

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.

```
graph LR
    subgraph "Fragmented Islands"
        DMR((DMR Radio))
        M17((M17 Radio))
        YSF((YSF Radio))
        P25((P25 Radio))
    end

    subgraph "URFD Bridge"
        Reflector[URFD Reflector]
        TCD[Transcoder]
    end

    DMR -- "AMBE+2" --> Reflector
    M17 -- "Codec2" --> Reflector
    YSF -- "AMBE+2" --> Reflector
    P25 -- "IMBE" --> Reflector

    Reflector <--> TCD

    Note right of TCD: "Converts Audio\nSo everyone hears everyone"
```

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.

```
graph TD
    subgraph "Docker Host / RF Network"
        Clients((Radio Clients)) -->|UDP Broadcast| URFD_Service
    end

    subgraph "Docker Composition"
        subgraph "URFD Container"
            URFD_Service[urfd Service]
            AudioRec[Audio Recorder]
        end

        subgraph "TCD Container"
            TCD_Service[tcd Service]
        end

        subgraph "Dashboard Container"
            Dash_Backend[Dashboard Backend (Go)]
            Dash_Frontend[Vue.js Frontend]
        end
    end

    %% IPC / Network
    URFD_Service <-->|UDP Transcode Protocol| TCD_Service
    URFD_Service -->|NNG Pub/Sub (Events)| Dash_Backend

    %% Audio Pipeline
    AudioRec -->|Writes .ogg| SharedVol[(Shared Audio Vol)]
    SharedVol -->|Reads .ogg| Dash_Backend

    %% External Access
    Dash_Backend -->|HTTP/WS| Browser((User Browser))
    Browser -->|Live Audio| Speakers
```

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.

```
graph LR
    Input(Packet In) --> Route{Router}

    Route -->|M17| M17[M17 Protocol]
    Route -->|YSF| YSF[YSF Protocol]
    Route -->|DMR| DMR[DMR Protocol]

    subgraph "Session Management"
        M17 --> UserCheck{Valid User?}
        UserCheck -->|Yes| Stream[Packet Stream]
        Stream -->|Reflect| Output(Packet Out)
        Stream -->|Audio| Recorder[Audio Recorder]
    end

    Recorder -->|Save| Disk[/Disk Storage/]
```

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)