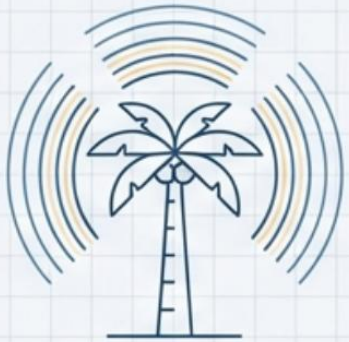
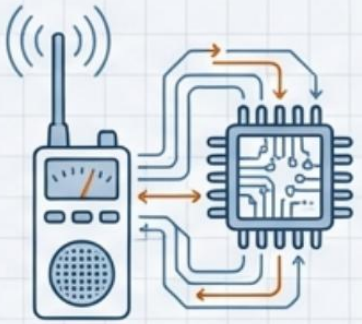
Born from the Islands: The Genesis of Packet





1970

1976

1980s

Terminal Black
ALOHAnet (Univ. of Hawaii)
Inter Medium

The first wireless packet data network.

Inter Medium
X.25 Standard
Inter Regular

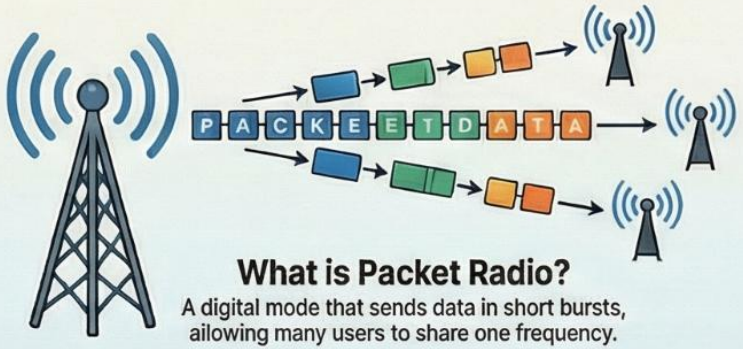
Commercial packet switching (CCITT).

Oscilloscope Amber
AX.25 v2.0 (TAPR)
Inter Regular

Amateur adaptation for noisy, half-duplex channels.

The Adaptation:
Inter Medium
AX.25 (Amateur X.25) was designed to create error-free, shared-channel data communication using Bell 202 tones (1200 baud).
Inter Regular

A Visual Guide to AX.25 Packet Radio



What is Packet Radio?

A digital mode that sends data in short bursts, allowing many users to share one frequency.

The Foundation of Ham Packet Radio

AX.25: The Protocol for Hams

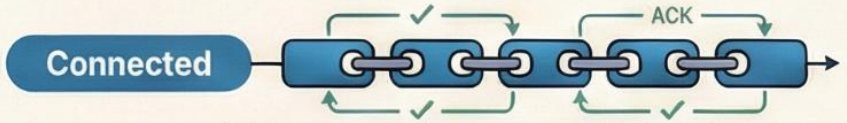
It adapts professional data protocols for amateur use with callsign addressing and collision avoidance.

Key Implementations

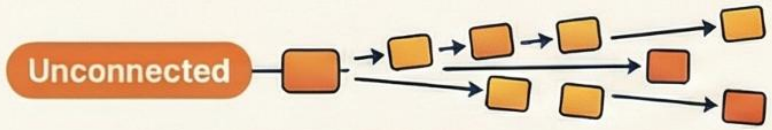
The protocol can be managed by hardware (TNC) or modern software like Dire Wolf.

Anatomy of a Transmission

Two Ways to Communicate



Reliable, sequenced link with error-checking and retransmissions.



Unrellable "fire-and-forget" broadcast with no acknowledgment.

Sample type:

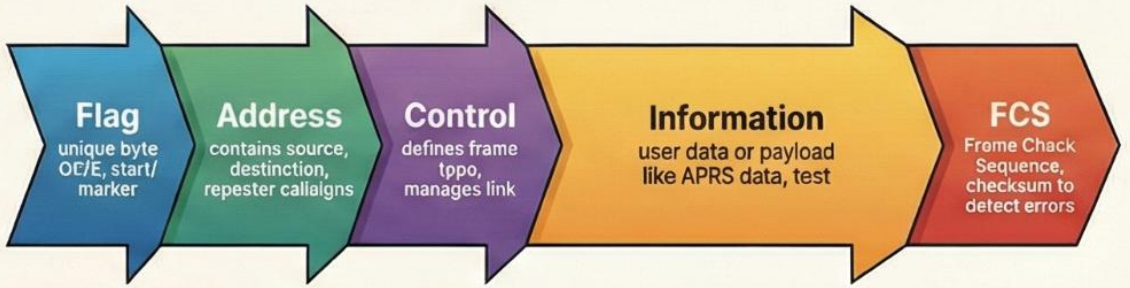
I-frame (Information)

Common uses: Winlink email, file transfers, BBS access.

UI-frame (Unnumbered Info)

Common uses: APRS position reports, general beacons.

The Structure of a Packet

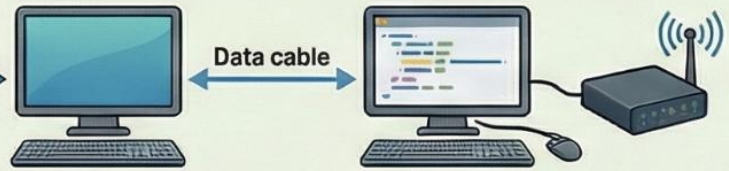


Each data packet is wrapped in a standard frame format for transmission.

The Packet Radio Ecosystem

Terminal Node Controller (TNC)

The "modem" for packet radio, encoding data into audio tones and decoding received tones.



The KISS Protocol

A simple standard allowing a computer to use a TNC for packet transmission without handling the full AX.25 protocol.

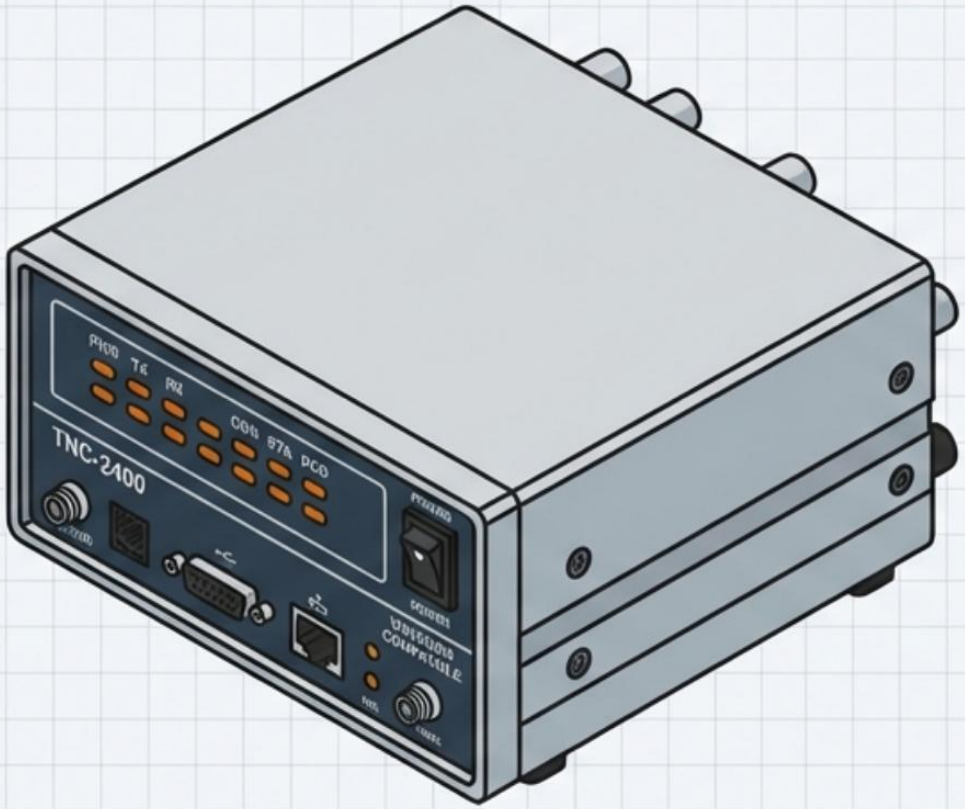
Popular Applications Today

Winlink

Widely used for the Automatic Packet Reporting System (APRS) and the Winlink global email system.

JetBrains Mono bold, tracking -10

The Hardware Legacy: Terminal Node Controllers



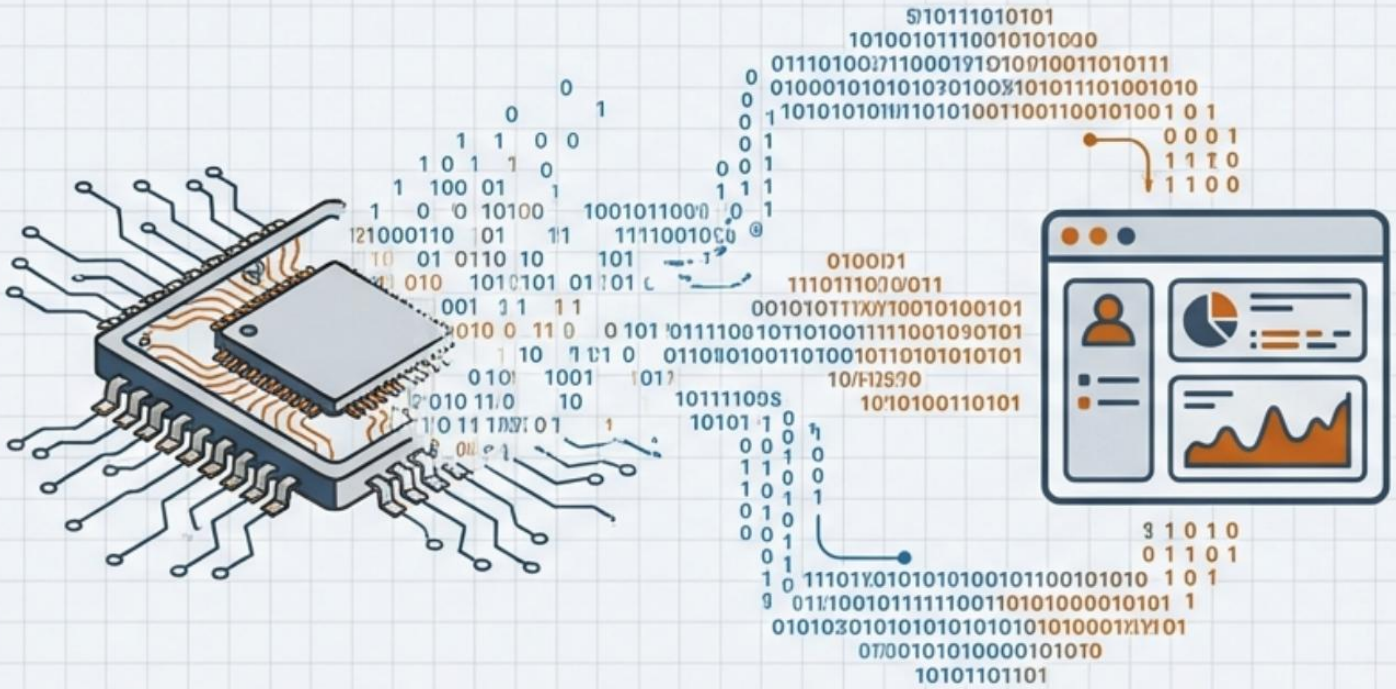
- **Definition:** Dedicated microcontroller + modem firmware.
- **Role:** Demodulates audio to bits; handles PTT.
- **Pros:** Highly reliable, computer-independent.
- **Cons:** Expensive, difficult to upgrade.

The Interface: Keep It Simple, Stupid (KISS)

Problem: Hardware TNCs were too rigid.
Solution: **KISS** offloads the protocol logic to the computer.
The TNC becomes a simple frame encapsulator.

JetBrains Mono bold, tracking -10

The Software Revolution: Soundcards & DSP

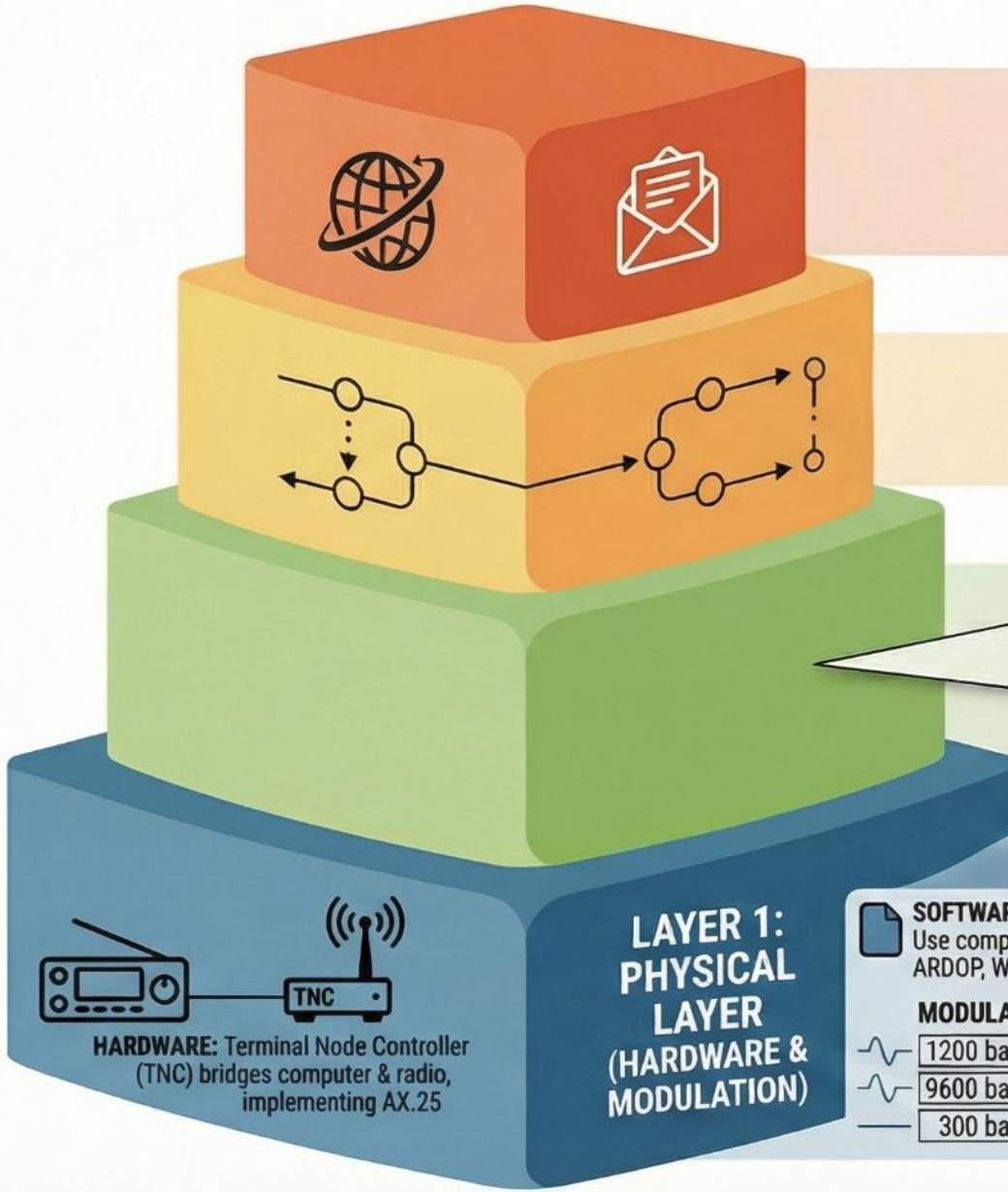


Soundmodem (UZ7HO): **Virtual KISS TNC**. Uses the PC sound card to decode packet.

Direwolf: The gold standard. Software modem with **Digipeater**, **IGate**, and **FX.25 Forward Error Correction**.

Modern CPUs perform Digital Signal Processing (DSP) that outperforms legacy hardware in weak signal decoding.

The Anatomy of Amateur Packet Radio: A Layered Protocol Stack



LAYER 7: APPLICATION LAYER

WINLINK GLOBAL RADIO EMAIL: Exchange email via HF/VHF radio without internet for mariners & emergency responders

APRS (AUTOMATIC POSITION REPORTING SYSTEM): Real-time tracking of mobile objects, weather reporting, and short messaging

MODES: CONNECTED (Reliable file transfers, BBS) vs. **UNCONNECTED** (Beacons, APRS position reports)

LAYERS 3 & 4: NETWORK & TRANSPORT

TCP/IP INTEGRATION: AX.25 as data link layer for IPv4, enabling standard internet applications

ARQ (AUTOMATIC REPEAT REQUEST): Receiver automatically requests retransmission of corrupted packets

PID (PROTOCOL IDENTIFIER): 1-octet field identifying Layer-3 protocol (e.g., 0x08 for IP, 0xF0 for no Layer 3)

LAYER 2: DATA LINK (THE AX.25 STANDARD)

AX.25 PACKET STRUCTURE

FLAG (Gs1E)	ADDRESS (CALLSIGNS - Source, Dest, Repeaters)	CONTROL	PID	INFORMATION (Payload)	FCS (Error Check)	FLAG

CALLSIGN ADDRESSING: Addresses derived from amateur callsigns to simplify regulation compliance

HDLC SYNTAX: AX.25 uses High-Level Data Link Control syntax and NRZI encoding

LAYER 1: PHYSICAL LAYER (HARDWARE & MODULATION)

HARDWARE: Terminal Node Controller (TNC) bridges computer & radio, implementing AX.25

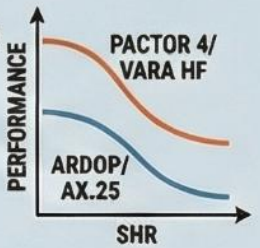
SOFTWARE-DEFINED MODEMS: Use computer soundcards (e.g., VARA, ARDOP, WINMOR) to process signals

MODULATION STANDARDS

- 1200 baud — Bell 202 (VHF/UHF)
- 9600 baud — G3RUH (VHF/UHF)
- 300 baud — Bell 103 (HF)

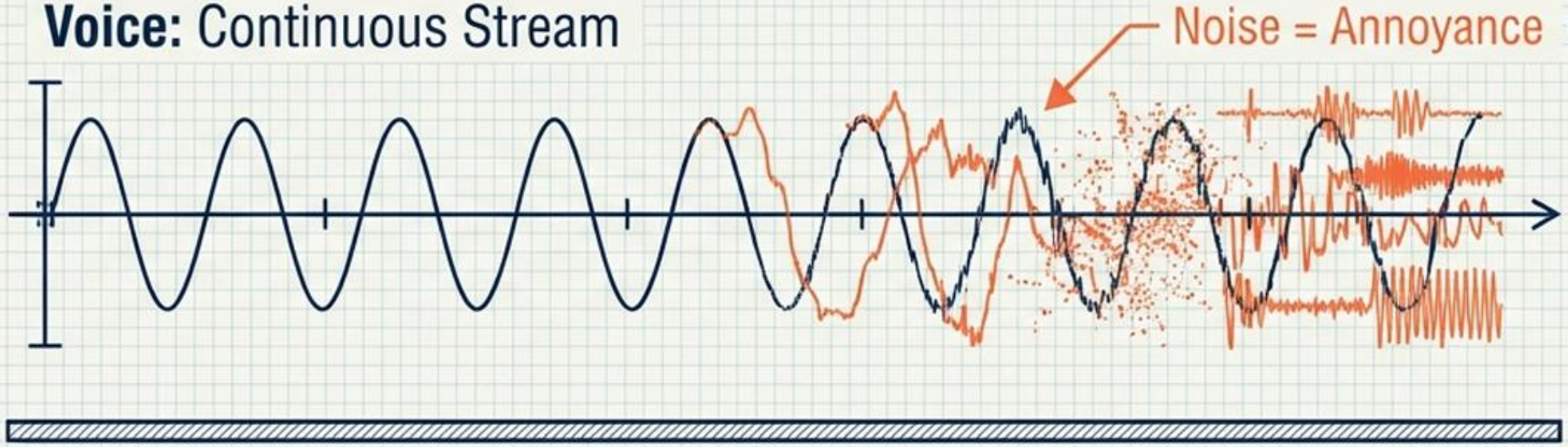
HF/VHF PERFORMANCE COMPARISON

	PERFORMANCE CONTEXT	KEY CHARACTERISTIC
PACTOR 4	High-end HF Hardware	Clear leader in good multipath conditions; expensive
VARA HF	Software Modem	Exceptional performance; low-cost shareware
ARDOP	Open Software	Free alternative; generally slower and less stable
AX.25/FX.25	Standard Packet	Baseline for VHF/UHF; "FX.25" adds FEC

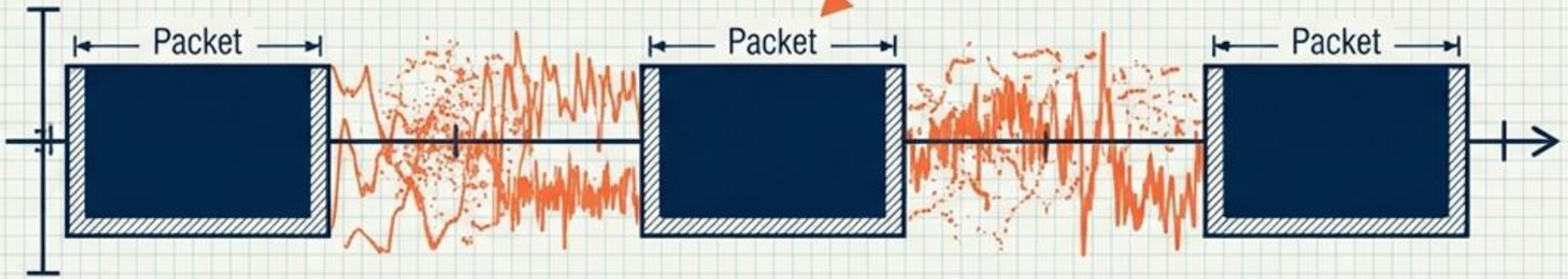


Burst Transmission: Solving the Noise Problem

Voice: Continuous Stream



Packet: Burst Data



TECHNICAL CONTEXT

Analog radio channels are inherently noisy. Unlike voice, where the human brain filters static, digital data requires perfection. Packet radio solves this by chopping data into discrete blocks. Each block is an "all-or-nothing" attempt.

The Anatomy of an AX.25 Packet

Start Flag

A 1-byte sequence (0x7E) that marks the beginning of the packet.

Control Field

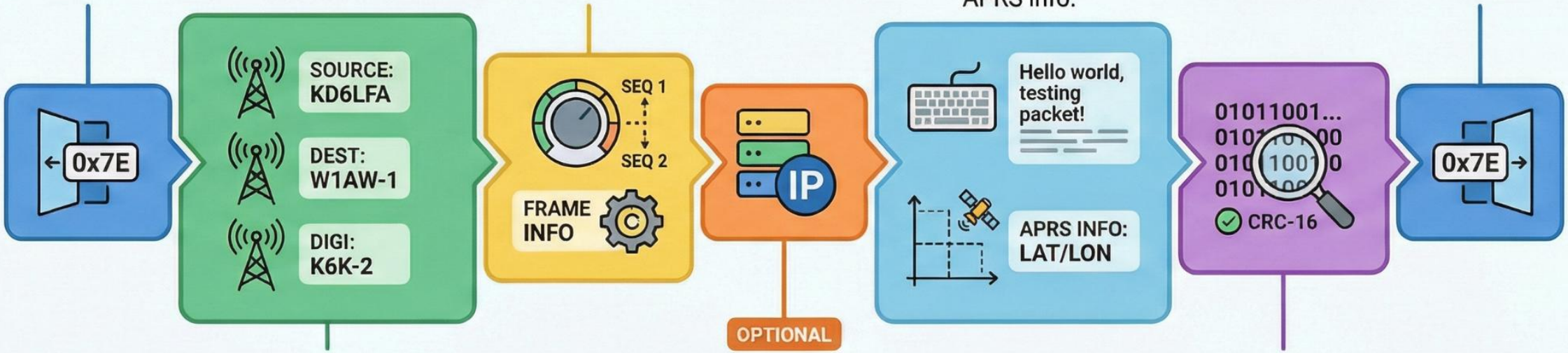
1-2 bytes that define the frame type and include sequence numbers.

Information Field (Payload)

0-256 bytes carrying the actual user data, like text or APRS info.

End Flag

A 1-byte sequence (0x7E) that marks the end of the packet.



Address Field

14+ bytes containing source, destination, and optional repeater callsigns.

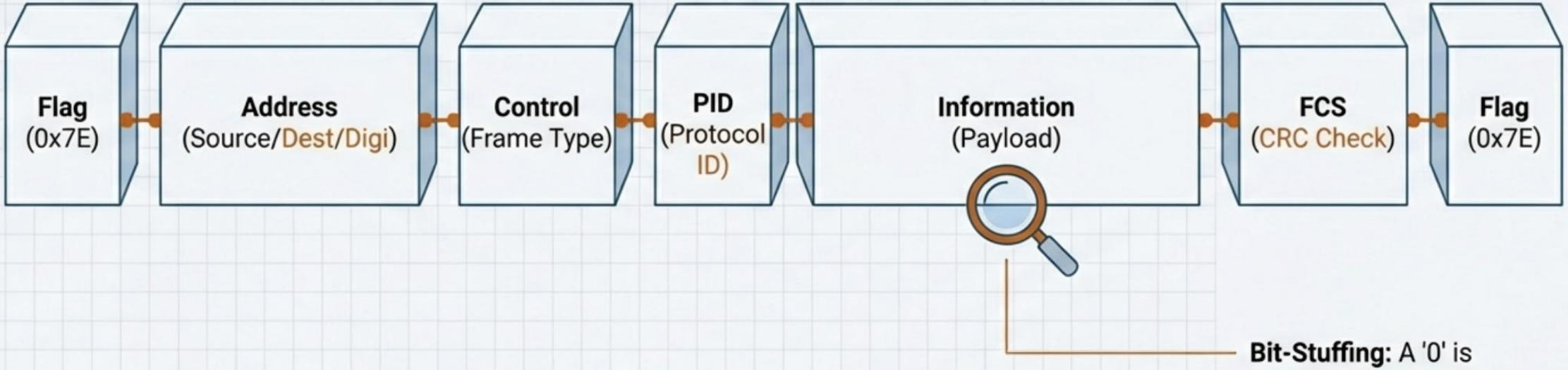
Protocol ID (PID) Field

An optional 1-byte field identifying the Layer 3 protocol (e.g., IP).

Frame Check Sequence (FCS)

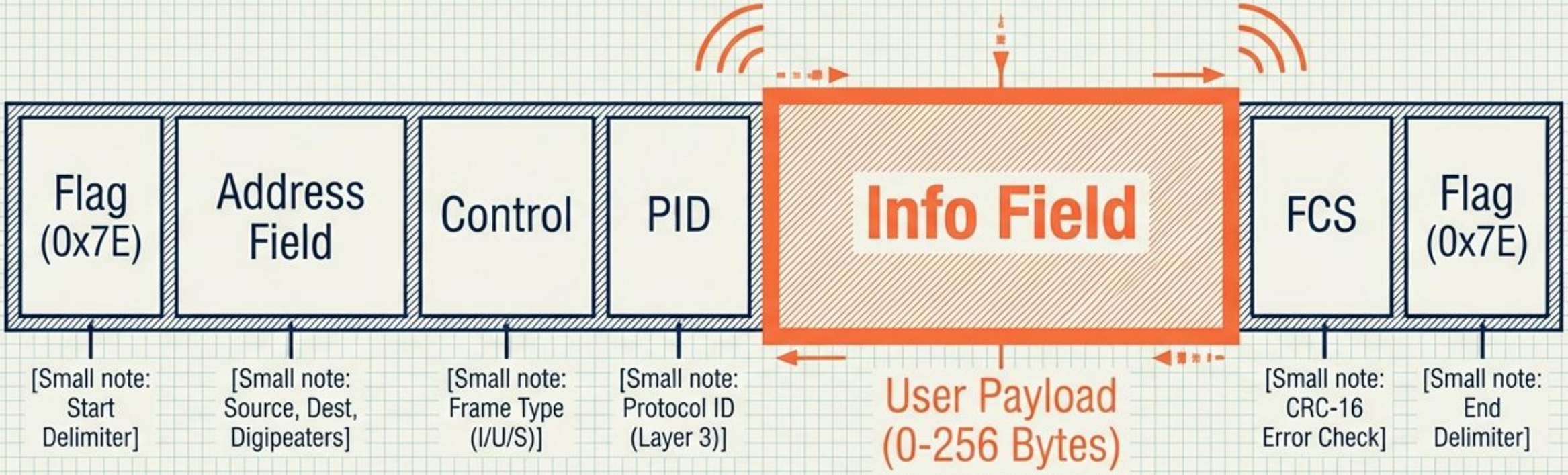
A 2-byte checksum (16-bit CRC) used to detect transmission errors.

Anatomy of a Packet: The AX.25 Frame



Bit-Stuffing: A '0' is forcibly inserted after five '1's to maintain clock sync.

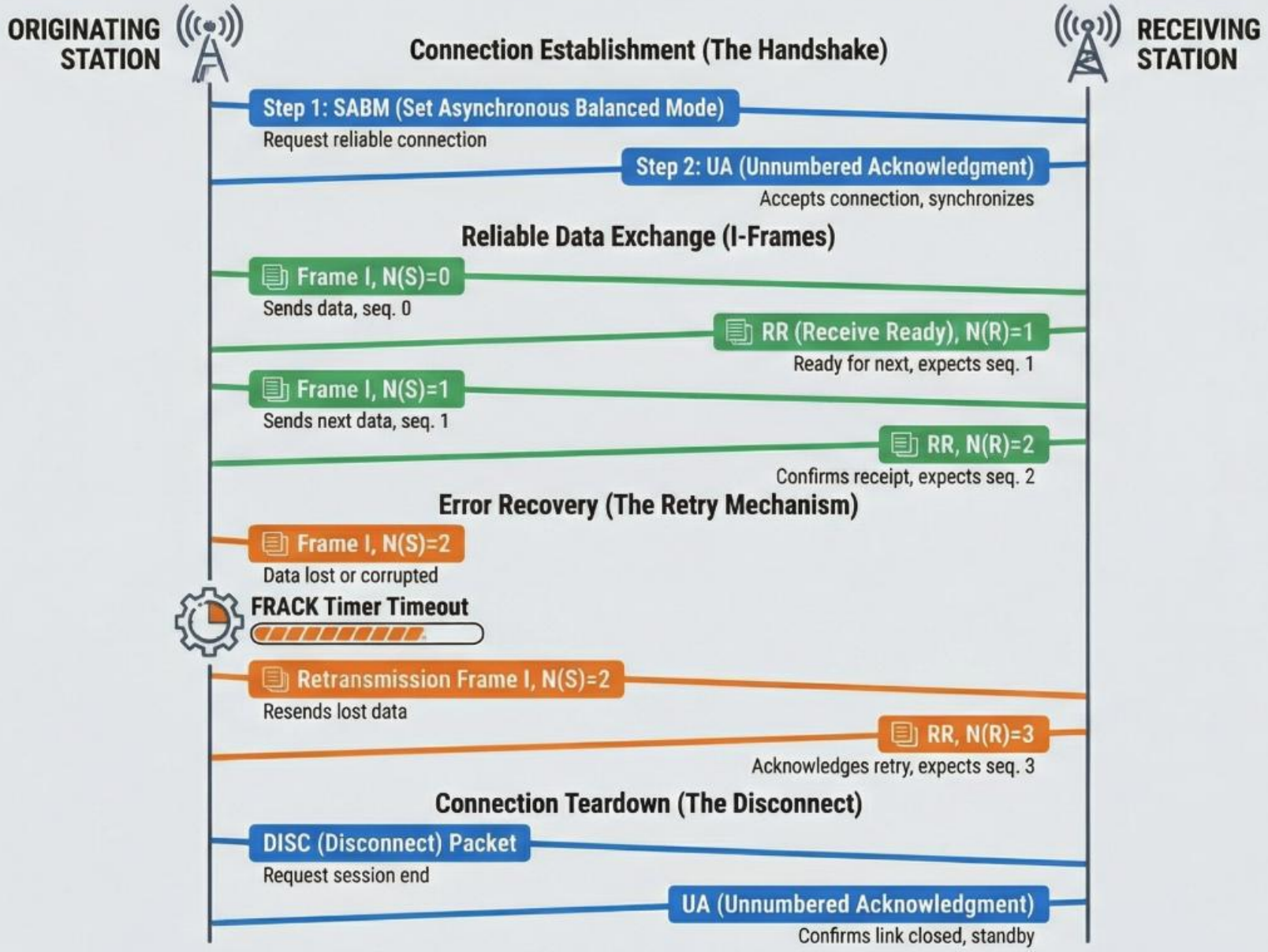
Anatomy of the Envelope: The AX.25 Frame



TECHNICAL NOTE

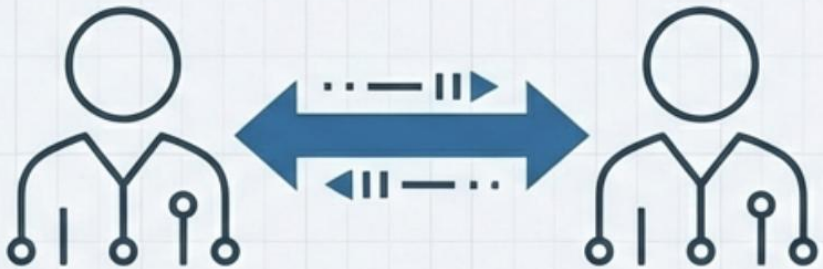
The payload is encapsulated in **headers** that provide routing instructions and error detection. Bit-stuffing prevents the flag pattern (`01111110`) from accidentally appearing inside the data.

Inside the AX.25 Protocol:
A Connected-Mode Transmission Sequence



Modes of Operation: I-Frames vs. UI-Frames

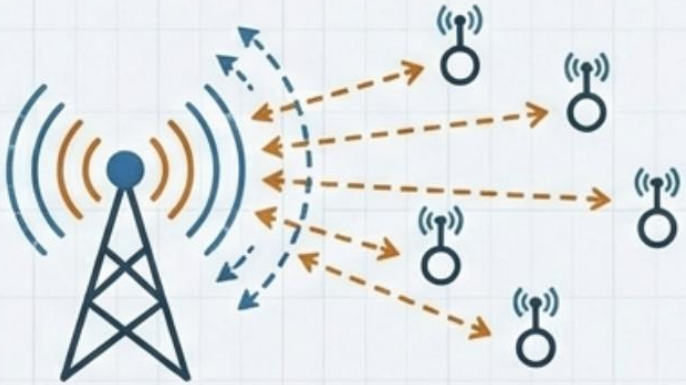
Connected (I-Frames)



The Handshake

- Virtual Circuit (SABM → UA)
- Guaranteed Delivery (ACKs)
- Use: Email, File Transfer

Unconnected (UI-Frames)



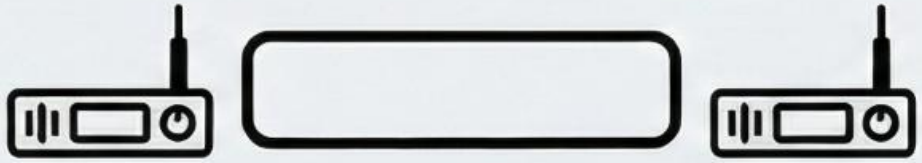
The Shout

- Datagram / Broadcast
- Fire and Forget (No ACK)
- Use: APRS, Beacons

CONNECTED
(Guaranteed Data Delivery)

Reliable Session

Relies on Information (I) frames



Acknowledgments & Retries
(Virtual Circuit, Handshake Required)

Targeted Chat, BBS, Keyboard-to-Keyboard

UNCONNECTED
(High-Efficiency Broadcasting)

Fire-and-Forget

Utilizes Unnumbered Information (UI) frames

No Confirmation of Receipt
(Datagram, Instant Send)

Public Beacons, APRS, CQ Calls

AX.25 PACKET RADIO: The fundamental choice is between guaranteed delivery and efficient broadcasting

Digipeaters: Extending the Reach of Packet Radio

Station A (K1ABC-0)

Digipeater 1 (W1AW-1)

DIGIPEATER 1

Digipeater 2 (K9AN-2)

DIGIPEATER 2

Station B (W9XYZ-0)

THE SIMPLEX RELAY PROCESS: Digipeaters receive, decode, and retransmit packets from local stations on a single frequency, allowing multi-hop connections between two stations unable to communicate directly due to distance or obstacles. They function at the AX.25 level by modifying address fields rather than just repeating audio.

AX.25 PACKET FRAME

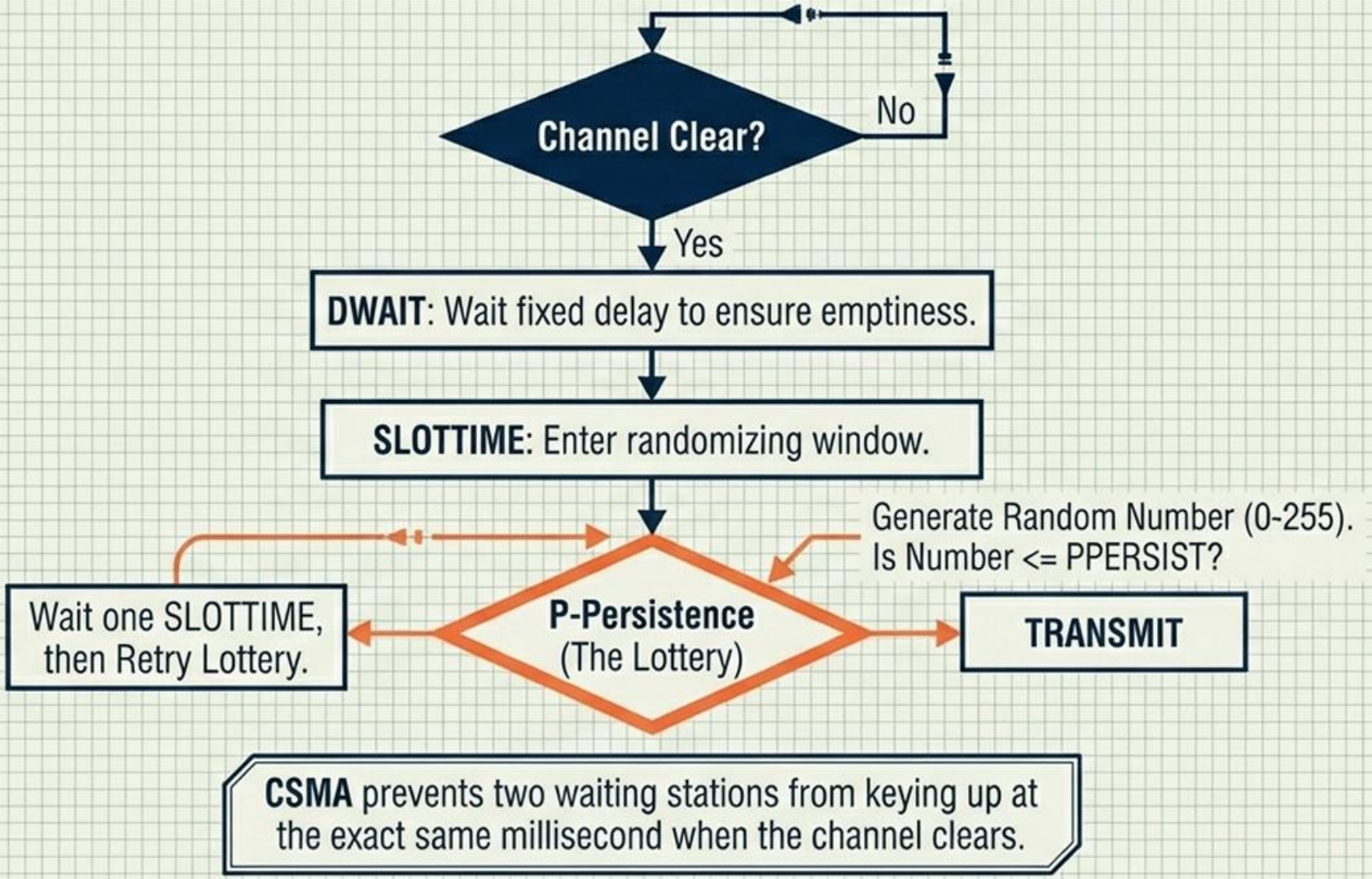
FLAG	ADDRESS	CONTROL	PID	INFORMATION	FCS	FLAG

ANATOMY OF AN AX.25 PACKET: Callsign-Based Addressing

DESTINATION	SOURCE	DIGIPEATER 1	DIGIPEATER 2
W9XYZ -0 SSID (4-bit)	K1ABC -0 SSID (4-bit)	W1AW -1 SSID (4-bit)	K9AN -2 SSID (4-bit)
The final station receiving the packet.	The station that originated the transmission.	The first relay station in the path.	The second relay station in the path.

SOURCE ROUTING: The sender specifies the entire relay path in the address field before transmission. Digipeaters use embedded control bits (the "Repeated" bit) in the address field to track which relay hops are complete.

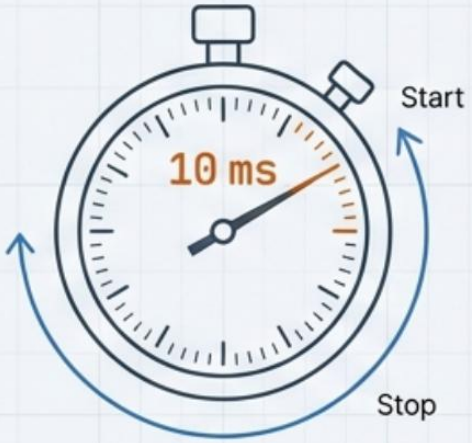
The Polite Protocol: Carrier Sense Multiple Access (CSMA)



CSMA prevents two waiting stations from keying up at the exact same millisecond when the channel clears.

Tuning the Engine: Critical Parameters

TXDELAY

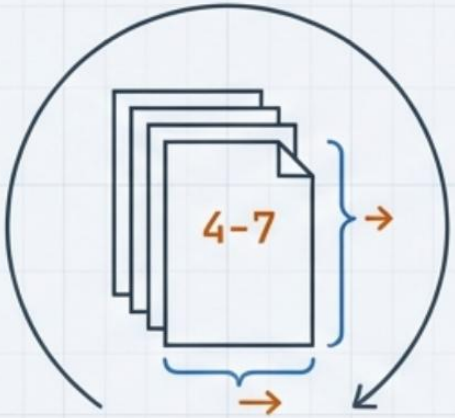


Delay between PTT and Data.
(Allows radio to stabilize)

FRACK

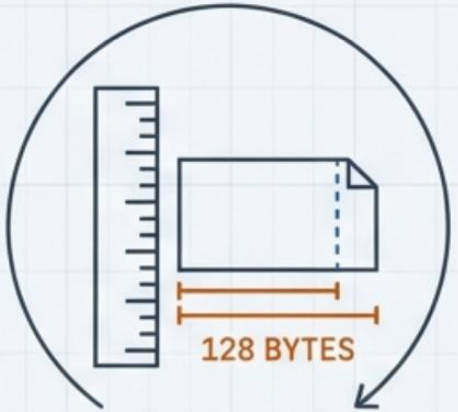
Frame Acknowledgment.
Time to wait for ACK
before retry.

MAXFRAME



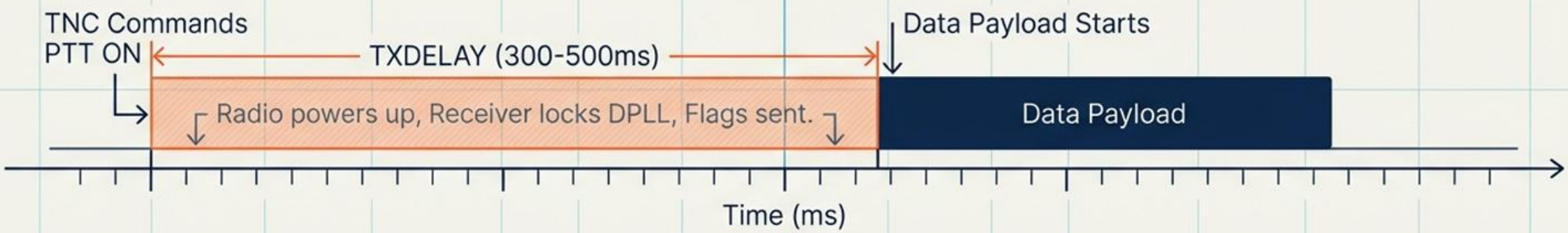
Window Size (1-7).
Frames sent before
waiting for ACK.

PACLEN



Packet Length.
Short (40-80) for HF/Noise,
Long (128-256) for VHF.

Waking the Hardware: The TXDELAY Parameter

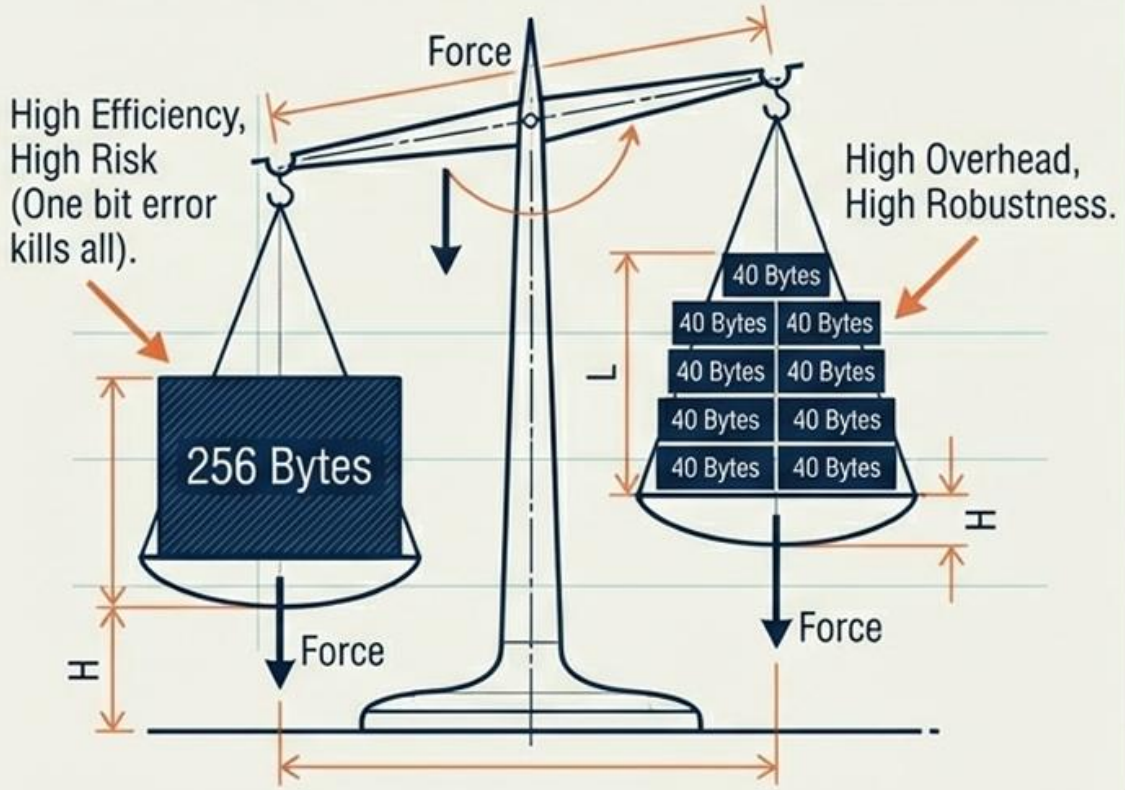


What If A: TXDELAY Too Short

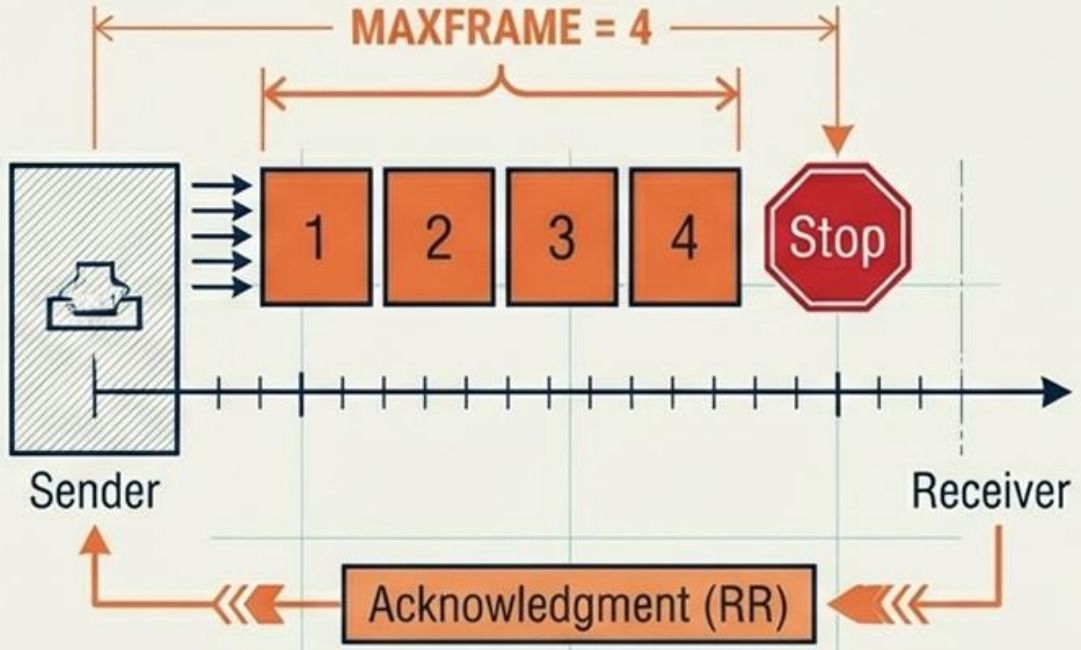
What If B: TXDELAY Too Long

Throughput & Flow Control: PACLEN and MAXFRAME

PACLEN (Packet Length)



MAXFRAME (Window Size)



Strategy: Increase PACLEN/MAXFRAME on clear VHF paths. Reduce significantly on noisy HF paths.

The Waiting Game: ARQ and FRACK

Packet Transmitted

Timer
Counting Down

Start **FRACK** Timer

09:34

ACK Received?

Yes

Success / Send Next

No / Timer reaches 0

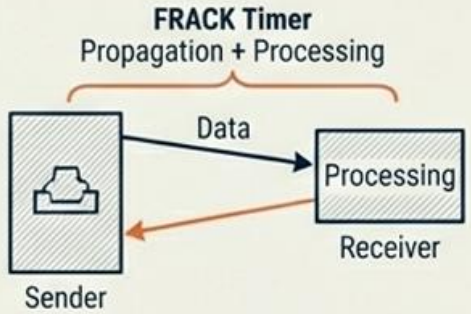
Retransmit

Increment **RETRY** Counter

Link Failure if RETRY > 10

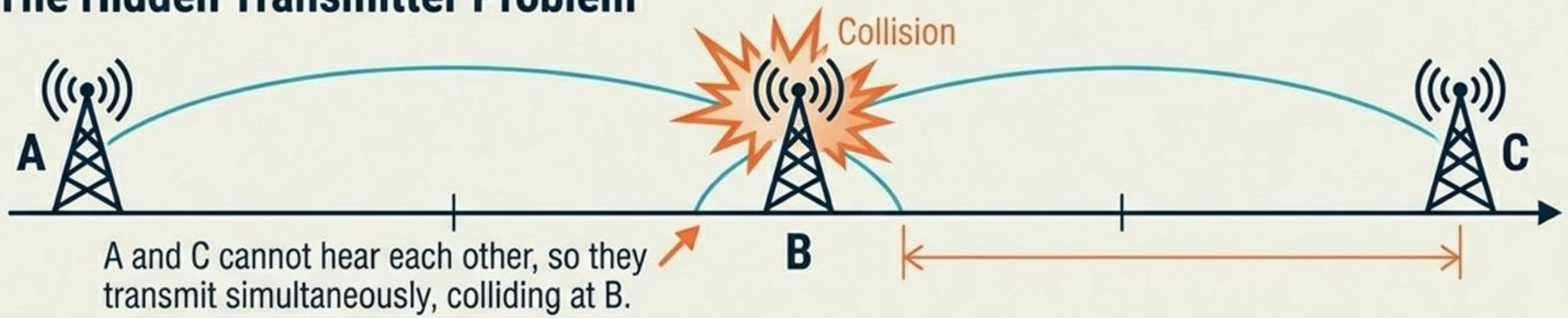
Note: FRACK

FRACK (Frame Acknowledgment) accounts for propagation delay and receiver processing time.

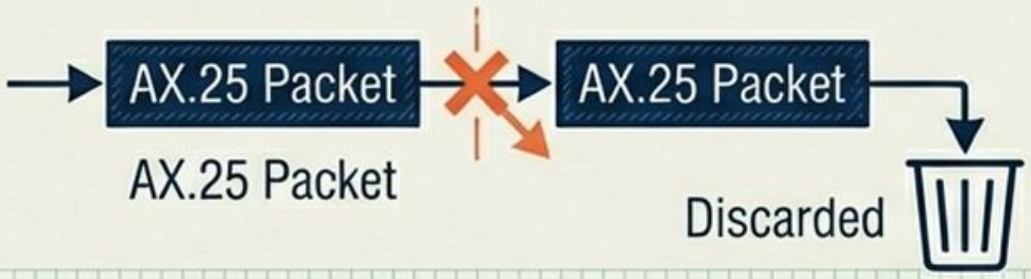


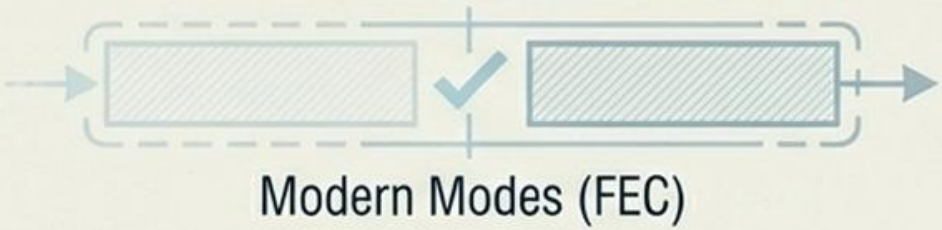
The Limits of AX.25

The Hidden Transmitter Problem



No Forward Error Correction (FEC)





Strategy: Understand these limitations for optimal deployment.

Operator's Guide: Tuning the Parameters

Parameter	Symptom	Corrective Action
TXDELAY	Packets heard but not decoded	↑ Increase (Radio needs more time to open squelch)
PACLEN	Frequent retransmissions on HF	↓ Decrease (Smaller targets are harder to hit)
MAXFRAME	Channel congestion / Hogging	↓ Reduce (Allow other stations to interleave)
FRACK	Retrying too fast on slow paths	↑ Increase (Account for satellite/digipeater latency)

Optimization Rule: On noisy or shared channels, slow down and shorten packets. →

How an APRS I-Gate Bridges Radio to the Web

Phase 1: Local RF Reception

Radio Signal Capture

An FM transceiver receives AX.25 “UI” frames containing GPS coordinates or telemetry data.

TNC Decoding

A Terminal Node Controller or software like Dire Wolf converts analog tones into digital data.

Fire-and-Forget Protocol

APRS uses unconnected mode for unreliable but efficient “fire-and-forget” position reporting.

Phase 2: Internet Bridging & Visualization

I-Gate Relaying

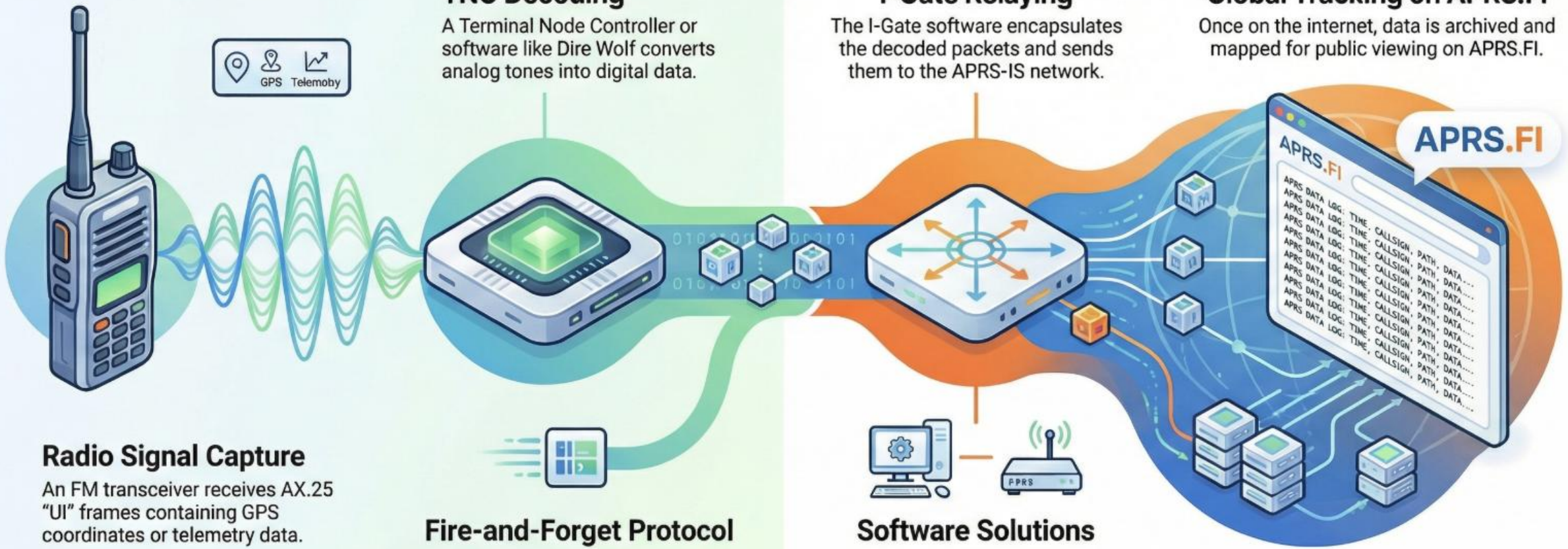
The I-Gate software encapsulates the decoded packets and sends them to the APRS-IS network.

Software Solutions

Tools like Dire Wolf or hardware like PTC-Ipro modems can act as standalone gateways.

Global Tracking on APRS.FI

Once on the internet, data is archived and mapped for public viewing on APRS.FI.

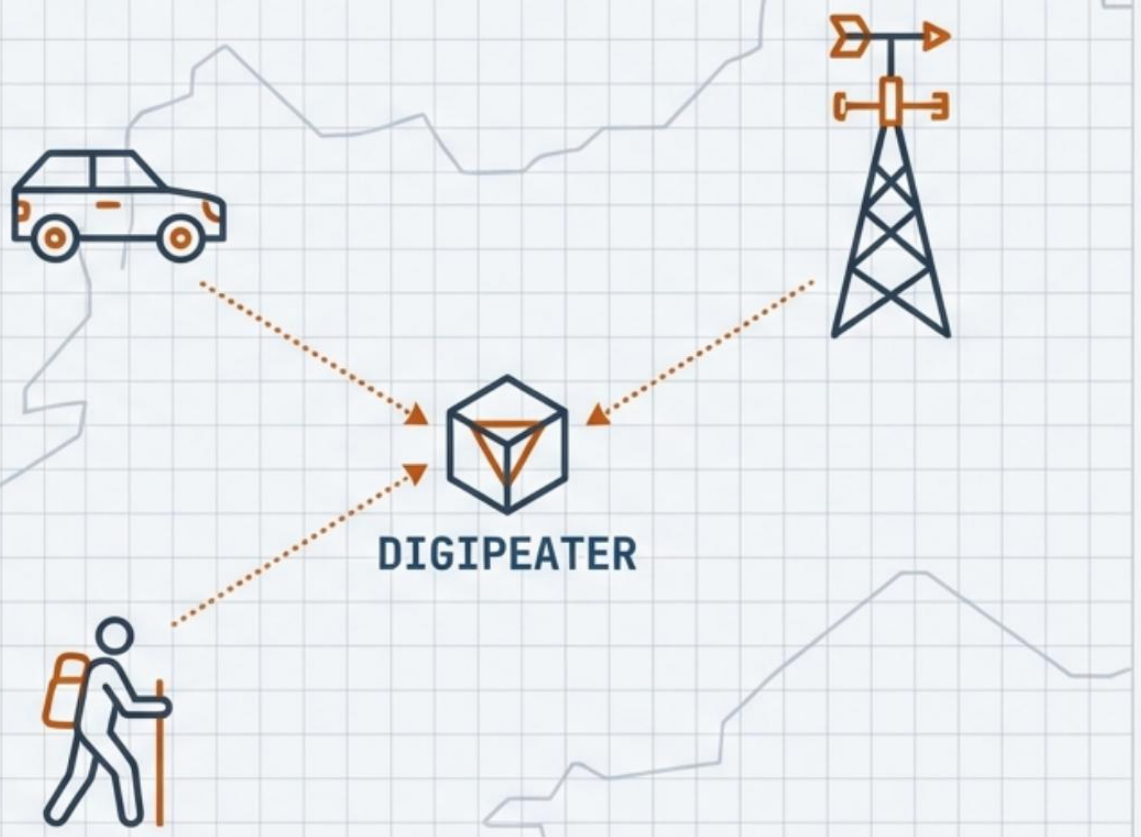


Situational Awareness: APRS

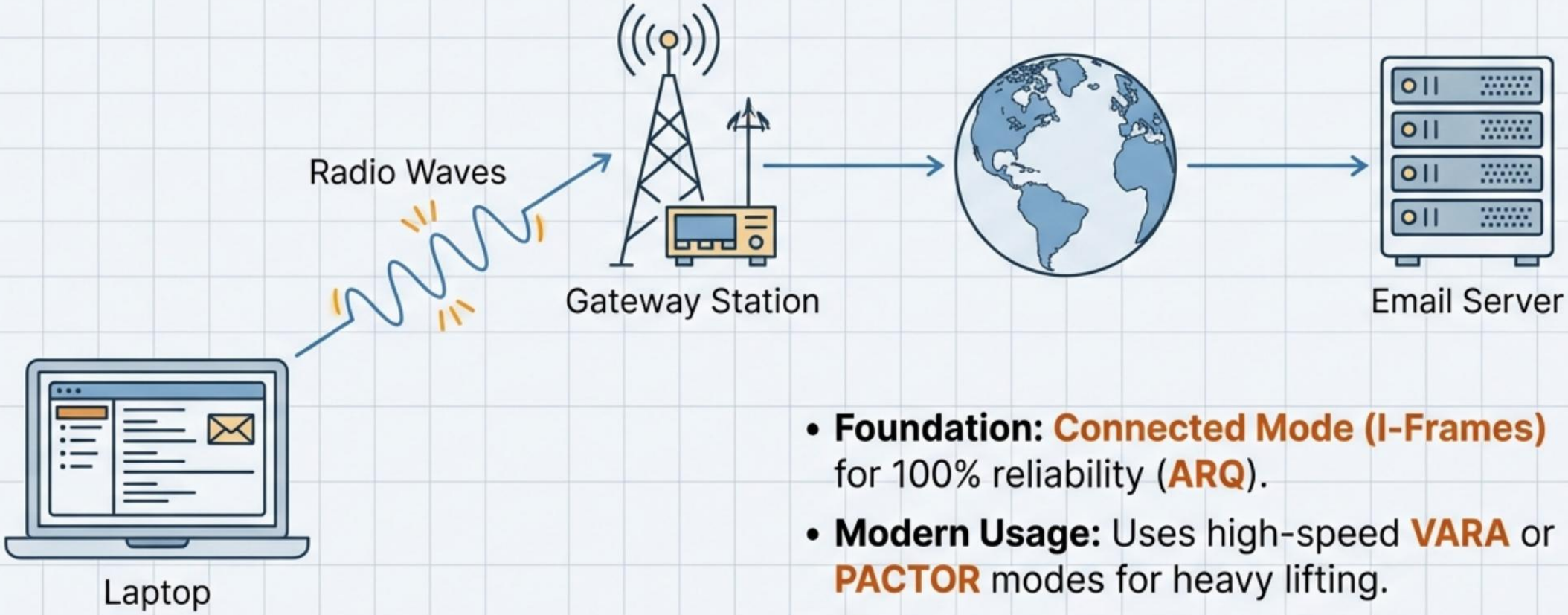
Automatic Packet Reporting System

Protocol: Unconnected (UI-Frames) exclusively.

Why? In tactical tracking, fresh data is more valuable than old data. We do not retry missed packets; we wait for the next position update.



“When All Else Fails: Winlink Global Email”



- **Foundation:** **Connected Mode (I-Frames)** for 100% reliability (**ARQ**).
- **Modern Usage:** Uses high-speed **VARA** or **PACTOR** modes for heavy lifting.
- **Critical for Emergency Communications** (**EmComm**).

The Need for Speed: PACTOR & VARA

Hardware (Robust & Expensive)

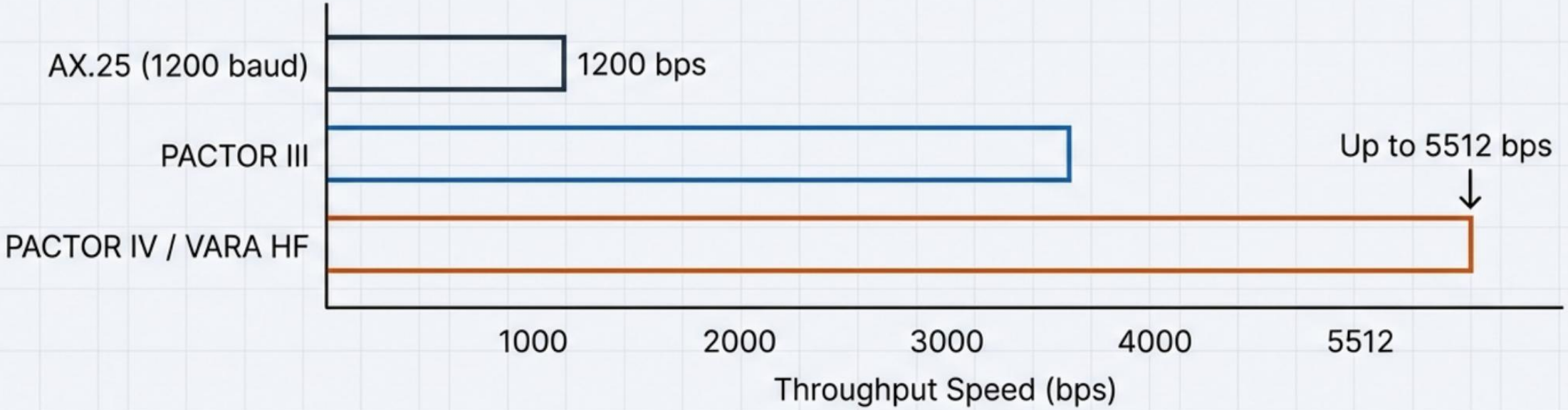
WAVECOM

PACTOR IV: Up to 5512 bps.
Extreme reliability in noise.

Software (Fast & Accessible)

WINLINK Global Radio Email®

VARA HF: "Soundcard PACTOR."
Uses OFDM. High speed, low cost.



How to Connect Your Computer to a Ham Radio for Digital Modes

Computers generate and decode audio signals for digital modes. This infographic illustrates the three main ways to transfer that audio data between your devices for over-the-air communication.

Method 1: Direct USB Connection

The All-in-One Cable for Modern Radios

Best for newer radios with a built-in USB sound card and CAT control.

A single USB cable connects the radio directly to the computer.

This connection handles audio in/oot, radio control (CAT). and Posh-to-Talk (PTT)

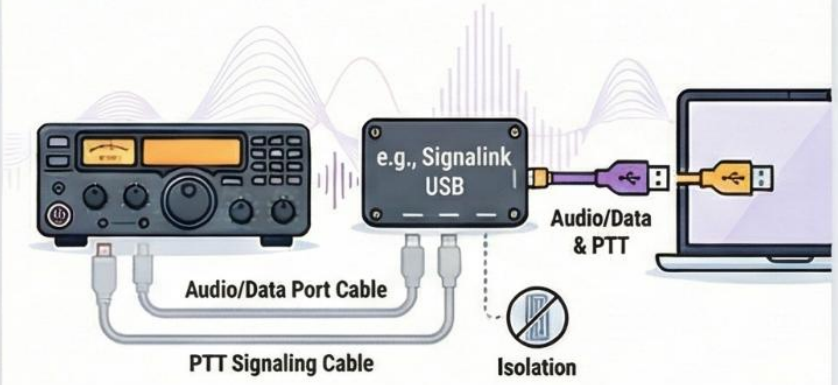
Install vendor-specific drivers on your PC.

The computer recognizes the radio as a new sound device (USB Audio CODEC).

Method 2: External Sound Card Interface

The Universal Adapter for Any Radio

Used for radios that lack a built-in USB sound card interface.



Common devices include the Signalink USB and Digirig.

These devices act as an external sound card and radio interface.

The interface connects to the PC via USB and to the radio via dedicated audio/data port cables.

It handles audio transfer and PTT signaling, isoiating the computer from the radio

Method 3: Wireless Bluetooth Connection

The Cable-Free Option for Portable Setups

Ideal for connecting smartphones to portable digital radios like LoRa/Meshtastic nodes.

The radio device pairs wirelessly with a smartphone or laptop.

An application on the phone or computer sonds and recoives messages via Bluetooth

The radio then transmits the data over the air.

Creates a completely portable, off-grid messaging or data system.

The Enduring Utility of AX.25

The Standard

The universal link layer for VHF/UHF data.

The Flexibility

From keyboard chat to satellite telemetry.

The Future

Evolving via Direwolf, FX.25, and IL2P.