more and more NET/ROM nodes pop up on a network and begin to exchange routing tables, there needs to be some kind of way of preventing a long path from being taken when a shorter path is possible. This is remedied by the quality metric associated with the port.

NET/ROM routing broadcasts emitted from a port will contain a quality, and any subsequent retransmissions of other routing tables will have some quality shaved off with each routing table emission from each node along a path.

[10] Remember, a no-L2 connection is a plain AX.25 textual connection!

NET/ROM Serial Protocol: When the original NET/ROM-capable TNC ROMs became available in the mid-80s, KISS mode was the *de facto* standard for driving TNCs; for efficiency reasons, several hams realized they could drop the AX.25 encapsulation and *just* carry NET/ROM packets to and from the TNC. This became known as the **NRS** protocol.

ROSE

The RATS Open Systems Environment is a direct port of the *X.25 PLP* (Packet Layer Protocol) to run on top of AX.25. Like the original X.25 PLP, ROSE uses the standard 10-digit X.25 addressing scheme (frequently called ***X.121*** addresses) and requires manual mapping of callsigns to network numbers. Like NET/ROM, full routing is permitted.

Unfortunately, ROSE was not very well-adopted; the Linux kernel's AX.25 stack contains the most complete implementation of ROSE, but even it is buggy and not worth running.

Internet Protocol

Despite many efforts to establish some alternate protocol as the dominant network protocol of the world, the *ARPA Internet Protocol* became the world standard; you probably used IP to get this document!

IP is very often seen alongside several other protocols riding on top of it:

- **`TCP`** (Transmission Control Protocol), used to set up virtual circuits with reliable connections that handle drop-outs, unexpected disconnections, and other similar failures
- **`UDP`** (User Datagram Protocol), used to transmit non-reliably-delivered datagrams between hosts
- **`ICMP`** (Internet Control Message Protocol), used to allow network hosts to test communication (this is the **`ping`** command), detect adjacent routers (ICMP redirects), and alert hosts that UDP ports are not listening
- **`SCTP`** (Stream Control Transmission Protocol), an evolved version of TCP that never caught on

The structure of an IP packet is as follows:

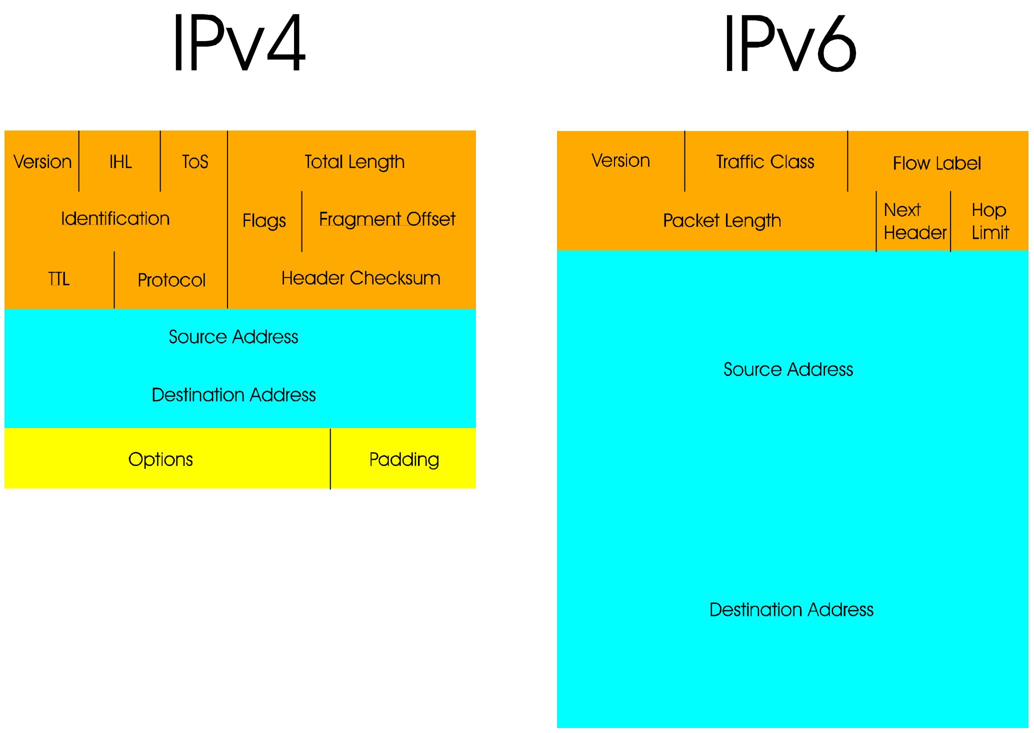

Figure 6. IPv4 and IPv6 Packets

The source and destination IP addresses can be seen, as well as the **protocol** number, which will be discussed further down. The **TTL** (Time-to-Live) field specifies the amount of routing hops a packet can take before routers will stop routing it.

IPv4 and IPv6: Furthermore, there are two distinct versions of IP: ***IPv4*** and ***IPv6***: IPv6 was created to rectify the address-space-exhaustion issue IPv4 was facing in the late 90s. IPv4 addressing takes the form of four dotted-decimal octets (i.e. an eight-bit number; these run 0 to 255) -- for example,**`44.192.15.221`**. IPv6 addresses, on the other hand, are much more complex (as they consist of eight hexadecimal 16-bit words, running 0 to FFFF) **`2062:41FE:653A:9882:511:FFE9:8392 :412D`**. Note that zeros are omitted from this IPv6 addressing scheme -- an address that has entire words of zeros can be abbreviated. Take the following example IPv6 address:**`2062:41FE:653A:0000:0000: 0000:8392:412D`**. This can be shortened down to**`2062:41FE:653A::8392:412D`**

Subnetting: Another important concept in IP networking are the important definitions of the *host address, host address, broadcast address., and netmask.* The host address is what you already saw before -- something like **`192.168.9.21`**. For our example, let us say that the netmask is set to **`255.255.255.0`**. Now, if you convert both the network address and netmask into binary, you can discover what the netmask does, what our network address is, and also our broadcast address. Examine this example to see that conversion:

```
192.168.9.21     11000000.10101000.00001001.00010101
255.255.255.0    11111111.11111111.11111111.00000000
```

When you examine this example, you can see that the subnet mask is completely overlaying all of the first three octets of that host address. If we zero out all the bits on the portion of the host address that aligns with the zeros in the netmask, you get the network address; likewise, if we set all of those bits to one, you get the broadcast address *for that network.* These addresses look like this:

```
192.168.9.21     11000000.10101000.00001001.00010101
255.255.255.0    11111111.11111111.11111111.00000000
192.168.9.0      11000000.10101000.00001001.00010000
192.168.9.255    11000000.10101000.00001001.11111111
```

Now, let's up the anté! How about if we use that same address, but we change the address to **`255.255.255.128`**. We can now recompute the addresses:

```
192.168.9.21     11000000.10101000.00001001.00010101
255.255.255.128  11111111.11111111.11111111.10000000
192.168.9.0      11000000.10101000.00001001.00010000
192.168.9.127    11000000.10101000.00001001.01111111
```

Rather than writing out long netmasks, there is an abbreviation (colloquially called CIDR, pronounced "cider") that allows you to write the netmask by just noting the amount of bits in the netmask. Since the bit consumption of the netmask always marches left-to-right, with no zeros that have any ones to the right of the address (at least until the end), one can write "192.168.1.15 with a netmask of 255.255.255.0" as "192.168.1.15/24"!

IPv6 addressing follows the same scheme, except the examples are large enough to roll off the page!

About subnetting

The practice described above, **subnetting**, is used to divide networks into different segments. Otherwise, every host on the Internet would be on the same logical network, and a single broadcast packet would easily bring the worldwide network to it knees. The key thing to know here is that *hosts who share different network addresses are no longer on the same network, and you must use a **router** to allow those hosts to communicate* A router forwards packets between networks, facilitating the creation of the Internet.

Link-Layer Address Resolution: A key part of both IPv4 and IPv6 is the concept of discovering what Ethernet MAC address/AX.25 callsign/PPP peer maps to an IP address. IPv4 does this with a protocol called ***ARP***, the Address Resolution Protocol. IPv6 does this with the ***Neighbor Discovery*** subset of ***ICMPv6***.

To understand ARP, examine this simple example of two hosts trying to communicate:

- PC 1 and PC 2 are on an Ethernet network. PC 1 has the IP address 192.168.1.5, and PC 2 has the IP address 192.168.1.10 -- both are on the same subnet (as in, they fall within the same network addressing range). PC 1 sends a **`ping`** packet to PC 2.
- PC 1 does not know PC 2's Ethernet MAC address, so it cannot send IP packets encapsulated in Ethernet frames. To remedy this, the following things occur:
  1. PC 1 sends an ARP request for 192.168.1.10 to the Ethernet broadcast address, **`FF.FF.FF.FF.FF.FF`**
  2. PC 2 responds to PC 1's request by directing an ARP reply directly to PC 1's MAC address.
  3. Both PC 1 and PC 2 know each others' MAC addresses, so they are free to exchange the ping packet.

Substitute "Ethernet" for "AX.25" and the portion above would still read true.

Address Classes: There is an important consideration to be had here: it is possible to have an *implicit netmask* based on the range that the host address falls into. This table shows the class, range, and implicit netmask:

Table 1. **IPv4 Address Classes**

Class	Range	Default Netmask
A	0.0.0.0 - 127.255.255.255	255.0.0.0
B	128.0.0.0 - 191.255.255.255	255.255.0.0
C	192.0.0.0 - 223.255.255.255	255.255.255.0
D	224.0.0.0 - 239.255.255.255	*none, used for multicast*
E	240.0.0.0 - 255.255.255.255	*none, experimental*

Class D addresses are used for **multicast**, wherein one host can send a packet to several other hosts. This requires the medium to be able to handle broadcast packets (which Ethernet and Wi-Fi, the two most common link layer protocols that carry IP, support; so does AX.25) or a router capable of processing **`IGMP`** packets (Internet Group Management Protocol, which sets up multicast groups). Once a multicast group has been set up, any host can send packets directed to the multicast group address, and every host within that group will be able to receive those packets (so long as they are listening on the *port* desired).

TCP and UDP: As mentioned before, **`TCP`** and **`UDP`** are the most common protocols that run on top of IP (besides ICMP); these are the protocols that applications actually use to transfer data between hosts. Since it would not make sense to only allow one connection between two hosts, TCP and UDP provide a **port multiplexing** method wherein program listen on various port numbers; the other side, which wishes to connect to a host listening on some port, simply opens a connection to that port! Some ports are reserved for specific application protocols; here are some common ports:

Table 2. **Common TCP and UDP Ports**

Protocol	Application	Port Number
TCP	FTP	20, 21
TCP	SSH	22
TCP	Telnet	23
TCP	SMTP	25
TCP/UDP	DNS	53
UDP	DHCP/BOOTP	67
UDP	TFTP	69
TCP	HTTP	80
TCP	POP3	110
UDP	NTP	123
TCP	IMAP4	143
UDP	SNMP	161
TCP	HTTPS	443

TCP and UDP themselves are identified in the IP packet through the **protocol number** which follows the destination IP and source IP; here are some common IP protocol numbers:

Table 3. **Common IP Protocol Numbers**

Protocol	**Description**
1	ICMP
2	IGMP
4	IP-in-IP
6	TCP
17	UDP
50	IPsec ESP
51	IPsec AH
93	AX.25-in-IP
94	KA9Q IP-in-IP

Tunnels: Since IPv4 is the dominant protocol on the internet, clever network engineers have sought to run protocols that did not win the standards race over the Internet -- this is accomplished in the form of a **tunnel.** For our purposes, we will be discussing ***AXIP tunnels***, since we wish to join otherwise-disconnected packet radio networks over the internet -- examples for how to set this up on the various packet radio stacks will be provided below (contingent on support existing for them).

TexNet

When you read the AX.25 Protocol Number list above, you probably saw *TexNet* on that list! This is a defunct protocol that is similar to NET/ROM, and was used for the Texas/Oklahoma/Arkansas packet network of the same name. Nearly all sites on TexNet were 9600 baud stations, *in the mid-1980s!* Needless to say, though it is defunct, its position in the development of NET/ROM is important to at least note.

The Linux Kernel AX.25 Stack

Compiling/Installing the Packages

Before we get too carried away, you're going to want to be using a Linux system that contains the following packages:

- **`libax25`**, the base library for all Linux AX.25 programs
- **`ax25-apps`**, a set of programs for making and receiving AX.25 connections
- **`ax25-tools`**, some programs used for configuring network protocols and devices
- **`node`** or **`uronode`**, to create and run a packet radio node/shell[11]
- **`aprsd`**, for creating and running an APRS digipeater
- **`direwolf`**, a software TNC, *install this if you do not have a real TNC or do not want to use it*
- **`inetutils`**, which contains FTP/Telnet/ntalk servers and clients
- **`socat`**, used to create loopback TTY devices (fake serial ports) -- this will be used for AX.25 tunnels

It is also recommended that you install these too for troubleshooting and debugging:

- **`net-tools`**, which provides the older**`ifconfig`**,**`arp`** and **`route`** commands that understand the various packet radio protocols
- **`tcpdump`**, a terminal-based network traffic monitor tool
- **`wireshark`**, a graphical network traffic monitor tool that produces easy-to-follow lists of network traffic
- **`screen`** or **`tmux`**, programs that allow you to run a command-line program on a disconnectable virtual terminal

Some of this you'll probably need to compile yourself. Debian calls the node program "ax25-node" to avoid interfering with the NodeJS programming language runtime (see that footnote). Do note that libax25 requires the Linux kernel headers; these can be installed from most package repositories by installing a package called linux-headers *(or something similar to that)*. Compiling these is as easy as finding the source code, extracting the archive, and compiling like so:

[11] "node" refers to the ax25-node package, not NodeJS! This program is becoming increasingly hard to find, but can be found by Googling **`node_0.3.2.tar.gz`**.

```
$ cd libax25
$ ./configure --prefix=/usr
$ make -j8
# make install          <--- note: requires root, prefix with sudo if necessary
$ cd ..
$ cd ax25-apps
$ ./configure --prefix=/usr
$ make -j8
# make install
$ cd ..
$ cd ax25-tools
$ ./configure --prefix=/usr
$ make -j8
# make install
$ cd ..
$ cd node               <--- note: UROnode compiles the same way
$ ./configure  --prefix=/usr
$ make -j8
# make install
$ cd ..
# ln -s /usr/etc/ax25 /etc/ax25
```

Note: these instructions are not entirely exact; if you are not passingly familiar with UNIX software installation and maintenance, I recommend you just use the packages available in your Linux distribution's package repository!

Configuring the Base Stack

Linux has two ways of identifying AX.25 ports:

- The *port name*, a textual name that the AX.25 commands use
- The *interface name*, the name that the Linux kernel knows the network device by[12]

To define an AX.25 port, edit **`/etc/ax25/axports`**, and, use tabs for everything, not spaces:

```
# name callsign speed paclen window description
#----- -------- ----- ------ ------ -----------
radio  WA4XYZ-1 1200  256    7      Real TNC
```

Each field is as follows:

- **`name`**: a descriptive name of the port (the “port name” described above)
- **`callsign`**: the unique callsign and SSID used for the port[13]
- **`speed`**: the baud rate used on the interface's serial link[14]
- **`paclen`**: the packet length, 256 is standard for VHF/UHF links
- **`window`**: the window size for the port (see the above notes in the AX.25 section)

[12] These devices always start with **`ax`** so, **`ax0`**.

[13] For a terminal callsign (as in, your own personal terminal), if you wish to use it, simply replace the SSID with zero. For example:**`WA4XYZ-0`**.

[14] This is the ***serial port baud rate***, not the RF modem baud rate -- configuring that on a real TNC is likely something you will need to read further down to learn about.

- **description**: a bit of text for your convinence

For ***NET/ROM*** ports, you want to edit**/etc/ax25/nrports** (again, use tabs instead of spaces):

```
# name callsign alias  paclen description
#----- -------- ------ ------ -----------
netrom WA4XYZ-7 EVIE1  236    NET/ROM Switch Port
```

Likewise, the fields are as follows:

- **name**: the port name
- **callsign**: the unique NET/ROM callsign for this port[15]
- **alias**: the NET/ROM node alias, with a maximum length of ***6*** letters
- **paclen**: the packet length of the NET/ROM frames emitted from this interface. *It is important that it is **20 bytes less** than the paclen of the AX.25 interface that will do the most NET/ROM networking!*
- **description**: text

You also need to define the port to the NET/ROM daemon (used to send and receive routing frames), so edit **/etc/ax25/nrbroadcast**:

```
# ax25_name min_obs def_qual worst_qual verbose
#---------- ------- -------- ---------- -------
radio       5       192      100        0
```

The fields are as follows:

- **ax25_name**: the corresponding AX.25 port that you want to send and receive NET/ROM node broadcasts on
- **min_obs**: the minimum obsolecence value for the port (the time before nodes are removed from the table)
- **def_qual**: the default quality announced when the node includes itself in a routing table frame broadcast; the 192 to 200 range is fine
- **worst_qual**: the lowest quality number this node will accept for other nodes listed in routing table frames
- **verbose**: set this to **1** to allow this node to announce *other NET/ROM nodes that it has heard -- this allows it to function as a NET/ROM router (which is probably what you want).*

For ***ROSE***, edit **/etc/ax25/rsports**:

```
# name address     description
#----- ----------  -----------
rose   1000100002  ROSE Switch Port
```

The fields are as follows:

- **name**: the switch port name
- **address**: the 10-digit X.121 address for this node as it applies to all TNC ports
- **description**: text

Starting Ports and Daemons: After you have defined all of those ports, you now need to start them. In this day and age, most Linux distributions do not automatically load the Linux kernel modules for packet radio, so load

[15] Remember the footnote earlier? It is highly recommended that you do not, under any circumstances, reuse a callsign/SSID pair used anywhere else! Doing so breaks AX.25-noL3 connections (and sometimes also NET/ROM connections)!

them yourself:[16]

```
# modprobe ax25
# modprobe netrom
# modprobe rose
```

Once that has been done, you must now associate your TNC serial port with your interface name (note that you will not need to set the baud rate ahead of time) with **`kissattach`**:

```
# kissattach /dev/ttyS0 radio
```

If you are using a 6PACK TNC in lieu of a KISS TNC, you can use**`spattach`** or the **`-6`** option of **`kissattach`**:

```
# kissattach -6 /dev/ttyS0 radio
# spattach /dev/ttyS0 radio
```

If your TNC requires CRC (Direwolf does, but that will be covered in a future section), enable it with this command:

```
# kissparms -c 1 -p radio
```

You now need to initialize your NET/ROM and ROSE ports:

```
# nrattach netrom
# rsattach rose
```

In order for NET/ROM to work, you must start its daemon:

```
# netromd -i -t 10
```

This transmits a routing table frame as soon as the program starts, and then every 10 minutes after that.

In order to build up a list of heard AX.25 stations (which can be accessed with the **`mheard`** command later), run this daemon:

```
# mheardd
```

IPv4 over AX.25 will be discussed later.

Making Connections: By the time you have completed the above commands, you should have several interfaces added to the output of the **`ifconfig`** command; invoke it and see for yourself:[17]

[16] You don't need to do this if you compiled your own monolithic kernel with the modules baked in.

[17] It is highly recommended that you install the older**`net-tools`** package to have the **`ifconfig`** command (among others), as the newer **`iproute2`** package is not very good with packet radio.

```
ax0: flags=67<UP,BROADCAST,RUNNING>  mtu 256
        ax25 WA4XYZ-1  txqueuelen 10  (AMPR AX.25)
        RX packets 919130  bytes 52973823 (50.5 MiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 1791658  bytes 235437942 (224.5 MiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

nr0: flags=193<UP,RUNNING,NOARP>  mtu 255
        netrom WA4XYZ-7  txqueuelen 1000  (AMPR NET/ROM)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 264196  dropped 0 overruns 0  carrier 0  collisions 0

rose0: flags=193<UP,RUNNING,NOARP>  mtu 128
        rose 1000100002  txqueuelen 1000  (AMPR ROSE)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 264196  bytes 8454272 (8.0 MiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

The callsigns can be seen on the ports, which is correct.

Now, to open a connection to another node, do so with the**call** command:

```
$ call radio n4abc-10
```

This will start a fullscreen program that allows you to have a basic textual conversation with another user's terminal, packet node, packet BBS, or some other such thing -- it depends on how they have their node configured and what it is listening for. To escape from a session, enter a tilde, followed by a period, then strike Enter.[18]

To make a NET/ROM connection, use a similar command:

```
$ call netrom NYBBS
```

To make a ROSE connection, use this:

```
$ call rose AA4XY 1019542251
```

Listening and Beaconing: Inevitably, you will want to discover adjacent NET/ROM nodes, listen for AX.25 packets on the air, and send out beacons. To discover adjacent NET/ROM nodes, run these two commands:

```
$ cat /proc/net/nr_nodes
$ cat /proc/net/nr_neigh
```

If you want to listen for AX.25 packets on all interfaces, run this:

```
# listen -c -a
```

If you wish to view a list of stations you have heard so far, invoke this (note: if you are tuned to the APRS frequency, you may get hundreds of lines of output in a busy city):

```
$ mheard
```

[18] This is the same break key sequence that **cu** and**ssh** use.

To send out a beacon announcing your presence, you can do so by transmitting AX.25 UI-frames on a fixed timer (this transmits it on the AX.25 port named **radio**):

```
$ beacon -t 10 radio "WA4XYZ Packet Radio Node"
```

While connected, you can use **netstat** to get information about active connections:

```
$ netstat --ax25
$ netstat --netrom
$ netstat --rose
```

Running TCP/IP on AX.25

IP is heavily used on packet radio networks in places where advanced packet adoption is high, so it is best to familiarize oneself with it. Please note that the *IP addresses used here are non-global, not unique on the internet, and you should probably go get some IP addresses that start with 44 (which you can discover how to do after some brief internet searches).* Alas, let us construct a sample example with LAN addresses.

Before going further, you should assign an IP address to your AX.25 interface:

```
# ifconfig ax0 192.168.44.100
```

Note that **ax0** corresponds to the AX.25 port named**radio**, and you can make this association by observing the output from the **kissattach** command.

Rather than having to retroactively assign the IP address using the**ifconfig** command, you can actually specify it as the last argument to the **kissattach** command:

```
# kissattach /dev/ttyS0 radio 192.168.44.100
```

At this point, you should be able to ping other hosts. It is recommend that you send one ping at a time, though, as to not overwhelm the frequency with packets every second:

```
$ ping -c 1 192.168.44.125
```

When this ping command starts, it will emit ARP packets (just like described in the IP intro section before); when the other node replies, IP commuication can start.

Telnet Daemon: Note that ***you should not use encrypted protocols***, like SSH, over AX.25; instead, use Telnet. To start a Telnet server and permit remote login into your node (which is a **security risk**), continue reading.

To run a Telnet server on a Linux system with **systemd** installed (which is most of them), install **inetutils** and run this command:

```
# systemctl start telnet@.socket
```

To run a Telnet server without the aid of systemd and instead use the **inetd** program included in inetutils, edit**/etc/inetd.conf** and add in the following line:

```
telnet  stream  tcp   nowait  root  /usr/libexec/telnetd telnetd
telnet  stream  tcp6  nowait  root  /usr/libexec/telnetd telnetd
```

At this point, invoke **inetd**:

```
# /usr/libexec/inetd
```

Note for Arch Linux users: if you are using Arch Linux and running inetd to run a telnet server (in lieu of having systemd control the socket), you need to replace the**/usr/libexec/telnetd** command invocation in**inetd.conf** with the following:[19]

```
telnetd --exec-login=/usr/bin/login
```

Alternatively, if you wish to use **xinetd** in lieu of traditional inetd, edit **/etc/xinetd.conf** and make sure this is in here:[20]

```
service telnet {
    flags          = REUSE
    socket_type    = STREAM
    wait           = no
    user           = root
    server         = /usr/libexec/telnetd
    server_args    = --exec-login=/usr/bin/login
    log_on_failure += USERID
    disable        = no
}
```

You can start xinetd by simply typing **xinetd** on the command line. *Note that the Arch Linux fix has already been applied here.*

To make a Telnet connection, simply type something like this:

```
$ telnet 192.168.44.95
```

Note that when the connection opens, you will see the remote system's login prompt; you do not directly specify the username on the command line.

Routing - Basic: If you have two networks, say **192.168.1.0/24** and**192.168.44.0/24** (the packet radio "LAN" used in the above example). If we wish to route between these two networks, two things need to happen:

1. The routing node (our packet radio box) needs to have **IP forwarding** (i.e. routing) enabled
2. All nodes on both networks need to be made aware that they can route to the other network, and told how to get there

Examine the following diagram of the setup:

[19] For some reason, Arch Linux has a misplaced **login** program, which is normally at **/sbin/login**; this is a workaround to allow telnetd to find the program.

[20] Note that **xinetd** also likes to check the**/etc/xinetd.d/*** files; this behavior can be altered by editing**/etc/xinetd.conf**.

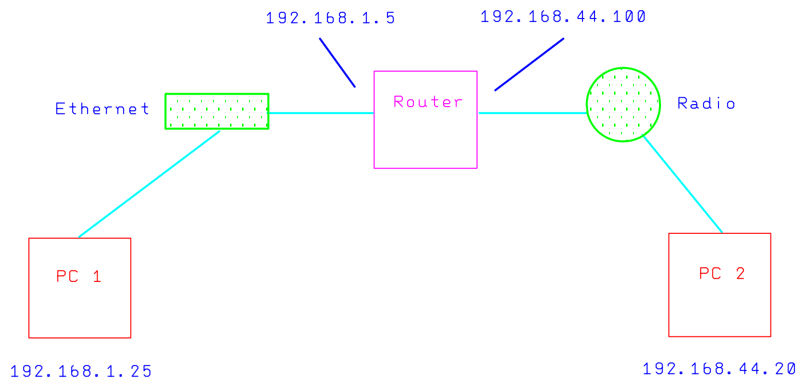

Figure 7. IP Routing Example

For PC 1 to reach PC 2, it must pass the packets through the routing node. First, you must engage **IP forwarding** (routing) on the packet node:

```
# echo 1 > /proc/sys/net/ipv4/conf/all/forwarding
```

Now, we have to populate routing tables. For this to be done, you should first check the output from **`ifconfig`** on the packet node:

```
eth0: flags=4675<UP,BROADCAST,RUNNING,ALLMULTI,MULTICAST>  mtu 1500
        inet 192.168.1.5  netmask 255.255.255.0  broadcast 192.168.1.25
        ether aa:00:04:00:07:04  txqueuelen 1000  (Ethernet)
        RX packets 310597188  bytes 69593025608 (64.8 GiB)
        RX errors 0  dropped 4673197  overruns 0  frame 0
        TX packets 28622761  bytes 3296809890 (3.0 GiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

ax0: flags=67<UP,BROADCAST,RUNNING>  mtu 256
        inet 192.168.44.100 netmask 255.255.255.0  broadcast 192.168.100.25
        ax25 WA4XYZ-1  txqueuelen 10  (AMPR AX.25)
        RX packets 919130  bytes 52973823 (50.5 MiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 1791658  bytes 235437942 (224.5 MiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

First, you need to tell *PC 1* how to reach the packet radio subnet (which, naturally, includes PC 2):

```
# route add -net 192.168.44.0/24 gw 192.168.1.5
```

Remember, **`192.168.1.5`** is the Ethernet port on the packet node!

Likewise, you need to provide PC 2 with a routing table entry. This consists of:

```
# route add -net 192.168.1.0/24 gw 192.168.44.100
```

Now, you can execute ping commands (or anything else that uses TCP/IP) and route between the two networks!

Routing - NAT: If you wish to access the Internet via packet radio, you will need to employ **NAT** (Network

Address Translation) routing.[21]

Examine the following image to visualize the setup:

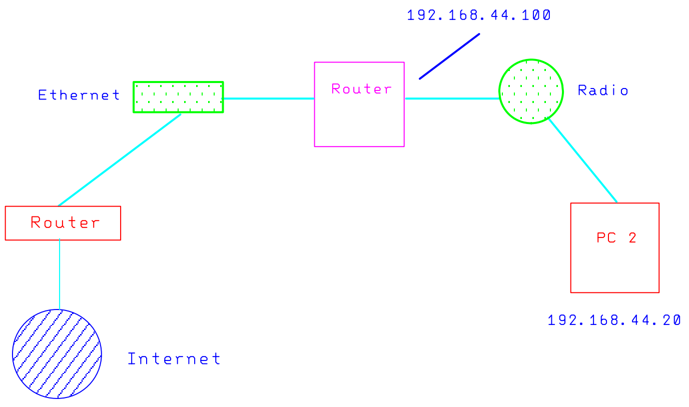

Figure 8. IP NAT Example

Note that the IP addresses on the Ethernet subnet are no longer shown -- they are no longer significant. Instead, what matters most is the packet radio subnet. Now, enter the following commands on the packet node to engage NAT routing, then I will explain what is going on and why.

```
# iptables -t nat -a POSTROUTING -o eth0 -j MASQUERADE
# iptables -A FORWARD -i eth0 -o ax0 -m state --state RELATED,ESTABLISHED -j ACCEPT
# iptables -A FORWARD -i ax0 -o eth0 -j ACCEPT
```

So, what's going on here? Well, whenever a host on the packet radio subnet sends packets directed at the Internet, they will be transmitting them to the packet routing node. It will then modify the packet's source and destination address such that the packets look like they are coming from the packet routing node PC; at the same time, the router attached to the internet connection and Ethernet LAN does the same thing.[22]

BPQ Ethernet Interface

If you wish to run packet radio protocols in the gigabits range, the BPQ Ethernet driver is your friend. The **`BPQETHER`** allows you to encapsulate AX.25 frames (and, by extension, NET/ROM, ROSE, FlexNet, IP, and such) over Ethernet (and, with some modification, Wi-Fi). This provides a high-speed backbone and testing environment over Ethernet LANs; non-Ethernet connections (T1 lines, synchronous serial links, dialup links) will want to use an *AXIP or AXUDP* tunnel (which will be documented later).

Before this can work, you must first *ensure that the Ethernet device name* has not been “renamed” by something; in other words, the network interface is named **`eth0`**. To do this, you will need to pass a kernel parameter to the kernel; this can be done by editing the GRUB/ELILO/Limine configuration. How to do this is out-of-scope for this document, but you will need to pass the following parameter: **`net.ifnames=0`**

Once that change has been made, you will need to enter another port into **`/etc/ax25/axports`** like so:

[21] “NAT” used here is a colloquial term for what Cisco IOS calls **NAT Overload**, some network engineers call **PAT** (Port Address Translation), and Windows calls “Internet Connection Sharing.” There is some debate as to which term is the true one, but most people just call it “NAT.”

[22] This is a “double-NAT” setup, since it does not require entering any routes on that edge router.

```
# name callsign speed paclen window description
#----- -------- ----- ------ ------ -----------
radio  WA4XYZ-1 1200  256    7      Real TNC
bpq    WA4XYZ-5 19200 1024   7      BPQETHER Port
```

There is no **kissattach** command to run here, as we can *directly* use the port after assigning the address to the**bpq0** device:

```
# ifconfig bpq0 hw ax25 WA4XYZ-5 up
```

When this has been done, the **call** command will read**/etc/ax25/axports** to resolve the port name to its associated callsign -- after this is done, the connection opens.

It is also possible to enable that port for NET/ROM, simply by editing **/etc/ax25/nrbroadcast**:

```
# ax25_name min_obs def_qual worst_qual verbose
#---------- ------- -------- ---------- -------
radio      5       192      100        0
bpq        5       192      100        0
```

It is not necessary to update the ROSE configuration.

AXIP and AXUDP Tunnels

Sometimes, it is necessary to bridge a packet radio network over the Internet (or some other network link that speaks TCP/IP natively, and does not natively support AX.25). In order to do this, one can construct an **AX/IP** tunnel -- this encapsulates the AX.25 frames into IPv4 packets. Likewise, to encapsulate TCP/IP into UDP packets, one can create an **AX/UDP** tunnel.[23]

Before creating an AX/IP or AX/UDP tunnel, it is necessary to understand the differences between AX/IP and AX/UDP in detail:

- ***AX/IP***: uses IP protocol number 93
- ***AX/UDP***: uses UDP port 10093 *(or whichever you'd like)*

The program that controls this tunnel is **ax25ipd**, and it has two operating modes (IP and UDP, as mentioned before). The configuration file is located at **/etc/ax25/ax25ipd.conf** -- start with a sample like this for ***AX/IP*** mode:

[23] While AX/IP packets are technically smaller than AX/UDP packets, it is generally not possible to "port-forward" an AX/IP tunnel. This resulted in the creation of *AX/UDP*, which can be port-forwarded through a NAT router and firewall.

```
# Socket type:
socket ip

# Use mode "tnc" or "digi"
mode tnc

# Beaconing
beacon after 600
btext YOUR BEACON TEXT HERE

# Use the PTY device created with socat
device /dev/ttyS30

# Line speed
speed 115200

# Log level, 0 to 4 (4 being the highest)
loglevel 0

# Broadcast ourselves?
broadcast QST NODES

# AX/IP connections go here
route NH6AB-2 12.34.56.78
```

Likewise, for an ***AX/UDP*** tunnel, start with this:

```
# Socket type:
socket udp

# Use mode "tnc" or "digi"
mode tnc

# Beaconing
beacon after 600
btext YOUR BEACON TEXT HERE

# Use the PTY device created with socat
device /dev/ttyS30

# Line speed
speed 115200

# Log level, 0 to 4 (4 being the highest)
loglevel 0

# Broadcast ourselves?
broadcast QST NODES

# AX/IP connections go here
route NH6AB-1 12.34.56.78 udp 10093
```

Now, one may wish to emit broadcasts on a tunnel, and/or also provide a default route on that interface. This can be done with the**`b`** and **`d`** letters appended to the end of the**`route`** lines. For example, to set a link as both broadcast-capable (in other words, for to make NET/ROM work) and a default route:

```
route NH6AB-1 12.34.56.78 udp 10093 b d
```

As you might imagine, you must also enter this into**/etc/ax25/axports**, like so:

```
# name callsign speed paclen window description
#----- -------- ----- ------ ------ -----------
radio  WA4XYZ-1 1200  256    7      Real TNC
bpq    WA4XYZ-5 19200 1024   7      BPQETHER Port
axip   WA4XYZ-3 19200 1024   7      AX/IP Port
```

Likewise, edit **/etc/ax25/nrbroadcast** to make the port elegible for NET/ROM communication:

```
# ax25_name min_obs def_qual worst_qual verbose
#---------- ------- -------- ---------- -------
radio       5       192      100        0
bpq         5       192      100        0
axip        5       192      100        0
```

Once you have defined the **axports** entry, you can now create the *fake serial port* used to allow **ax25ipd** to communicate with the Linux kernel; the **socat** program does this:

```
# socat -d -d PTY,link=/dev/ttyS30 PTY,link=/dev/ttyS31
```

Now that **socat** is running, you can now start the daemon:

```
# ax25ipd
```

Accepting Inbound Connections

Inevitably, in the construction of a packet radio network, you will find it necessary to allow some packet nodes to communicate with your node. This can be in the form of two different methods:

1. **Keyboard-to-keyboard chat**, with inbound connections answered by a program like **ttylinkd.**
2. **A node**, a packet radio “shell” that provides BBS-esque functions

This guide will cover the setup of both listed options.

Configuring ax25d: Before you can accept any inbound connections, you will need to configure a program called **ax25d.**[24] Configuration is relatively simple, and is done by editing the**/etc/ax25/ax25d.conf** configuration file. If you are familiar with configuring **inetd**, **ax25d** is intended to be somewhat analogous to that. Examine the following sample configuration file:

[24] This is from the **ax25-apps** package.

```
[WA4XYZ-1 VIA radio]
NOCALL   * * * * * *  L
default  * * * * * *  - root  /usr/local/bin/node   node
#
[WA4XYZ-5 VIA bpq]
NOCALL   * * * * * *  L
default  * * * * * *  - root  /usr/local/bin/node   node
#
[WA4XYZ-3 VIA axip]
NOCALL   * * * * * *  L
default  * * * * * *  - root  /usr/local/bin/node   node
#
<netrom>
NOCALL   * * * * * *  L
default  * * * * * *  - root  /usr/local/bin/node   node
#
{* via rose}
NOCALL  * * * * * *  L
default * * * * * *  -  root  /usr/local/bin/node   node
```

In the above example, the **node** program is being invoked -- this is an example of *case 2* on the above list. Substituting some other program name will result in that program being invoked.

Note also that this program can accept AX.25, NET/ROM, and ROSE connections.

Configuring the Node Program: **Node** is a basic packet radio shell program, allowing inbound users to run commands of their choosing. The base program is not very feature-rich, so adding custom commands is highly recommended.

The configuration file is located at **/etc/ax25/node.conf** -- consult the following example:

```
# Idle timeout (seconds).
IdleTimeout     900

# Timeout when gatewaying (seconds).
ConnTimeout     14400

# Visible hostname. Will be shown at telnet login.
HostName        my.host.name

# Node ID.
NodeId          WA4XYZ-1

# ReConnect flag.
ReConnect       on

# "Local" network.
LocalNet        192.168.1.0/24

# Hidden ports.
#HiddenPorts    2

# Netrom port name. This port is used for outgoing netrom connects.
NrPort          netrom

# Logging level
LogLevel        3

# The escape character (CTRL-T)
# Use this to return to the node if a telnet connection or comma
d fails or hangs.
EscapeChar      ^T

# Resolve IP numbers to DNS addresses?
ResolveAddrs    on

# Node prompt.
NodePrompt      "WA4XYZ-1>"
```

Before starting **node**, you must also configure some account permissions. To do that, edit **/etc/ax25/node.perms**:

```
# user  type    port    passwd  perms
# Default permissions per connection type.
# 63 means they can connect out to any host through telnet.
*       ax25    *       *       63
*       netrom  *       *       63
*       local   *       *       63
*       ampr    *       *       63
*       inet    *       *       63
*       host    *       *       63
```

A Word on Node Security

Giving **inet** users (i.e. users that connected to the node through Telnet) access to telnet out to any other host on the Internet is a risky move. A clever attacker (though unlikely) could use this as a way to frame you for all manner of denial-of-service attacks!

Now that user permissions have been set, you now should edit the MOTD (Message of The Day) file to configure the banner users will see when connecting to the node. Edit **`/etc/ax25/node.motd`**:

```
This is John Smith's Super Duper Cool Packet Radio Node!

Type ? for a list of commands. help <commandname> gives a
description of the named command.
```

Assuming that you have configured the node correctly this far, the only thing that is required to start the program is actually to start**`ax25d`**:

```
# ax25d
```

After testing the node, you will likely want to define some custom commands to make the node do something useful. The command syntax consists of the following elements:

1. **`ExtCmd`**
2. *<command name>*
3. *<command flags*
   - 1: run command through pipe
   - 2: reconnect prompt
   - 3: change user and then run through pipe
4. *<username that the program runs at, likely root>*
5. *<full path to Linux program invoked when the command is ran>*
6. *<name of the program, without the full path>*
7. *<command arguments>*

For some cooked examples, see the below lines:

```
ExtCmd PS 1 nobody /bin/ps ps ax
ExtCmd PMS 3 root /usr/sbin/pms pms
```

You can also **allow TCP Node connections** by allowing users to connect via the Telnet protocol. This is done by adding a line to**`/etc/inetd.conf`** just like before for the standard Telnet daemon:

```
node    stream  tcp   nowait  root  /usr/bin/node node
node    stream  tcp6  nowait  root  /usr/bin/node node
```

However, before restarting **`inetd`**, you must also update**`/etc/services`**:[25]

```
node    3694/tcp
```

If you are using **`xinetd`** instead, the configuration is similar *(but does still require the* **`/etc/services`** *fix)*

[25] **`inetd`** uses port names resolved from the lines of**`/etc/services`** by convention, but you can also replace "node" in the first word of the line with a port number to achieve the same effect.

```
service node {
    flags          = REUSE
    socket_type    = STREAM
    wait           = no
    user           = root
    server         = /usr/bin/node
    log_on_failure += USERID
    disable        = no
}
```

If you are using **`systemd`**, you will need to edit two files:

1. **`/usr/lib/systemd/system/node.socket`**

   ```
   [Unit]
   Description=Packet Radio Node

   [Socket]
   ListenStream=3694
   Accept=true

   [Install]
   WantedBy=sockets.target
   ```

2. **`/usr/lib/systemd/system/node@.service`**

   ```
   [Unit]
   Description=Node Server
   After=local-fs.target

   [Service]
   ExecStart=-/usr/sbin/uronode
   StandardInput=socket
   ```

To apply these changes, invoke the following two commands:

```
# systemctl daemon-reload
# systemctl start node.socket
```

Using URОnode Instead of Node: For the most part, it is highly recommended that you use ***URONode*** in lieu of traditional Node; not only does URONode have more functionality, but it is more secure.

Compilation and installation is relatively simple; at the time of this document's composition, URONode can be found on GitHub after a quick Internet search -- if this information no longer applies in the future, it should surely still be findable!

However, there are some things that should be noted. By default, the October 2021 version of URONode deposits all files into the **`/usr/local`** prefix -- you can fix this by running the following commands to compile URONode:

```
$ export ETC_DIR=/etc
$ export SBIN_DIR=/usr/sbin
$ export BIN_DIR=/usr/bin
$ export LIB_DIR=/usr/lib
$ export DATA_DIR=/usr/share
$ export MAN_DIR=/usr/share/man
$ export VAR_DIR=/var/lib/ax25
$ ./configure
<say no to interactive mode>
$ make -j4
# make install
```

Now that URONode has been installed, it must now be configured. Since URONode is a fork of Classic Node, editing**`/etc/ax25/uronode.conf`** is *relatively* simple! Note that you must also edit these files; check them off as you go:

__ 1. **`/etc/ax25/uronode.announce`** - announcements and notices

__ 2. **`/etc/ax25/uronode.info`** - information file for users that run the **`info`** command

__ 3. **`/etc/ax25/uronode.motd`** - Message of the Day

__ 4. **`/etc/ax25/uronode.perms`** - user permissions, *it is critical you understand the security ramnifications here!* :

__ 5. **`/etc/ax25/uronode.routes`** - static pinned routes such that users do not have to specify a port name on outbound connections :

__ 6. **`/etc/ax25/uronode.users`** - callsigns, usernames, and passwords to allow sysop users to drop into a Linux shell

Note that you can also *edit inetd, xinetd, or systemd's configuration* to allow ***TCP connections*** to URONode; simply replace **`node`** with **`uronode`** and it should work!

APRS Digipeater/I-Gate

If you wish to build an APRS digipeater or I-Gate with the Linux AX.25 stack, you have several options:

1. **`aprx`**, a dedicated APRS daemon[26]
2. **NOSaprs**, see the JNOS section below
3. **XRouter APRS**, see the XRouter section below
4. **Dire Wolf** integrated APRS support, see the Dire Wolf section below

Since this manual portion is present amongst the Linux AX.25 setup, let us examine **`aprx`**!

Compilation: Compiling **`aprx`** is relatively simple:

```
sh configure
make -j4
sudo mkdir /usr/local/aprx
sudo cp aprx /usr/local/aprx
sudo cp aprx.8 /usr/local/aprx
```

[26] **`aprx`** was forked from the earlier **`aprsd`** project.

Bidirectional I-Gate Configuration: APRS I-Gates that can transmit are a *rather rare commodity* in the world of amateur radio. As such, you should probaby try to build one! Start editing**`/usr/local/aprx/aprx.conf`**:

```
mycall N0CALL-10
myloc lat 3639.50N lon 08724.50W

<aprsis>
    passcode 12345
    server noam.aprs2.net
    filter "m/25"
</aprsis>

<logging>
    pidfile /usr/local/aprx/aprx.pid
    rflog /usr/local/aprx/aprx-rf.log
    aprxlog /usr/local/aprx/aprx.log
    #dprslog /usr/local/aprx/dprs.log
    #erlangfile /usr/local/aprx/aprx.state
</logging>

<interface>
   ax25-device        $mycall
   tx-ok              true
   telem-to-is        true
</interface>

<beacon>
    beaconmode both
    cycle-size 20m
    beacon object "N0CALL-10" symbol "I#" lat "1234.50N" lon "01234.50W"
         comment "N0CALL TXing I-Gate and Digi"
    beacon raw ")123456zThis is aprx 2.9.1"
</beacon>

<telemetry>
    transmitter       $mycall
    via               TRACE1-1
    source            $mycall
</telemetry>

<digipeater>
    transmitter       $mycall

    <source>
       source         $mycall
       relay-type     digipeated
       viscous-delay  0
       ratelimit      60 120
       filter         t/poimqstunw
    </source>

    <source>
       source         APRSIS
       relay-type     third-party
       viscous-delay  0
       ratelimit      60 120
       via-path       WIDE1-1
       msg-path       WIDE1-1
       filter         t/poimqstunw
    </source>
</digipeater>
```

Configuring Dire Wolf

If you don't have a real TNC (or don't want to use it), Dire Wolf is a software TNC that works marvels; WB2OSZ did a wonderful job writing it!

Compiling and Installation: To install this wonderful program, follow the compilation directions on the GitHub page. I **highly** recommend that you compile it yourself, to ensure that you are getting the latest version!

Of interest is the support for *CM108 USB sound card keying* through its GPIO pins -- the CM108 is a cheap USB sound card famously known for the availability of some extra GPIO pins on its controller, and these can be used to key the radio.

Configuration: Here is a basic config file for your viewing pleasure, usually located at **`/usr/local/share/doc/direwolf/conf/direwolf.conf`** (unless you did not install Dire Wolf from the source code). Ensure the configuration file contains the following elements:

```
ADEVICE soundhw:4.0
CHANNEL 0
MYCALL WA4XYZ-1
MODEM 1200
ARATE 48000
DTMF
TXDELAY 5
TXTAIL 5
FULLDUP OFF
PTT /dev/ttyUSB0 RTS
AGWPORT 8000
KISSPORT 8001
```

Breaking down the config file, the configuration statements are as follows:

- **`ADEVICE`** - select audio device[27]
- **`CHANNEL`** - select channel 0 (Dire Wolf can emulate a multi-port TNC)
- **`MYCALL`** - set default callsign, overwritten by the KISS callsign
- **`MODEM`** - set modem RF baud rate
- **`ARATE`** - set sound card sample rate[28]
- **`DTMF`** - do DTMF decoding
- **`TXDELAY`** - transmit keyup delay (time from PTT activation to stable, modulated RF emission)
- **`TXTAIL`** - transmit tail
- **`FULLDUP`** - select full-duplex operating mode
- **`PTT`** - PTT device selection:
  - **`<serial port device name> <signal pin>`**: use the selected TTY device and RTS/DTR for keying
  - **`GPIO <pin number>`**: use Raspberry Pi GPIO pins for keying (prefix the number with a - for an active-low signal

[27] Use **`arecord -l`** to list audio devices.

[28] 48000 is good for 1200 and 2400; use 96000 for 9600 and 19200 baud

  - **CM108**: use GPIO pin 3 of the CM108 or CM119 USB sound chip
- **AGWPORT** - AGW Packet Engine socket
- **KISSPORT** - KISS socket

After configuring Dire Wolf, start it with this command:

```
# direwolf -p
```

This will cause Dire Wolf to start, and it will create a KISS TNC PTY device at **/tmp/kisstnc** You can then run**kissattach** on that port, provided that you enter the port into**/etc/ax25/axports** as follows:

```
# name callsign speed paclen window description
#----- -------- ----- ------ ------ -----------
radio  WA4XYZ-1 1200  256    7      Real TNC
radio2 WA4XYZ-3 1200  256    7      Dire Wolf
```

Don't forget to enter it into **/etc/ax25/nrports** and start the rest of the packet stack.

Important! You need to run **kissparms -c 1 -p <Dire Wolf port name>** *before* trying to make any connections with any of the user programs!

List of Linux Packet Programs

The following table provides a list of programs, their associated package, and a brief description:

Table 4 (Page 1 of 3). **Linux Packet Programs**

Command	**Package**	**Description**
mheard	ax25-tools	List AX.25 callsigns recently heard over some given timeframe
ax25d	ax25-tools	Listen for and accept AX.25, NET/ROM, and ROSE connections
axctl	ax25-tools	Configure or kill active AX.25 connections
axparms	ax25-tools	Manipulate the kernel UID/callsign mapping table
axspawn	ax25-tools	Provide automatic AX.25 login and possibly create accounts
beacon	ax25-tools	Periodically broadcast a beacon on a port
bpqparms	ax25-tools	Change what MAC address the BPQETHER driver uses
mheardd	ax25-tools	Listen for AX.25 stations and populate the mheard list
rxecho	ax25-tools	“Dummy routing”/bridging between two AX.25 ports
sethdlc	ax25-tools	Alter settings for an HDLC-based port
smmixer	ax25-tools	Change volume levels for the in-kernel soundcard softmodem
smdiag	ax25-tools	Display status and modulation diagram for soundcard modem driver
kissattach	ax25-tools	Attach serial KISS or 6PACK interface
kissnetd	ax25-tools	Allocate several PTYs and emulate a KISS network (or use multiple serial ports)
kissparms	ax25-tools	Alter KISS TNC settings (TX delay/tail, CRC, etc)
net2kiss	ax25-tools	Directly output AX.25 packets from an interface on a serial port
mkiss	ax25-tools	Operate a multi-port KISS TNC with one serial port
nodesave	ax25-tools	Write NET/ROM routing table to a shell script for running later

nrattach	ax25-tools	Attach NET/ROM port
nrparms	ax25-tools	Configure NET/ROM nodes, aliases, and routes
nrsdrv	ax25-tools	Use a NET/ROM Serial Pro-tocol TNC with kissattach (via a PTY)
netromd	ax25-tools	Send and receive NET/ROM routing table broadcasts
rsattach	ax25-tools	Attach ROSE port
rsuplnk	ax25-tools	Accept AX.25 connections and dump packets into a ROSE net
rsdwnlnk	ax25-tools	Accept ROSE packets and dump into an AX.25 host
rsparms	ax25-tools	Configure ROSE nodes and routes
ttylinkd	ax25-tools	TTYLink daemon (AX.25, NET/ROM, ROSE, TCP)
rip98d	ax25-tools	Send and receive RIP98 routing messages for IP net-works
ax25_call	ax25-tools	Make AX.25 conection
netrom_call	ax25-tools	Make NET/ROM conection
rose_call	ax25-tools	Make ROSE conection
tcp_call	ax25-tools	Make TCP5 conection
yamcfg	ax25-tools	Configure YAM interface
dmascc_cfg	ax25-tools	Configure PI2, PackeTwin, and other DMASCC devices
ax25ipd	ax25-apps	AX/IP and AX/UDP tunnel manager
a25rtd	ax25-apps	AX.25 routing daemon
ax25rtctl	ax25-apps	ax25rtd control program
call	ax25-apps	Make AX.25, NET/ROM, or ROSE connections
listen	ax25-apps	Monitor AX.25, NET/ROM, ROSE, and IP traffic on an AX.25 port
soundmodem	soundmodem	Soundcard AX.25 modem driver program (SoundBlaster)
soundmodemconfig	soundmodem	Configure soundcard modem driver

baycom	baycom	Drive Baycom modem by manipulating the 8250 UART chip
aprsd	aprsd	Original APRS daemon
aprspass	aprsd	Compute APRS-IS access passcode
aprsdigi	aprsdigi	Original APRS digipeater
aprsmon	aprsdigi	aprsdigi monitor tool
aprx	aprx	Improved APRS digipeater and i-gate
aprx-mon	aprx	aprx monitor tool
node	ax25-apps	AX.25, NET/ROM, ROSE, and TCP packet radio shell program
uronode	uronode	Improved version of classic node
linpac	linpac	Advanced packet radio shell program

JNOS

NOTE: before proceeding with this, install all of the optional programs listed at the beginning of the Linux AX.25 section!

Introduction

KA9Q NOS was a packet radio stack for MS-DOS PCs that saw tremendous popularity in the late 80s and early 90s; its creator, Phil Karn, included the *source code* with every release. Since NOS was open-source, many amateurs ported it and made it available on a number of operating systems:

- Windows 3.x
- Windows NT
- OS/2 (PM-NOS)
- UNIX (WAMPES)
- AmigaOS (AmigaNOS, AmigaTCP)[29]
- *and many, many more*

Alas, NET/NOS (as it became to be known) quickly found itself obsolete and many forks emerged. One of those were **TNOS**, the Tampa Network Operating System. Running up until about 2004 or so, TNOS introduced many new features and was ported to run on the new and popular *Linux* system, something I am sure you are passingly familiar with. In October 2004, VE4KLM (Maiko Langelaar) combined the JNOS 1.11F release (itself an updated NET/NOS port that continued to run on MS-DOS, maintained by N5KNX, James Dugal, until 1996) with the portability improvements of TNOS 2.40. JNOS 2 was Linux-native, could work on other OSes (including BSD), and even gained IPv6 support!

Despite there being many NOSes, this guide will cover configuring JNOS 2 first. Before beginning, it is helpful to familiarize oneself with the features this stack has:

- Link-layer protocols: AX.25, Ethernet (disused), PPP, SLIP
- Network-layer protocols: NET/ROM, IPv4, IPv6
- Tunnel protocols: AXIP, AXUDP, IPENCAP (protocol 94), IPIP (protocol 4)
- Applications: SMTP, POP3, BBS, FTP, HTTP, DNS server/client, user database manager

Compilation

To actually compile JNOS, you need to retrieve the source code from VE4KLM's website:[30]

```
$ rsync -a www.langelaar.net::official jnos
```

You now need to configure the program:

[29] Not to be confused with *AmiTCP*, which later evolved into *GENESiS* -- this is unrelated to the later/more common *Roadshow* stack

[30] This is true as of 2026/01/20, when this was written.

```
$ cd jnos
$ ./configure
$ make -j8
# mkdir /jnos
# cp -rv jnos jnospwmgr usage /jnos
```

With that last command being ran, JNOS has been installed. You may now proceed to configuration.

Advanced Configuration: If you wish to manually maniplate the configuration file for the features baked into JNOS, you may edit **`config.h`** in the JNOS source directory. To turn on a config option, ensure **`#define`** is present on the line; **`#undef`** disables an option. For example:

```
#define NETROMSESSION
```

This option is *enabled.*

Configuration

JNOS is configured by editing the **`autoexec.nos`** file present in the JNOS program working directory; in this example, it will be present at **`/jnos/autoexec.nos`**. This file contains a series of commands that are ran at startup, so any JNOS command that you type in during JNOS's execution may be ran at startup (provided that you key it in).[31]

Rather than providing a long and linear **`autoexec.nos`** file as a sample, I find it better to slowly start creating one (and, don't worry, the entire example will be available at the end).

First, we should enable logging and set the escape key to something easy:

```
log on
escape !
```

We can optimize our TCP settings for a radio link, since we will be running TCP/IP over AX.25:

```
tcp mss 216
tcp window 4096
tcp timert linear
tcp irtt 5000
tcp maxw 9000
tcp bl 2
tcp ret 12
tcp syn on
tcp maxwait 30000
tcp retries 5
```

We likely want to respond to pings:

```
icmp echo on
icmp trace 2
```

Set the IP TTL to something decent:

```
ip ttl 225
ip rt 4
```

[31] This scheme is reminscent of **`autoexec.bat`** on MS-DOS systems

Set our default IP address, DNS hostname, and callsign:

```
ip address 203.0.113.25
hostname jnos2.wa4xyz.radio
ax25 mycall WA4XYZ-3
```

Linux allows us to attach a “tunnel” device, allowing JNOS to talk directly to the Linux kernel's TCP/IP stack *without* the aid of a simulated KISS tunnel:[32]

```
attach tun tun0 1500 0
ifconfig tun0 ipaddress 192.168.48.2
ifconfig tun0 netmask 0xffffff00
ifconfig tun0 mtu 1500
# Give it a chance to come up
pause 1
# This runs a command on the host to initialize the tunnel device:
shell ifconfig tun0 192.168.48.1 pointopoint 192.168.48.2 mtu 1500 u
```

If you are using a KISS TNC on the first COM port, **`ttyS0`**:

```
attach asy ttyS0 - ax25 ax0 4096 256 9600
ifconfig ax0 description "KISS TNC"
ifconfig ax0 ax25 irtt 1000
ifconfig ax0 ax25 t2 100
ifconfig ax0 ax25 t3 60000
ifconfig ax0 ax25 t4 120
ifconfig ax0 ax25 paclen 256
ifconfig ax0 ax25 window 16384
ifconfig ax0 ax25 maxframe 4
ifconfig ax0 ax25 maxwait 10000
ifconfig ax0 mtu 256
ifconfig ax0 ipaddr 203.0.113.25
ifconfig ax0 netmask 0xffffff00
ifconfig ax0 broadcast 203.0.113.255
mode ax0 datagram
```

If you wish to have a cross-connection to the Linux AX.25 stack, enter these commands (note that the IP address on this subnet is**`198.18.44.0/24`**):

```
attach asy ttyS32 - ax25 ax1 4096 256 9600
ifconfig ax1 description "KISS PTY emulation"
ifconfig ax1 ax25 irtt 1000
ifconfig ax1 ax25 t2 100
ifconfig ax1 ax25 t3 60000
ifconfig ax1 ax25 t4 120
ifconfig ax1 ax25 paclen 256
ifconfig ax1 ax25 window 16384
ifconfig ax1 ax25 maxframe 4
ifconfig ax1 ax25 maxwait 10000
ifconfig ax1 mtu 256
ifconfig ax1 ipaddr 198.18.44.5
ifconfig ax1 netmask 0xffffff00
ifconfig ax1 broadcast 198.18.44.255
mode ax1 datagram
```

[32] This “simulated tunnel” is the same as a **`socat`** fake PTY seen on the Linux **`ax25ipd`**example.

Since we are doing TCP/IP over AX.25, we need to add two routes: one for our tunnel device and one for our TNC:[33]

```
route add 203.0.113.0/24 ax0 direct 5
route add 198.18.44.0/24 ax1 direct 5
# The following IP address is our router's IP:
route add default tun0 192.168.1.1
```

Configure a DNS server:

```
domain addserver 192.168.1.110
```

Set up some AX.25 beacons:

```
ax25 bctext "JNOS/Linux"
ax25 bcinterval 600
ax25 bcport ax0
ax25 bcport ax1
```

Turn on ARP polling, such that your machine can network with other IP/AX.25 hosts:

```
# ARP functions:
arp eaves tun0 on
arp eaves ax0 onn
arp eaves ax1 onn
arp eaves encap on
# ARP polling:
arp poll tun0 on
arp poll ax0 onn
arp poll ax1 onn
arp poll encap on
arp maxq 10
```

Set some AX.25 parameters to increase performance:

```
ax25 maxf 2
ax25 timert linear
ax25 version 2
ax25 win 2048
ax25 pacl 128
ax25 bcinterval 600
ax25 ret 12
ax25 irtt 2500
ax25 maxw 7000
ax25 blimit 3
ax25 hsize 50
```

Turn on the “heard list” list to keep track of stations:

```
ax25 heard ax0
ax25 hport ax0 on
ax25 heard ax1
ax25 hport ax1 on
```

[33] Note that the example shown here assumes that your edge router knows that it can access the **`192.168.48.0/24`** network through your Linux's machine; in reality, you may struggle to do this or have to resort to setting up NAT. If this is the case, see the earlier NAT example under the *Linux AX.25* example.

Start configuring NET/ROM, and make a provision for running TCP over NET/ROM:

```
attach netrom
netrom alias JNOSXX
netrom call WA4XYZ-8
netrom interface ax0 192 143
netrom interface ax1 192 143
ifconfig netrom tcp blimit 3
ifconfig netrom tcp irtt 300000
ifconfig netrom tcp maxwait 900000
ifconfig netrom tcp mss 216
ifconfig netrom tcp retries 25
ifconfig netrom tcp timertype linear
ifconfig netrom tcp window 432
netrom nodefilter mode none
netrom acktime 100
netrom choketime 60000
netrom derate on
netrom hidden on                # show nodes that start with #
netrom irtt 8000
netrom minquality 143
netrom nodetimer 60             # broadcast interval
netrom obsotimer 1200           # how long nodes last for
netrom promiscuous on
netrom qlimit 2048
netrom retries 5
netrom timertype linear
netrom ttl 18
netrom g8bpq on                 # BPQ Packet Engine extensions
netrom bcpoll ax0               # this is our TNC
netrom bcnodes ax0
netrom bcpoll ax1               # this is our Linux pipe
netrom bcnodes ax1
ifconfig netrom ipaddress 203.0.113.26 netmask 0xfffffffc
route add 203.0.113.24/30       # 203.0.113.25-26 are for NET/ROM IP
```

JNOS has an HTTP server:

```
start http 80 /wwwroot          # /jnos/wwwroot is the real path
http absinclude on
http maxcli 15
http multihomed on
http simult 15
http tdisc 180
```

Configure the FTP server:

```
ftptdisc 300
ftype B
ftpclzw on
ftpslzw on
ftpmaxservers 15
```

Configure the SMTP server to forward messages to and from the BBS and the Internet:[34]

[34] I am only assuming that you are familiar with the inner workings of SMTP; the **`smtp gateway`** command will allow you to direct messages to an SMTP proxy that could rewrite the address -- see the Appendix for that.

```
smtp quiet on
smtp maxclients 25
smtp maxservers 25
smtp batch on
smtp t4 300
smtp tdisc 920
smtp timer 920
smtp use on
# smtp gateway 192.168.1.145
```

Start all of the server programs:

```
start ax25
start telnet
start smtp
start finger
start pop
start ttylink
start netrom
start ftp
start convers
start forward
```

If you need an AX/IP tunnel:

```
attach axip axi0 256 192.168.44.1
```

If you need an AX/UDP tunnel (in this case, the local and remote port are both 10093):

```
attach axudp axu0 256 192.168.44.1 N4XYZ-3 10093 10093
```

Note that you must have equivalent commands for all of the interface-dependent commands above for AX/IP and AX/UDP tunnels!

Managing Users: Before you can run JNOS, you should create some users. Remember, JNOS's primary job is to be a mailbox and BBS system, so you *really should* do this. Users are stored in the**`ftpusers`** file, which is located at **`/jnos/ftpusers`** in our example. Here is a sample file:

```
N4HAM pass123 /jnos/public 0x437F
univperm * /jnos/public 0x405F
```

The **`univperm`** line is the fall-through for users who are not registered and who connected to your node. The “permission value” (the hex value on the end of the line) is computed by ORing the following values:[35]

[35] If you are unfamiliar with how to do this, the Calculator program on most graphical OSes (as well as most graphing calculators) will permit you to change it into *programmer mode* (that's what Windows Calculator calls it, OS X Calculator has the same mode accessible via command-3) and perform arithmetic on hex values.

Table 5 (Page 1 of 2). **JNOS User Permission Bits**

Name	Decimal Value	Hex Value	Comments
FTP_READ	1	0x1	Read file
FTP_CREATE	2	0x2	Create new files
FTP_WRITE	4	0x4	Overwrite or delete existing files
AX25_CMD	8	0x8	AX.25 gateway (out-bound connect) allowed
TELNET_CMD	16	0x10	Telnet gateway allowed
NETROM_CMD	32	0x20	NET/ROM gatrway allowed
SYSOP_CMD	64	0x40	User can try to enter sysop mode
EXCLUDED_CMD	128	0x80	Ban user from BBS
PPP_ACCESS_PRIV	256	0x100	Allow user to connect via PPP
PPP_PWD_LOOKUP	512	0x200	PPP peer ID/password lookup
NO_SENDCMD	1024	0x400	Disallow “send” command
NO_READCMD	2048	0x800	Disallow “read” command
NO_3PARTY	4096	0x1000	Disallow third-party mail from other BBSes
IS_BBS	8192	0x2000	This callsign is a remote BBS
IS_EXPERT	16384	0x4000	Allow access to “expert” shell
NO_CONVERS	32768	0x8000	Disallow access to the “convers” chat server
NO_ESCAPE	65536	0x10000	Disable the escape character
NO_LISTS	131072	0x20000	No lists displayed from the mailbox
NO_LINKEDTO	262144	0x40000	Disable the “*** linked to” text
NO_LASTREAD	524288	0x80000	Ignore the lastread file in the shared accounts directory

NO_FBBCMP	1048576	0x100000	No F4FBB BBS compression
XG_ALLOWED	20971572	0x200000	Allow the “xg” (dynamic IP route) command

Provided that you tailored this file accordingly, you should now have a working JNOS system. It is recommended that you run JNOS in a**screen** session:

```
 a
# socat -d -d PTY,link=/dev/ttyS34 PTY,link=/dev/ttyS35 &
# screen -S jnos
# cd /jnos
# ./jnos
<press control-A then D>
```

Now that JNOS is up, configure the Linux AX.25 stack (as seen before) to have a port entry for the JNOS pipe. Start by adding it to**/etc/ax25/axports**:

```
# name callsign speed paclen window description
#----- -------- ----- ------ ------ -----------
radio  WA4XYZ-1 1200  256    7      Real TNC
jnos   WA4XYZ-5 19200 1024   7      JNOS/Linux
```

Ensure it is also in **/etc/ax25/nrbroadcast**:

```
# ax25_name min_obs def_qual worst_qual verbose
#---------- ------- -------- ---------- -------
radio      5       192      100        0
jnos       5       192      100        0
```

Now, connect Linux's stack to the *other side* of the fake serial cable provided by **socat**:

```
# kissattach /dev/ttyS35 jnos 198.18.44.10
```

Now, everything is set. JNOS is running, and Linux can communicate with it by using IP on the **tun0** interface, or by using AX.25 on the **jnos** port (which would be **ax0** if you have no other **kissattach**'d TNCs active).

In this canned example, JNOS can be reached in either of the following examples from its Linux host:

```
$ call jnos WA4XYZ-3 (AX.25-noL3)
$ call netrom JNOSXX (NET/ROM aka AX.25-L4)
$ telnet 192.168.48.2 (tun0 interface)
$ telnet 198.18.44.5 (TCP/IP over AX.25)
```

Using JNOS

Before running any JNOS commands, invoke **ifconfig** to see the interfaces. You should see at least four ports:

```
ax0      IP addr 203.0.113.25 MTU 256 Link encap AX25
         Link addr WA4XYZ-3  BBS WA4XYZ-3  Paclen 256   Irtt 5000
         BCText: JNOS/Linux
         flags 0xfb2 trace 0x0 netmask 0xffffff00 broadcast 203.0.113.255
         sent: ip 0 tot 1092405 idle 0:00:00:19
         recv: ip 1437715 tot 1751311 idle 0:00:00:07
ax1      IP addr 198.18.44.5 MTU 256 Link encap AX25
         Link addr WA4XYZ-3  BBS WA4XYZ-3  Paclen 256   Irtt 5000
         BCText: JNOS/Linux
         flags 0xfb2 trace 0x0 netmask 0xffffff00 broadcast 198.18.44.255
         sent: ip 0 tot 1092405 idle 0:00:00:19
         recv: ip 1437715 tot 1751311 idle 0:00:00:07
tun0     IP addr 192.168.48.2 MTU 1500 Link encap TUN
         flags 0x300 trace 0x0 netmask 0xffffff00 broadcast 0.0.0.0
         sent: ip 3023005 tot 3023005 idle 0:00:00:16
         recv: ip 3137736 tot 3137736 idle 0:00:00:13
encap    IP addr 0.0.0.0 MTU 65535 Link encap None
         flags 0x300 trace 0x0 netmask 0xffffffff broadcast 255.255.255.255
         sent: ip 0 tot 0 idle 243:23:38:35
         recv: ip 0 tot 0 idle 243:23:38:35
```

To make an AX.25 connection, use the following command:

```
jnos> connect ax0 N4ABC-7
```

List NET/ROM nodes with:

```
jnos> netrom route nodes
jnos> netrom neigh
```

To make a NET/ROM connection:

```
jnos> netrom connect MYNODE
```

You can make a Telnet connection:

```
jnos> telnet 192.168.1.1
```

Using the JNOS BBS: One of the most standout features of the JNOS package (and, by extension, its adjacents like those listed at the start of this section) is its wonderful **BBS.** Whereas Linux requires the F6FBB BBS package, JNOS has one built in!

Users can access the BBS in one of two ways:

1. Invoke the **`bbs`** command at the **`jnos>`** prompt
2. Telnet, AX.25-connect, or NET/ROM-connect to the JNOS node

When you connect, via Telnet in this example, you will be greeted with a logon prompt. By specifying any callsign, you can log in and register:[36]

[36] To disallow anonymous/unregistered users access to the BBS (and therefore node in general), you can specify that for the**`univperm`** user by setting the **`EXCLUDED_CMD`** permission bit.

```
% telnet 192.168.48.2
Trying 192.168.48.2...
Connected to 192.168.48.2.
Escape character is '^]'.

JNOS (jnos2.wa4xyz.radio)

login: w4abc
Password:
[JNOS-2.0p-B1FHIM$]
You have 0 messages.

Please type 'REGISTER' at the > prompt.
Area: w4abc (#0) >
```

At this point, you can register as an anonymous user:

```
Area: w4abc (#0) >
register
Your current settings are:
Name = Someone
AX.25 Homebbs Address  = Unknown
Internet Email Address = Unknown

First name.(CR=cancel)
Somebody
AX.25 homebbs.(CR=cancel all)
WA4XYZ-3
Internet Email.(CR=ignore)
w4abc@arrl.net
Area: w4abc (#0) >
```

If you check the **`ftpusers`** file, you will note that the user is *not* there; instead, the user can be found at the bottom of **`/jnos/spool/users.dat`**:

```
w4abc 1769026100 M20   A X     -nSomebody -hWA4XYZ-3 -ew4abc@arrl.net
```

To give the user persistent, registered access, you must key them into **`ftpusers.`**

To **send a message**, use the **`S`** command:

```
Area: w4abc (#0) >
s w4abc
Subject:
test email
Enter message.  End with /EX or ^Z in first column (^A aborts):
this is a test message to demonstrate JNOS's BBS.
/EX
Send(N=no)? y
Msg queued
Area: w4abc (#0) >
```

To **read a message**, you only need to *press the Enter key:*

```
Area: w4abc (#0) >

Message #1
Date: Wed, 21 Jan 2026 14:12:14 CST
From: w4abc@jnos2.wa4xyz.radio
To: w4abc
Subject: test email

this is a test message to demonstrate JNOS's BBS.

You have new mail. Please Kill when read!
Area: w4abc (#1) >
```

Now, the BBS tells you need to **kill** the message when you receive it; this is the shorthand for **deleting a message:**

```
k
Msg 1 Killed.
Area: w4abc (#1) >
```

Now, the **`#1`** in the parathenses to the right of your callsign is the **message number.** You can switch messages by *typing in the corresponding number and pressing enter:*

```
Area: w4abc (#0) >
1
Message #1
Date: Wed, 21 Jan 2026 14:12:14 CST
From: w4abc@jnos2.wa4xyz.radio
To: w4abc
Subject: test email

this is a test message to demonstrate JNOS's BBS.

Area: w4abc (#1) >
2
Message #2
Date: Wed, 21 Jan 2026 14:15:14 CST
From: n4ham@jnos2.wa4xyz.radio
To: w4abc
Subject: welcome to the BBS!

Welcome to the BBS, Example Human Being!

Area: w4abc (#1) >
```

At this point, you can use the **`kill`** command to remove the old messages; otherwise, you can save the messages and log out:

```
Area: w4abc (#1) >
b
Connection closed by foreign host.
```

You will return to the shell prompt.

Advanced Mode: If your user account has been keyed into **`ftpusers`** and you are marked as an *advanced user*, you will be able to see a more complex shell prompt, but also possibly enter sysop mode to break into a JNOS shell and run any command. With advanced mode on, your shell prompt changes to this:

```
login: n4ham
Password:
ﬃJNOS-2.0p-B1FHIM$“

You have 0 messages.
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
```

Advanced mode was intended to emulate the user interface of TheNet, BPQ, K-node, and other such popular packet radio packages; you will notice that this long shell prompt of letters will show up on several other BBSes.

Now that we are in advanced mode, we can enter some commands to *discover adjacent* **NET/ROM** *nodes.* and also connect to them. Use the **n** command to list nodes, then use **c** to connect to them:

```
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
n
EVIE1:WA4XYZ-7
*** 1 nodes displayed
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
c evie1
Trying...  The escape character is: CTRL-T
*** connected to EVIE1:WA4XYZ-7
nodes
WA4XYZ-1} Nodes:
JNOSXX:WA4XYZ-8   EVIE1:WA4XYZ-7
bye

*** reconnected to JNOSXX:WA4XYZ-8


Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
```

Making NET/ROM connections is fairly easy, but making **AX.25-NoL3** connections will require you to be aware of the port. You can use the **p** command:

```
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
p
Available AX.25 Ports:
ax2
ax1
ax0
Available HFDD Ports:
Available VARA Ports:

Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
```

In this mode, it can be rather difficult to determine which port is present on which frequency/interface; as such, *sysops should assign descriptive names if they wish to remedy this!* Alas, you can use the **c** command to bring up a connection:

```
c ax1 wa4xyz-1
Trying...  The escape character is: CTRL-T
*** connected to WA4XYZ-1
nodess
WA4XYZ-1} Nodes:
JNOSXX:WA4XYZ-8   EVIE1:WA4XYZ-7
byee

*** reconnected to JNOSXX:WA4XYZ-8
```

You can also make **Telnet** connections with the **T** command:

```
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
t 192.168.48.1
Resolving 192.168.48.1... Trying...  The escape character is: CTRL-T
*** connected to 192.168.48.1:telnet
login: ^T

Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
```

As shown above, pressing **control-T** will drop you from the connection.

Sysop Mode: With all of this in mind, advanced mode may be more ideal for registered users. However, there is one more mode that we must cover: sysop mode. Since it may sometimes be necessary to access the JNOS shell remotely, the JNOS authors were sure to include a mechanism to do so; enter the **@** command to switch:

```
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
@ pass123

Type 'exit' to return
Jnos> ip status
( 1)ipForwarding              1     ( 2)ipDefaultTTL             225
( 3)ipInReceives        5451444     ( 4)ipInHdrErrors              0
( 5)ipInAddrErrors            0     ( 6)ipForwDatagrams            0
( 7)ipInUnknownProtos         0     ( 8)ipInDiscards               0
( 9)ipInDelivers        4737473     (10)ipOutRequests        4530960
(11)ipOutDiscards             0     (12)ipOutNoRoutes              4
(13)ipReasmTimeout            4     (14)ipReasmReqds         1422918
(15)ipReasmOKs           708947     (16)ipReasmFails             101
(17)ipFragOKs                 0     (18)ipFragFails                0
(19)ipFragCreates             0
Jnos> exit
Area: n4ham Current msg# 0.
?,A,B,C,CONV,D,E,F,H,I,IH,IP,J,K,L,M,N,NR,O,P,PI,R,S,T,U,V,W,X,Z >
```

Now that you are familiar with basic JNOS usage, let us also understand some of the more advanced features this package provides.

Advanced Configuration

JNOS provides more features than are readily documented in this manual; it is highly recommended that you explore not only the old JNOS manuals, but also press **?** frequently to discover new things!

IPIP Tunnels: An IPIP tunnel, using IP protocol 4, is a useful method of bridging two disparate networks. Note that you *cannot port-forward* an IPIP tunnel unless your router is using OpenBSD**`pf`**.[37]

To create one of these, first define it on the target operating system. Since this depends on the OS in question, several examples will be provided for various OSes. In this example, **`198.18.0.0/24`** is the subnet within the tunnel, and **`192.168.48.0/24`** is the subnet used on the **`tun0`** device to communicate with the host. *If the target host is **not** the same machine running JNOS, you will need to engage **IP forarding** (i.e. routing) to allow the target host and remote host to communicate.*

Linux, old method:

```
# iptunnel add mode ipip local 192.168.48.1 remote 192.168.48.2
# ifconfig ipip0 198.18.0.1 dstaddr 198.18.0.2 up
```

Linux, new method:

```
# modprobe ipip
# modprobe new_tunnel
# ifconfig tunl0 198.18.0.1 pointopoint 192.168.48.2 up
```

FreeBSD:

```
# ifconfig gif0 create
# gifconfig gif0 inet 192.168.48.1 192.168.48.2
# ifconfig gif0 198.18.0.1 netmask 255.255.255.252 198.18.0.2
# ifconfig gif0 mtu 1500 up
```

Cisco IOS:

```
interface Tunnel1
 ip address 198.18.0.1 255.255.255.252
 tunnel mode ipip
 tunnel destination 192.168.48.4
 tunnel source 192.168.48.1    <--- change me!
!
```

JNOS:

```
route add 198.18.0.0/24 encap 192.168.48.1
```

Note that there are also **NOS tunnels** (sometimes called *KA9Q tunnels*) that use **IP protocol 94** instead. The reason for this is historical in nature, but it will require that the setup commands are now different.

SLIP: SLIP is **Serial Line IP**, and is a simplistic way of framing IP packets on a serial cable (either synchronous or asynchronous). If you need to get JNOS to talk to an embedded device, SLIP might be ideal!

Setup is fairly straightforward, *but note that modern operating systems like FreeBSD have actually removed SLIP support.*

Linux:

[37] You can enter a rather simplistic **`pf.conf`** rule like so, where **`$ext-if`** is the external interface, and **`$lan_ip`** is the IP address of a host on your LAN running JNOS (possibly one route hop away):

```
match in on $ext_if proto { 4, 94 } rdr-to $lan_ip
```

```
# slattach -L -p slip -s 9600 /dev/ttyUSB0
# ifconfig sl0 198.18.0.2 dstaddr 198.18.0.1 up
```

JNOS:

```
jnos> attach asy ttyU0 - slip sl0 4096 296 9600
jnos> ifconfig sl0 ipaddress 198.18.0.1 netmask 0xffffffff up
jnos> route add 198.18.0.2/32 sl0
```

PPP: The **Point-to-Point Protocol** is a multiprotocol link-layer protocol intended to replace SLIP on serial connections. PPP is *intelligent,* and more than IP can be ran over it.[38]

The difficulty of this configuration lies in not JNOS, *but the host instead;* there is a standard PPP command (**pppd**) but other OSes have different methods. Some are as follows:

Linux:

```
# pppd nodetach local noauth passive debug nobsdcomp \
    nodeflate noccp nocrtscts 198.18.0.1:198.18.0.2 \
    /dev/ttyUSB0 115200
```

FreeBSD:

```
# ppp
ppp ON bsdserver> set device /dev/ttyu2
ppp ON bsdserver> set speed 115200
ppp ON bsdserver> set ctsrts off
ppp ON bsdserver> set ifaddr 198.18.0.1 198.18.0.2
ppp ON bsdserver> set log Phase Chat Connect LCP IPCP IPV6CP CCP
ppp ON bsdserver> disable pap chap passwdauth
ppp ON bsdserver> open lcp
ppp ON bsdserver> open ipcp
```

If you get strange errors about **/var/lock** not existing, run**mkdir /var/lock** to alleviate them.

JNOS:

```
jnos> attach asy ttyU0 - ppp ppp0 4096 1500 115200
jnos> ppp ppp0 lcp open
jnos> ppp ppp0 ipcp open
jnos> ifconfig ppp0 netmask 0xffffff00
jnos> route add 198.18.0.1/32 ppp0
```

JNOS will request and acquire an address from the remote. If you wish for JNOS to instead provide an address to the remote, enter these commands:

```
jnos> ppp ppp0 ipcp local address 198.18.0.2
jnos> ppp ppp0 ipcp remote address 198.18.0.1
```

IPv6: With newer versions of JNOS 2.0, the package has full IPv6 support; this makes it the only amateur packet stack to support it. While this guide will not configure IPv6 setup in detail (and will certainly not explain how to set up IPv6 on your home network, good luck though!), basic IPv6 configuration will be described.

[38] At the time of writing this, I have set up IPv4, IPv6, DECnet, IPX, SNA, AppleTalk, OSI/CLNS, CDP, VINES, XNS, and Apollo/Domain over PPP.

If JNOS can communicate with the host using IPv4 with a *tun device*, IPv6 uses a ***tap device*** -- the reason for this is because there is no assurance that the protocol number (which conveys IPv6 presence) will make its way through the **`tun`** device.[39]

As such, you must first create a **`tap0`** device for JNOS to use; the steps here depend on the OS running JNOS:

Linux, old method:

```
1. Create the tap device
# tunctl -t tap0 -u root
# ifconfig tap0 up
2. Create the bridge and assign the device to the bridge
# brctl addbr br0
# brctl addif br0 tap0
# ifconfig br0 up
# ifconfig br0 inet6 fd00:4::1/64
```

Linux, new method:

```
# ip tuntap add mode tap dev tap0
# ip link add dev br0 type bridge
# ip link set tap0 up
# ip link set tap0 master br0
# ip link set br0 up
# ip -6 addr add dev br0 fd00:4::1/64
```

FreeBSD:

```
1. Create the tap device
# ifconfig tap0 create
# ifconfig tap0 up
-- OR on old FreeBSD --
# kldload if_tap
# cat /dev/tap0
^C
# ifconfig tap0 up
2. Create the bridge and assign the device to the bridge
# ifconfig bridge0 create
# ifconfig bridge0 addm tap0 up
# ifconfig bridge0 inet6 fd00:4::1 prefixlen 64
# route add -inet6 fd00:4::/64 -iface bridge0
```

JNOS:

```
jnos> attach tun tap0 1500 0
jnos> ipv6 addr
(the default will be FD00:4::2/64)
jnos> ipv6 iface tap0
jnos> start telnet -6
jnos> start http -6
```

(note that the **`start`** *commands will replace the ones described earlier on in this guide)*

[39] This is particularly a problem on Linux, where both the application using the **`tun`** device driver and the kernel must make an inference based on the version number; BSD does not have this issue with its superior implementation of the **`tun`** driver.

RIP and Automatic Routing: In addition to using static routes, you can also use **RIP** to dynamically exchange routes. Note that poorly implementing this protocol in an uncontrolled fashion leaves your network not only open to attacks, but also massive breakage -- use it with caution!

Starting RIP on JNOS is done the same way as any other`start` command:

```
jnos> start rip
```

You now need to instruct JNOS to either request a router or listen for broadcasts; this is done explicitly:

```
jnos> rip request 192.168.50.1
```

To accept announcements:

```
jnos> rip accept 192.168.50.1
```

NOSaprs

APRS, while already covered, has *excellent* support within JNOS. Not only can JNOS be an **I-gate**, but also a full APRS BBS and mail relay! Let us examine the configuration.

First, enable or disable APRS logging. This will go at`/jnos/spool/log/aprs.log` if you enable it:

```
aprs log on
```

You then need to select interfaces to run APRS on:

```
aprs interface ax0
aprs interface ax1
```

Set the callsign used for APRS's I-gate client:[40]

```
aprs logon call WA4XYZ-3
```

When you log into the APRS-IS system, you need to specify a **filter** (or you will get no APRS traffic at all):[41]

```
aprs logon filter m/50
```

Inevitably, you will want to set up beacons. You can configure unique beacons for the APRS-IS side and the RF side(s), so enter those accordingly:

```
aprs bc stat "Super Cool JNOS APRS Box"
aprs bc pos "3561.22N/08723.75WBWA4XYZ-3 JNOS Rocks!"
aprs bc timer 10
aprs bc rfstat "Super Cool JNOS APRS Box"
aprs bc rfpos "3561.22N/08723.75WBWA4XYZ-3 JNOS Rocks!"
aprs bc rftimer 10
```

I will not provide an overtly-detailed explanation for this as it is somewhat out of the scope for this document, but the **`B`** between**`08723.75W`** and **`WA4XYZ-3`** is the **symbol selector** and the **`/`** between **`3561.22N`** and**`08723.75W`** is the **table selector.**[42]

[40] Normally, you would need to specify a login passcode; this is actually *not necessary* for NOSaprs.

[41] See the section earlier on **APRS Filters** to understand these!

[42] If you are confused, see the symbol table in the first half of this book.

The **stat** and **pos** beacons result in *two* effective lines of text; these show up as a purple object status text and a green object beacon text.

Configure the heard-station table size:

```
aprs hsize 50
```

Specify the contact and a locator that shows up on the TCP port 14501 HTTP status page that JNOS runs:

```
aprs contact m "wa4xyz@arrl.org"
aprs locator "https://aprs.fi"
```

You need to configure an **APRS server** to make the I-Gate function. This can be the public one, your own copy of **aprsc**, XRouter's APRS server, or others. Here is one example:

```
aprs server add noam.aprs2.net 14580
```

You can then enable APRS-IS to RF gating:

```
aprs calls fwdtorf *
aprs calls postorf *
aprs calls stattorf *
aprs calls wxtorf *
aprs calls obj2rf *
```

On the aforementioned APRS status page, you can also set the "public" IP address:

```
aprs internal 192.168.50.2
```

If you wish to allow web browser users to send and receive APRS messages using that interface, you need to authorize their IP addresses:

```
aprs calls ip45845 198.18.0.2
```

For APRS email, make JNOS's SMTP server process it:

```
aprs email local
```

Engage APRS listening on the interfaces you specified earlier:

```
aprs listen on
```

You are almost done. Start the APRS listeners:

```
# If you want the NOSaprs status page to be available,
# for example, 'http://localhost:14501'.
start aprs 14501
# If you want the NOSaprs browser based message center
# for example, 'http://localhost:14845'.
start aprs 14845
```

Engage the transmitting I-Gate functionality *and* digipeater operation with this:

```
aprs flags +aprs_txenable +digi
```

For any APRS packets to properly route out of the TNC interfaces, you need to add a special route for the logical callsign**APZ115**:

```
ax25 route add APZ115 ax0
```

Congratulations, you now have working NOSaprs. Check that the NOS node beacons out on both RF and APRS-IS (you can check that with**`https://aprs.fi`**, Xastir, UI-View32, YAAC, or any other APRS client), and have fun!

BPQ Packet Engine

John Wiseman, G8BPQ, has a long-standing history of influencing packet radio in *several* important ways; his most profound contribution is the **BPQ Packet Engine** (which has undergone several name changes over the course of its life).

There are several versions of BPQ:

- **BPQCODE**, for MS-DOS
- **LinBPQ**, for Linux
- **BPQ32**, for 32-bit Windows

First, we will discuss **LinBPQ** (since it is rather likely that you, as a ham radio operator, have plenty of Linux machines sitting around).

BPQ does, however, have stellar implementations of:

- APRS
- A mail system/PMS
- A chat server

Note conversely that BPQ does not have:

- TCP/IP
- A configuration GUI

LinBPQ

This section is for the Linux or BSD versions of BPQ.

Installation

Note that the following **dependencies** are required to compile LinBPQ:

- **`libconfig`**
- **`libpcap`**

LinBPQ can be compiled without too much difficulty. *Clone* the source code from GitHub as follows, then compile it:

```
$ git clone https://github.com/g8bpq/linbpq
$ cd linbpq
$ make
```

Once the compilation has completed successfully, you may start configuring it. Inevitably, you will want to **relocate** the**linbpq** binary to some other run directory; if this is a multiuser system and you would like to ensure its security, ensure that the directory permissions disallow world-write (and world-read if you like).[43]

Configuration

The BPQ configuration statements are stored in a file named**bpq32.cfg** *(and do note that the filename is case-sensitive).* Open that file with your favorite editor and begin entering as follows!

First, you will want to enable the features (i.e. services) that you'd like. These are **LINMAIL** and **LINCHAT**:

```
LINMAIL
LINCHAT
```

Now, you need to set the **sysop password**:

```
PASSWORD=bpqr0ck5
```

Set the node callsign, NET/ROM callsign, node alias, and gridsquare locator:[44][45]

```
NODECALL=WA4XYZ-8
NETROMCALL=WA4XYZ-8
NODEALIAS=MYBPQ
LOCATOR=FN03
MAPCOMMENT=Packet node in Neverland, NX
```

You now need to set various **NET/ROM parameters**:

```
                ; Max number of hops a node can be announced
OBSINIT=6            ; Threshold to remove nodes from broadcasts
OBSMIN=4
NODESINTERVAL=10     ; Routing broadcast interval (minutes)
L3TIMETOLIVE=20      ; Max L3 (NET/ROM) hops
L4RETRIES=3          ; Max packet retries before a session dies
L4TIMEOUT=60         ; How many seconds before a connection is dead
L4WINDOW=4           ; Window size in packets
MAXLINKS=256         ; Max L2 links
MAXNODES=512         ; Max nodes in routing table
MAXROUTES=144        ; Max adjacent node links
MAXCIRCUITS=160      ; Max L4 session circuits
MINQUAL=1            ; Lowest node quality allowed in the routelist
PACLEN=236           ; L3 packet size (assuming 256 for L2)
T3=120               ; Link keepalive time in seconds
IDLETIME=720         ; Number of seconds before a link closes
```

It should be noted that the following terms have special significance in the world of BPQ:

1. **Links** are AX.25 virtual circuits that are propped up between nodes to carry NET/ROM traffic
2. **Nodes** are known NET/ROM hosts

[43] For the Linux-impaired, this would consist of **chmod 700 bpq_directory_name**.

[44] BPQ, unlike the Linux AX.25 stack, is smart enough to distinguish the protocol ID in the AX.25 frames when multiple connection attempts occur. In other words, it is not necessary to use two different callsigns for NET/ROM and “plain” AX.25-noL3 communication.

[45] To **stay off the BPQ map,** simply set the locator to**NONE** and also include **MAPCOMMENT=NONE** in the configuration file.

3. **Routes** are known adjacent NET/ROM nodes and the path taken to get there
4. **Obsolecence** prevents stale routing table entries from locking up an entire packet network

You can emulate an **AGW Packet Engine** virtual TNC and allow all manner of AX.25 terminal programs to use BPQ as a “virtual TNC” (therefore permitting you to talk directly into the network without having several TNCs):[46]

```
AGWPORT=8100
AGWMASK=0x30
AGWSESSIONS=10
AGWLOOPMON=1
AGWLOOPTX=1
```

There are a few more extra config options that should be set:

```
AUTOSAVE=1          ; Save routing table in BPQNODES.dat
BBS=1               ; Set to 1 to include BBS support
NODE=1              ; Set to 1 to allow cross-port packet gating
HIDENODES=0         ; Set to 1 to hide nodes starting with '#'
ENABLE_LINKED=A     ; Only allow linking to application programs
```

Now, you will want to configure **broadcasts** and beacons:

```
BTINTERVAL=1        ; Flat beacon interval in minutes
BTEXT:
My Super Cool BPQ Node
***

IDINTERVAL=1        ; UI ID broadcast interval in minutes
IDMSG:
My Super Cool BPQ Node
***
```

When users connect, you will want to include a **information text** for them to view:

```
INFOMSG:
This is a packet radio shell.
Please do not just copy and paste these configuration statements,
but understand what they do.

***
```

You should also set a **connection text** that users see when they connect:

```
a
FULL_CTEXT=0        ; Set to 1 to display this on all connects
CTEXT:
Welcome to Anna Airwave's super cool packet node!
***
```

You can add **locked routes** if you wish, but our example will not have any:

```
ROUTES:
***
```

[46] **UZ7HO EasyTerm** is a good choice if you use Windows, otherwise use **QtTermTCP** on other OSes (note that this program can connect to the **`FBBPORT`** or to the **`AGWPORT`** depending on configuration options).

Ports

Now, we should configure **ports.** There are slightly different syntaxes for various types of interfaces, so here are some examples:

AX/IP and AX/UDP: These are managed by the same port driver:

```
PORT
 PORTNUM=20
 ID=AX/IP                       ; AX/IP/UDP Wormholes
 DRIVER=BPQAXIP                 ; Uses BPQAXIP.DLL
 QUALITY=192
 MINQUAL=191
 MAXFRAME=7                     ; Max outstanding frames (1 thru 7)
 FRACK=7000                     ; Level 2 timout in milliseconds
 RESPTIME=1000                  ; Level 2 delayed ack timer in milliseconds
 RETRIES=10                     ; Level 2 maximum retry value
 PACLEN=236
 CONFIG
  UDP 10093                     ; Listens for UDP packets on this UDP port
  MHEARD
  BROADCAST NODES
  AUTOADDMAP                    ; Automatically add lines based on UDP packets
  MAP WA4XYZ-1 198.18.12.4 B
  MAP N4HAM-3 192.168.50.2 B
  MAP AA4XY-2 44.96.23.12 UDP 10093 B
ENDPORT
```

Telnet Port: This allows inbound connections via **Telnet**, permitting easy node operation.

```
PORT
 PORTNUM=15
 ID=Telnet
 DRIVER=TELNET
 MHEARD=Y
 QUALITY=192
 CONFIG
  LOGGING=1
  TCPPORT=7300
  FBBPORT=8011
  HTTPPORT=81
  CMDPORT=23                              ; see note
  CTEXT=Connected to MYBPQ\nEnter ? for list of commands\n\n
  LOGINPROMPT=Callsign:
  PASSWORDPROMPT=Password:
  DisconnectOnClose=1
  MAXSESSIONS=10
  LOCALNET=10.0.0.0/24
  USER=n4ham,rizz123,N4HAM,,SYSOP         ; user,pass,call,command,sysop?
ENDPORT
```

Of important note is the **`CMDPORT`** field -- this will be used to create custom applications; see the **Applications** section below.

KISS TNCs: TODO

Applications: BPQ permits definition of various **applications** that permit access to remote systems or local services. These take the form of custom commands that users may invoke upon connecting. Here are some samples:

This is for access to the integrated **BBS**; **`BBS`** is the command, **`WA4XYZ-9`** is the logical callsign assigned to the application, and **`MYBBS`** is its NET/ROM node alias (since this is reachable outside of this node):

```
APPLICATION 1,BBS,,WA4XYZ-9,MYBBS,255
```

This is for access to the integrated **chat server**; the same parameters as above apply:

```
APPLICATION 2,CHAT,,WA4XYZ-10,MYCHT,255
```

The generic form of this command is:

```
APPLICATION n,cmd,newcmd,call,alias,quality,l2alias
```

- **`n`**: the application number, you can have up to 32
- **`cmd`**: the command the user types on the shell
- **`newcmd`**: the node command to be ran *(optional)*
- **`call`**: the callsign that, upon being connected to, executes the command immediately *(optional)*
- **`alias`**: the NET/ROM alias that serves the same purpose as the **`call`** field *(optional)*
- **`quality`**: the quality of the above **`call`** and**`alias`** Note: you need all three (**`call,alias,quality`**) for this to work *(optional)*
- **`l2alias`**: functions like the **`call,alias,quality`** triplet, but for AX.25-NoL3 connections

So, in order to create *local shell applications*, you need to do two things:

1. Create or update the **`CMDPORT`** line in a Telnet port definition
2. Create **`APPLICATION`** lines

First, let us understand the **`CMDPORT`** field. Within your Telnet port definition (which, in this example, holds port number 15) you will see that field. This is a space-delimited list of sockets that BPQ can connect to *on the host*.

These TCP ports are indexed from zero, but are unrelated to the actual ports themselves. For example, you could have these in your**`CMDPORT`** list:

```
CMDPORT 23 1023
```

This would allow you to connect to the host's Telnet socket and some other service on port 1023. ***However, we can use this technique to write custom commands!***

For example, let us create an example application that prints a message upon connection. First, update **`CMDPORT`**:

```
CMDPORT 60000 60001 60002
```

Note that there are three ports present here, we will only have an application listen on the first one, though!

You now need to create a program that outputs some text upon connection. This can be done using **`inetd`**, *systemd sockets*, or a totally custom server that accepts raw TCP connections.

Create the following shell script somewhere, like**`/usr/local/lib/bpqdemo.sh`**, with the following contents:

```
#!/bin/bash
echo "Demonstration BPQ Application"
```

Make this script executable and make sure that it runs:

```
$ chmod +x bpqdemo.sh
$ ./bpqdemo.sh
Demonstration BPQ Application
```

Next, if you are using **systemd**, you need to create two files -- one will be a *socket* and the other will be a *service*. First, edit**/lib/systemd/system/bpqdemo.socket**:

```
[Unit]
Description=Demo BPQ Application

[Socket]
ListenStream=60000
Accept=yes

[Install]
WantedBy=sockets.target
```

Likewise, update **/lib/systemd/system/bpqdemo@.service**:

```
[Unit]
Description=Demo BPQ App Server

[Service]
ExecStart=/usr/local/lib/bpqdemo.sh
StandardInput=socket
```

You now need to tell **systemd** of the changes. Run these commands as root:

```
# systemctl daemon-reload
# systemctl start bpqdemo.socket
```

Finally, test it:

```
$ nc localhost 60000
Demonstration BPQ Application
```

If you are using **inetd**, it is much easier; add the following line to **/etc/inetd.conf**:

```
600000  stream  tcp   nowait  root  /usr/local/lib/bpqdemo.sh bpqdemo.sh
```

Restart **inetd** as root:

```
# pkill -9 inetd
# inetd
```

Now that the server process is ready, you now need to **update the application line** for it. Looking above, you should see the**cmd** field of the **APPLICATION** line. In lieu of a normal **C** (**CONNECT**) command, you will be using a command like this:

```
C 15 HOST 0
```

The command arguments are as follows:

1. **C**: short for **CONNECT**
2. **15**: port number of the Telnet link driver, 15 in this example (but you can change the number)
3. **HOST**: logical callsign on the Telnet port to make TCP connections to **localhost:PORT** where **PORT** is one of the TCP ports listed in the **CMDPORT** argument on the port definition

4. **`0`**: use the “zeroth” port of the **`CMDPORT`** list, so the first one listed.

Usage

Inevitably, you will want to connect to your LinBPQ node by either pointing another packet radio node at it, but you have two other important options:

- QtTermTCP or BPQTermTCP
- Telnet

You will want to try all of these, starting with **QtTermTCP.**

QtTermTCP

This program is a cross-platform successor to ***BPQTermTCP*** and is quite slick! Installation will not be described in great detail, but John Wiseman has instructions on his site.

Assuming you created a Telnet port, take note of the**`FBBPORT`** that you entered earlier. With QtTermTCP open, go to **Setup -> Hosts -> New Host**. The options are as follows:

1. **Host Name**: the IP address of the LinBPQ node you are connecting to[47]
2. **Port**: the **`FBBPORT`** number entered in the Telnet port settings on the node
3. **User**: one of the username/password combinations in the Telnet port settings, which would be **`n4ham`** in this example
4. **Password**: the password corresponding to the above username, **`rizz123`** in this example
5. **Session Name**: a descriptive name of your choosing,**`MYBPQ`** in this example

Go to **Connect -> 127.0.0.1(MYBPQ** (or whatever you entered), and you should see output on the bottom window:

```
Connected to TelnetServer
```

Enter a command, like **`?`** for some help:

```
?
MYBPQ:WA4XYZ-8} BBS CHAT SHELL CONNECT BYE INFO NODES PORTS ROUTE
```

These various comands will do exactly what you might think:

```
nodes
MYBPQ:WA4XYZ-8} Nodes
MYBBS:WA4BPQ-9     MYCHT:WA4XYZ-8     JNOSXX:WA4XYZ-5
LNXVM:WA4XYZ-7     ZLNX2:WA4XYZ-2
```

To make a **connection to another node**, use the **`C`** command:

[47] Use **`127.0.0.1`** or **`localhost`** if you are running QtTermTCP and LinBPQ on the same machine.

```
c lnxvm
MYBPQ:WA4XYZ-8} Connected to LNXVM:WA4XYZ-7
?
WA4XYZ-7} Commands:
?, Announce, Bye, Connect, Desti, DXCluster, Escape, Finger, Help,
HOst
Info, INTerfaces, Jheard, JLong, Links, MSg, NEtstat, Nodes, Ping,
Quit
Routes, Sessions, STatus, Telnet, Users, Version, Who
bye
Disconnected
```

Note that when you disconnect from a remote node, you will be disconnected from the local node unless you go change that.

You may also wish to **set the monitor/screen split** for more screen real-estate; to do that, *right-click* and select “Set Monitor/Output Split.”

The other BPQ commands will work, including the **BBS**:

```
bbs
MYBPQ:WA4XYZ-8} Connected to BBS
[BPQ-6.0.23.76-IHJM$]
Hello Evie. Latest Message is 14, Last listed is 0
Please enter your Home BBS using the Home command.
You may also enter your QTH and ZIP/Postcode using qth and zip commands.
de N4HAM>
bye
Disconnected
```

The BBS commands here are common to the XRouter and JNOS BBS. As such, you should be able to learn how to use it rather quickly by typing **?**!

Telnet

To access the BPQ Telnet socket, simply connect to the**TCPPORT** value in the Telnet port configuration section:

```
% telnet 127.0.0.1 7300
Trying 127.0.0.1...
Connected to 127.0.0.1.
Escape character is '[]'.
callsign:n4ham
password:

Connected to MYBPQ:WA4XYZ-8
Enter ? for list of commands

?
MYBPQ:WA4XYZ-8} BBS CHAT SHELL CONNECT BYE INFO NODES PORTS ROUTES USERS MHEARD
bye
*** Disconnected from Stream 2
Connection closed by foreign host.
%
```

All the same commands apply as shown in the **QtTermTCP** section above!

BPQCODE

BPQCODE, otherwise just called the **BPQ Packet Engine,** is the aforementioned MS-DOS BPQ AX.25 stack. This provides basic *NET/ROM* support, and not much else.

While BPQCODE does provide KISS interface support, it also supports the ***BPQETHER*** interface -- this was described in the Linux AX.25 section. Do, however, note that BPQETHER requires the installation of *an additional network stack!*[48]

BPQETHER Prep (Novell VLM Client)

If you do wish to use BPQETHER, you need to edit**`C:\NWCLIENT\NET.CFG`** to resemble this:

[48] This *additional network stack* is the Novell VLM Client. This can be found by searching online (particulary on archive.org) for “Novell LAN WorkPlace 5” and installing that alongside a supported Ethernet card driver. This installation is out of the scope of this document.

```
Link Support
        Buffers 8 1500
        MemPool 6144
        Max Boards 4
        Max Stacks 8

Link Driver NCOMX
        IRQ 4
        PORT 3f8

Link Driver PCNTNW
        Frame ETHERNET_802.3
        Frame ETHERNET_II
        PROTOCOL IPX 0 ETHERNET_802.3
        PROTOCOL BPQ 8FF ETHERNET_II
        PROTOCOL TCPIP 8137 ETHERNET_II

Protocol TCPIP
        PATH TCP_CFG C:\NET\TCP
        ip_address 0.0.0.0 LAN_NET
        ip_netmask 255.255.255.0 LAN_NET
        ip_router 192.168.1.1 LAN_NET
        Bind PCNTNW #1 ETHERNET_II LAN_NET
        ip_address 0.0.0.0 PPP_NET
        Bind NCOMX #1 PPP PPP_NET

NWIP
        AUTORETRIES 1
        AUTORETRY SECS 10
        NSQ_BROADCAST ON
        NWIP1_1 COMPATIBILITY OFF

NetWare DOS Requester
        First Network Drive = F
        PREFERRED SERVER = HSNW4A

BPQPARAMS
        ETH_ADDR FF:FF:FF:FF:FF:FF
```

Configuration

Examine the following sample **BPQCFG.TXT** located in the same directory as **BPQCODE.EXE** and**BPQCFG.EXE**:

```
HOSTINTERRUPT=127 ; Sets the Interrupt used to access BPQ Host Mode. Will
                  ; normally be 127, but may be changed if this clashes w
                  ; other software. BTRIEVE seems to use 127, so if you a
                  ; using it, try INTERRUPT=126
EMS=0             ; dont use EMS RAM
DESQVIEW=0

NODECALL=WX4XYZ-1 ; NODE CALLSIGN
NODEALIAS=BPQNOD
BBSCALL=WX4XYZ-2  ; BBS CALLSIGN
BBSALIAS=BPQBBS   ; BBS ALIAS

IDMSG:
Network node (BPQ1)
***

UNPROTO=CQ                  ; DEFAULT UNPROTO ADDR

INFOMSG:
G8BPQ Packet Switch
Commands are basically the same as NET/ROM, but to connect to another
normal station (not another node), you must specify a port number before
the callsign. Use PORTS command to list available ports. The BBS command
connects you to the associated Mailbox.
***

CTEXT:
Welcome to G8BPQ's Packet Switch in Nottingham
Type ? for list of available commands.
***

FULL_CTEXT=0                  ; SEND CTEXT ONLY TO L2 CONNECTEES TO ALI

OBSINIT=5                     ; INITIAL OBSOLESCENCE VALUE
OBSMIN=4                      ; MINIMUM TO BROADCAST
NODESINTERVAL=1               ; 'NODES' INTERVAL IN MINS
IDINTERVAL=1                  ; 'ID' BROADCAST INTERVAL
BTINTERVAL=0                  ; NO BEACONS
L3TIMETOLIVE=25               ; MAX L3 HOPS
L4RETRIES=3                   ; LEVEL 4 RETRY COUNT
L4TIMEOUT=120                 ; LEVEL 4 TIMEOUT
L4DELAY=10                    ; LEVEL 4 DELAYED ACK TIMER
L4WINDOW=4                    ; DEFAULT LEVEL 4 WINDOW
MAXLINKS=30                   ; MAX LEVEL 2 LINKS (UP,DOWN AND INTERNOD
MAXNODES=120                  ; MAX NODES IN SYSTEM
MAXROUTES=35                  ; MAX ADJACENT NODES
MAXCIRCUITS=64                ; NUMBER OF L4 CIRCUITS
MINQUAL=10                    ; MINIMUM QUALITY TO ADD TO NODES TABLE
BBSQUAL=30                    ; BBS Quality relative to NODE - used to
                              ; limit 'spread' of BBS through the netwo
                              ; to your required service area. I've bee
                              ; asked to set a low default to encourage
                              ; to think about a suitable value. Max is
BUFFERS=255                   ; PACKET BUFFERS - 255 MEANS ALLOCATE AS
                              ; AS POSSIBLE - NORMALLY ABOUT 130, DEPEN
                              ; ON OTHER TABLE SIZES
PACLEN=120                    ; MAX PACKET SIZE DEFAULT
TRANSDELAY=1                  ; TRANSPARENT MODE SEND DELAY - 1 SEC
```

```
T3=180                          ; LINK VALIDATION TIMER (3 MINS)
IDLETIME=900                    ; IDLE LINK SHUTDOWN TIMER (15 MINS)

BBS=1                           ; INCLUDE BBS SUPPORT
NODE=1                          ; INCLUDE SWITCH SUPPORT

HIDENODES=0                     ; IF SET TO 1, NODES STARTING WITH # WILL
                                ; ONLY BE DISPLAYED BY A NODES * COMMAND

ENABLE_LINKED=Y                 ; CONTROLS PROCESSING OF *** LINKED COMMA
                                ; Y ALLOWS UNRESTRICTED USE
                                ; A ALLOWS USE BY APPLICATION PROGRAM
                                ; N (OR ANY OTHER VALUE) DISABLE
;TNCPORT
;       COM=1
;ENDPORT
;TNCPORT
;       COM=3
;       APPLFLAGS=4
;ENDPORT

PORT
        ID=ETHERNET
        TYPE=EXTERNAL
        PROTOCOL=KISS
        INTLEVEL=125
        SPEED=9600
        CHANNEL=A
        QUALITY=10
        MAXFRAME=7
        TXDELAY=500
        SLOTTIME=100
        PERSIST=64
        FULLDUP=0
        FRACK=7000
        RESPTIME=2000
        RETRIES=10
        PACLEN=256
ENDPORT


ROUTES:
***

APPLICATIONS=BBS,,*SYS,CHAT/C NMCHAT
```

Starting BPQCODE

In order to properly start BPQCODE, you must run several programs ahead of time:[49]

[49] If you are using the Novell VLM Client (i.e. LAN WorkPlace) at all, start that ahead of time before running any part of BPQ

```
C:\BPQ> bpqcfg
C:\BPQ> odidrv 125     <--- only if you are using BPQETHER
C:\BPQ> bpqcode
```

The **ODIDRV** command is part of the Novell VLM client. However, not everything is ready.

Using BPQCODE

Included in the BPQ package is a program named **PAC4**, and it is a stand-in for BPQTerm (Windows), BPQTermTCP, or QtTermTCP on modern LinBPQ and BPQ32. This program communicates with BPQ by using the interrupt vector specified with the **HOSTINTERRUPT** option in**BPQCFG.TXT**

Start that program:

```
C:\> pac4
```

Meshtastic

Meshtastic is a **non-AX.25 packet protocol.** Based on the LoRa protocol,Meshtastic offers a simple and non-networked protocol that is remarkably similar to APRS is; the major difference between the two is that AX.25 is the underlying network protocol that carries APRS, whereas LoRa itself is the underlying protocol that carries Meshtastic.[50]

The LoRa Protocol

LoRa, short for *Long Range*, is an ISM-band based protocol that is intended to provide excellent range (compared to other modulation modes, like AX.25's Bell 103 modem) for the amount of transmit power used (which, as one might imagine being on an ISM band, is in the milliwatts).[51]

ISM Bands

ISM is short for *Industrial, Scientific, and Medical;* these are radio bands intended for various devices of the same name. They are not intended for radio communication, but can be provided that the power is under a certain threshold.[52]

For reference, here are most of the ISM bands in the USA:

[50] It should be noted that "LoRa" is a catch-all for *several* protocols: the physical layer and the MAC layer (and sometimes the application layer).

[51] While I said LoRa is intended to be ran on the ISM bands, some amateur radio operators have actually ran LoRa on HF using a *transverter* to downconvert the 433 MHz signals to HF.

[52] Note that this guide is very USA-centric, and this rule *may not apply* in some other countries!

Table 6. **US ISM Bands**

Start	End	Notes
13.553 MHz	13.567 MHz	22-meter band, some run beacons here
26.957 MHz	27.283 MHz	CB radio
40.66 MHz	40.7 MHz	6-meter band, an amateur band in some places that aren't the US
433.05 MHz	434.79 MHz	Region 1 70-centimeter ISM band, shared with an amateur band
902 MHz	928 MHz	33-centimeter band, an amateur band in the US
2.4 GHz	2.5 GHz	13-centimeter band, commonly used for Wi-Fi and microwave ovens
5.725 GHz	5.875 GHz	5-centimeter band, commonly used for newer Wi-Fi systems

There are some other bands, but they have been omitted for brevity.

LoRa CSS Modulation

The LoRa protocol uses the **chirp spread-spectrum** modulation mode, wherein a carrier shifts in frequency within a certain bandwidth over a certain timeframe; the faster the shift, the more bandwidth is required as per a trade-off between bandwidth and SNR.

LoRa also has a **spreading factor**[53] that ranges 5 to 12 -- it controls how many bits are sent per each symbol and the bandwidth that each transmission will take. Like many other modems, LoRa allows the aforementioned SNR tradeoff wherein the data rate can increase at the expense of signal integrity.

LoRa also implements a **forward error correction** scheme to pre-emptively guard against various interference issues on the receiving station. Since the transmit power is so low (usually limited to +22 dBm), this error-correction scheme is paramount; with all of this, LoRa can still manage a link distance of about 3 miles in urban areas, and about 10 miles in rural areas (provided that there are no obvious obstructions along those paths).

LoRa Packet Format

For visual continence, the LoRa packet structure is as follows:

[53] Abbreviated **SF**

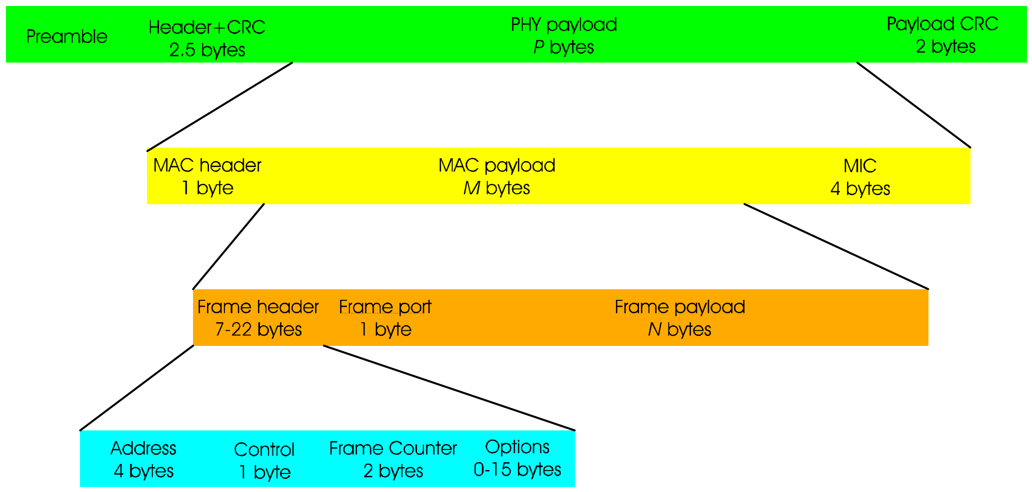

Figure 9. LoRa Frame Format

Meshtastic Protocol Introduction

Meshtastic has been around since 2020, and was designed by Kevin Hester. Like APRS, Meshtastic is a terrifically simple protocol. Rather than provide a protocol analogous to NET/ROM, Meshtastic is a simple per-note-repeating protocol; as such, Meshtastic would need to address the following issues:

1. High node battery consumption due to constant packet reception and processing on behalf of the nodes in the network
2. Excessive retransmissions which would end up filling all of the available transmission timeslots
3. Infinite packet retransmission would cause a jamming of the entire network

As such, the Meshtastic protocol needed to do several things to address those issues:

- Set the LoRa packet preamble to be as long as possible such that the node can sleep while listening for packets (and wake up just in time to decode the packet)
- Listen before transmitting, in the same way that most AX.25 TNCs do, to prevent packet collisions or other such classical network design issues
- Understand and rank the distance of received packets to control who gets digipeated first
- If a packet has been digipeated too many times, don't digipeat it[54]
- Do not retransmit a packet that has already been digipeated unless you were the one to originate it

Meshtastic functions at the **application layer** of the LoRa network stack.

[54] 7 is the colloquial maximum number of hops on a Meshtastic network, and this can result in upwards of 150 km of coverage in areas with reasonably-spaced nodes

Alternate Packet Modems

VARA HF/VHF/SAT

While the standard Bell 102/103 and G3RUH/KN9G AX.25 physical layer modems are rather popular, they simply do not offer very good performance in the modern age. EA5HVK created **VARA** as a successor to the aforementioned modems (and, more importantly, their shortcomings.

VARA has one key feature that sets it apart from the traditional packet TNCs and softmodems: *it can dynamically vary its speed with band conditions*. This is especially useful on HF, where band conditions could result in a rapidly-fluttering signal that would be totally unusable by traditional packet modems. VARA will detect this and vary its speed to compensate.

At the time of writing, there are three versions of VARA:

1. **VARA HF**, for HF communications within a 3000 Hz window[55]

2. **VARA FM**, intended for use in place of traditional FM packet TNCs, and is capable of hitting several kilobaud with a good radio[56]

3. **VARA SAT**, intended for use on the QO-100 geostationary satellite

VARA is a Windows-only program, written in Visual Basic 5. Furthermore, it features rather draconian copy protection (with an encrypted code segment that is decrypted at runtime).

TODO

ARDOP

TODO

FreeDATA (Codec2)

TODO

fldigi

TODO

[55] This is the globally-accepted "standard" for HF signal bandwidth on the amateur bands

[56] See the coming note on "VARA FM Wide" to understand this

Web Locations of Packet Radio Software

JNOS 2.0, Mainline

```
$ rsync -a www.langelaar.net::official jnos
```

JNOS 2.0, FreeBSD Port

```
https://github.com/HackerSmacker/jnos-freebsd
```

Linux AX.25 Programs

```
Wiki: https://linux-ax25.in-berlin.de/wiki/Main_Page
ax25-apps: https://linux-ax25.in-berlin.de/cgit/ax25-apps.git
ax25-tools: https://linux-ax25.in-berlin.de/cgit/ax25-tools.git
libax25: https:/:linux-ax25.in-berlin.de/cgit/libax25.git
```

BPQ Packet Engine, Mainline

```
https://github.com/g8bpq/linbpq
```

BPQ Packet Engine, FreeBSD Port

```
https://github.com/HackerSmacker/g8bpq-bsd
```

aprx for Linux

```
https://github.com/PhirePhly/aprx
```

Glossary

C

Constellation Diagram. A diagram that displays amplitude and phase for various digital modulation modes, including PSK and QAM.

CSS. Chirp Spread-Spectrum, a modulation mode often used for ISM band devices

I

ISM Band. Various unlicensed radio bands that permit some amount of transmit power, but barely any; almost all of them (except for the 40 MHz band in most countries) overlap amateur radio bands.

L

LoRa. “Long Range,” a CSS modulation mode with very good SNR

O

OSI Model. A reference model for a network stack also called the OSI Stack, which is often applied to other protocols. The layers are physical, data-link, network, transport, session, presentation, application

P

PSK. “Phase-Shift Keying,” a data modulation mode in which the phase of the signal is modulated

Q

QAM. “Quadrature Amplitude Modulation,” a data modulation mode where the amplitude and phase of the modulated analog waveform is varied

S

SNR. “Signal-to-Noise Ratio,” a ratio of the signal strength to the noise strength

Index

Part Number
0413-56

File Number
PACKET

Printed in U.S.A.

9963-0413-56

```
*** .EDF#INIT      500  13 <snap @zero@ls>
***
*** NAME         (INDEX) LCL AREA SIZE <VALUE>
***
*** &@zero@ls                    48     1 <0>
***
*** .EDF#INIT      500  13 <snap @zero@ls>
***
*** NAME         (INDEX) LCL AREA SIZE <VALUE>
***
*** &@zero@ls                    48     1 <0>
***
TABLE SPLIT ON PAGE 38.
'.EDFETABL' WAS IMBEDDED AT LINE 2136 OF 'PACKET'
TABLE SPLIT ON PAGE 39.
'.EDFETABL' WAS IMBEDDED AT LINE 2136 OF 'PACKET'
TABLE SPLIT ON PAGE 48.
'.EDFETABL' WAS IMBEDDED AT LINE 2632 OF 'PACKET'
'KP' WOULD EXCEED MAXIMUM SIZE.
'PACKET' LINE 3866: .BL
STARTING PASS 2 OF 3.
'KP' WOULD EXCEED MAXIMUM SIZE.
'.EDFEXMP' LINE 160: .br
'.EDFEXMP' WAS IMBEDDED AT LINE 1842 OF 'PACKET'
TABLE SPLIT ON PAGE 36.
'.EDFETABL' WAS IMBEDDED AT LINE 2136 OF 'PACKET'
TABLE SPLIT ON PAGE 37.
'.EDFETABL' WAS IMBEDDED AT LINE 2136 OF 'PACKET'
TABLE SPLIT ON PAGE 45.
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