

System Architecture Overview

This document provides a high-level overview of the **URFD (Universal Reflector for Digital)** system, including its internal architecture, transcoding subsystem, messaging layer, and dashboard integration.

1. The Problem: Digital Mode Fragmentation

In the world of Digital Amateur Radio, operators are often siloed into mutually exclusive ecosystems based on their radio hardware:

- **DMR (Digital Mobile Radio):** Uses AMBE+2 codec. Popular but complex.
- **System Fusion (YSF):** Uses AMBE+2, specific to Yaesu radios.
- **D-Star:** Uses AMBE, specific to Icom/Kenwood.
- **P25 / NXDN:** Public safety standards, incompatible with others.
- **M17:** A new, open-source mode using the Codec2 vocoder.

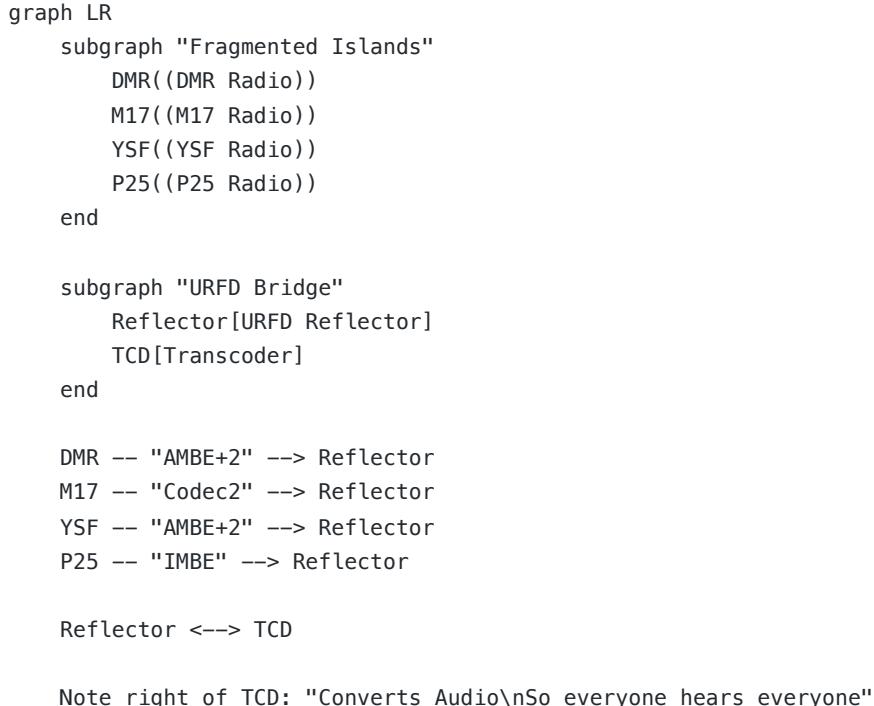
The "Walled Garden"

Without a bridge, a user on a **DMR** radio cannot talk to a user on an **M17** radio. They speak different "languages" (Vocoders) and use different transport protocols.

The Solution: Universal Reflector (URFD)

URFD acts as a **Universal Translator and Meeting Point**.

- **Multiprotocol Support:** It accepts connections from all major modes.
- **Transcoding:** It converts audio in real-time (e.g., Codec2 <-> AMBE).
- **Unified Dashboard:** It provides a single view of all activity, regardless of the source mode.



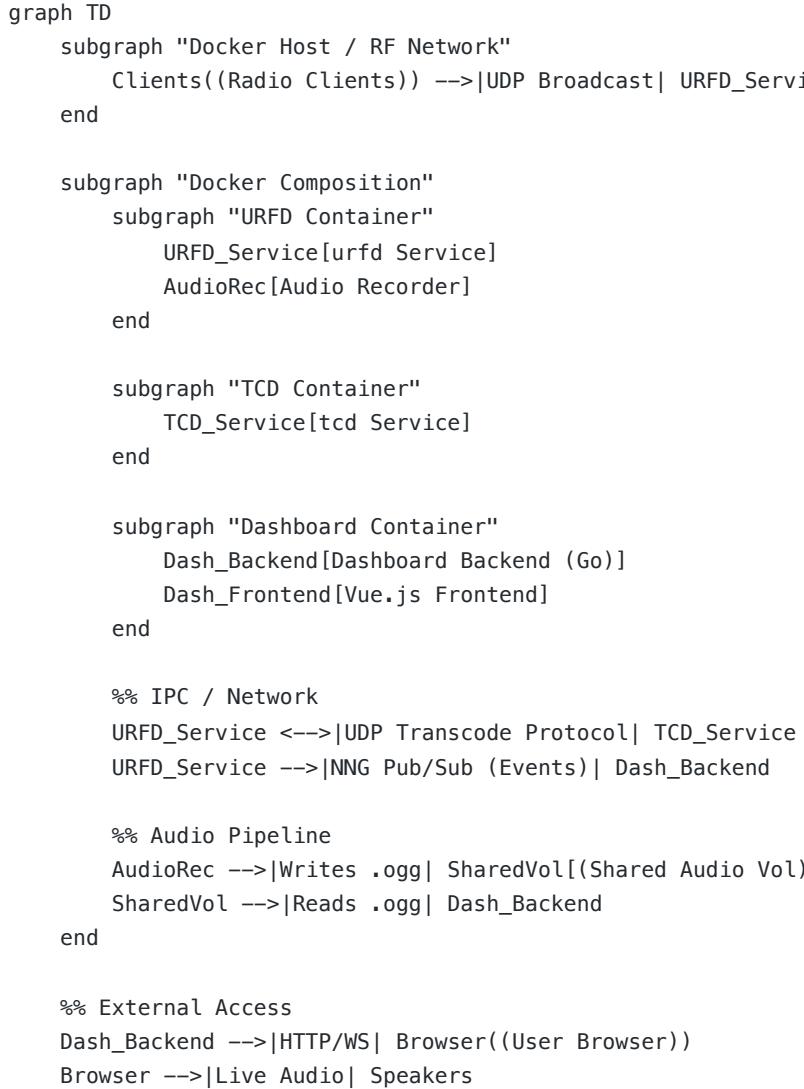
2. High-Level Architecture

The system is composed of three primary services running in Docker containers:

1. **urfd**: The core reflector application (C++) handling radio protocols.
2. **tcd**: The transcoder application (C++) converting audio codecs (e.g., M17 Codec2 <-> P25 IMBE).
3. **dashboard**: The web interface (Go/Vue.js) for monitoring and playback.

They communicate via:

- **NNG (Nanomsg Next Gen)**: IPC/TCP messaging for events (Hearings, Closings).
- **UDP / Host Networking**: Radio packet exchange and transcoding data.
- **Shared Volume**: Access to recorded audio files.

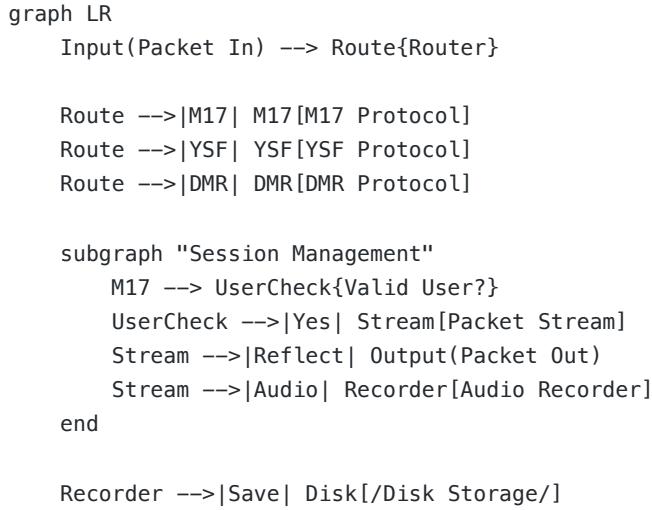


3. URFD Internal Architecture

URFD is the central hub. It listens for incoming transmission packets from gateways (Hotspots, Repeaters) across multiple protocols (M17, DMR, P25, YSF, NXDN).

Core Components

- **Reflector**: The main orchestrator (`CReflector`). Manages streams and routing.
- **protocols**: Specialized handlers for each mode (e.g., `M17Protocol`, `YSFProtocol`).
- **PacketStream**: Manages the buffer of packets for a specific transmission.
- **AudioRecorder**: Captures decoded/transcoded audio and writes to disk.



4. Transcoding (TCD)

TCD is a specialized service for converting vocoder formats. URFD offloads this CPU-intensive task to a dedicated process.

Hybrid Transcoding Engine

TCD utilizes the best available method for each codec:

1. Hardware Transcoding (AMBE Chipsets):

- Used for proprietary codecs like **AMBE+2** (found in DMR, YSF, P25 Phase 2) and **IMBE** (P25 Phase 1).
- Interfaces with **DVSI USB Dongles** (e.g., ThumbDV).
- Offloads processing to the dedicated hardware, ensuring legal compliance and low CPU usage.

2. Software Transcoding:

- **M17 (Codec2):** Fully open-source, handled natively in software via the `codec2` library.
- **Software AMBE:** Supports software-based decoding (via `md380_vocoder`) when hardware is unavailable, for compatible modes.
- **Flow:** URFD receives a packet (e.g., M17) -> Sends to TCD -> TCD converts (Software Decode -> Hardware Encode) -> Returns packet (e.g., DMR) -> URFD processes it.

```

sequenceDiagram
    participant URFD
    participant TCD

    URFD->>TCD: Packet (Source Format)
    Note right of URFD: "M17 (Codec2) Packet"
    TCD->>TCD: Decode -> PCM -> Encode
    TCD-->>URFD: Packet (Target Format)
    Note left of TCD: "P25 (IMBE) or PCM"

```

5. NNG Messaging & Audio Pipeline

We replaced custom TCP sockets with **NNG (Nanomsg Next Gen)** for robust, zero-mq style messaging.

Event Bus

URFD publishes events to the dashboard.

- **HEARING:** A transmission has started. Contains Callsign, Module, Talkgroup.
- **CLOSING:** A transmission has ended. Contains Duration and associated **Audio Filename**.

Recording & Playback Flow

1. **Capture:** `AudioRecorder` in URFD writes Opus-encoded packets to an Ogg container on the shared volume.
2. **Notification:** On transmission end, URFD fires a `CLOSING` event via NNG referencing the filename.
3. **Indexing:** Dashboard backend receives the event and updates its in-memory "Last Heard" list.
4. **Playback:**
 - **Live Mode:** Dashboard Frontend receives WebSocket event -> Auto-plays the new file.
 - **History:** User clicks "Play" -> Dashboard serves file from shared volume.

```
sequenceDiagram
    participant Radio
    participant URFD
    participant AudioDisk
    participant NNG
    participant Dashboard
    participant Browser

    Radio->>URFD: RF Transmission Start
    URFD->>NNG: PUB "HEARING" (Callsign)
    NNG->>Dashboard: Event Received
    Dashboard->>Browser: WS "HEARING" (Blink LED)

    loop Stream
        Radio->>URFD: Audio Packets
        URFD->>AudioDisk: Write .ogg
    end

    Radio->>URFD: Transmission End
    URFD->>AudioDisk: Close File (1234.ogg)
    URFD->>NNG: PUB "CLOSING" (File: 1234.ogg)
    NNG->>Dashboard: Event Received
    Dashboard->>Browser: WS "CLOSING" (New Track)

    Browser->>Dashboard: GET /audio/1234.ogg
    Dashboard->>Browser: Audio Stream
    Browser->>Browser: Auto-Play (Web Audio API)
```