A Software Based Implementation of an APCO Project 25 Compliant Packet Data Transmitter

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Abstract – *This paper describes the effort within the Project54 program at the University of New Hampshire to develop a software based implementation of an APCO Project 25 (P25) compliant packet data base station, utilizing a standard PC interfaced to a commercial analog VHF FM transceiver. The goal is to develop an affordable system (under $10,000) to provide P25 compliant packet data for smaller public safety agencies requiring only a single data capable channel. The base station system is comprised of a standard PC interfaced to a commercial VHF FM transceiver. Software running on the PC implements the standard IP network interface, the P25 Common Air Interface packet assembly, forward error correction encoding, and finally the packet baseband modulation. The resulting analog baseband modulated signal is then input to the commercial VHF FM transceiver which performs the RF modulation. The process is reversed for data packet reception. This paper will focus on the overall design of the software based P25 packet data transmitter, the testing of the various stages for P25 compliance, and the testing of the final result for interoperability with commercial P25 compliant mobile radios.*

1. Introduction

The APCO (Association of Public-Safety Communications Officials) Project 25 Systems and Standards Definition describes an open interface between mobile, portable, and base station radios [1]. The P25 suite of digital radio specifications is intended to provide the basis for voice communications interoperability among first responders. The state of New Hampshire has responded to this movement: nearly all state and local police agencies in NH now utilize P25 Phase I compliant digital VHF radios for voice communications.

One of the original goals of the P25 standards effort was to provide mixed voice and packet data services using the same digital radio. Using a single radio for both voice and data communications lowers the cost of providing wireless data services to vehicles and reduces the equipment clutter in the vehicles. In addition, unlike more commonly used commercial data services, P25 compliant packet data promises to provide a secure data communications capability for which the infrastructure is entirely controlled by the public safety agency. However, the use of P25 compliant data services is much less common than P25 voice communications. The New Hampshire Department of Safety was one of the first agencies nationally to implement P25 compliant mixed voice and data on a state wide basis. The NHDS P25 compliant mixed voice and data system supports multiple state agencies, and currently processes approximately 20,000 queries per month.

Available commercial P25 packet data capable base station equipment is designed to support large numbers of vehicles simultaneously, operating on multiple data capable channels in either conventional or trunking configurations. However, this complex functionality requires an infrastructure cost of hundreds of thousands of dollars, which is not cost effective for a smaller agency. The software based P25 packet data base station being developed within Project54 at UNH [2], in concert with commercial P25 compliant mobile radios, promises to provide an affordable P25 packet data system for smaller agencies requiring only a single data capable channel. The base station system is comprised of a standard PC interfaced to a commercial VHF FM transceiver. Software running on the PC implements the standard IP network interface, the P25 Common Air Interface packet assembly, forward error correction encoding, and finally the packet baseband modulation. The resulting analog baseband modulated signal is then input to the commercial VHF FM transceiver which performs the RF modulation. The process is reversed for data packet reception. This paper will focus on the overall design of the software based P25 packet data transmitter, the testing of the various stages for P25 compliance, and the testing of the final result for interoperability with commercial P25 compliant mobile radios [3].

2. APCO Project 25 Common Air Interface

A key open interface within the Project 25 standard is the Common Air Interface. The Common Air Interface (CAI) focuses on how to transmit digital voice and data over a radio channel.

The rate at which the communication occurs over the Common Air Interface is 4800 symbols per second, where a symbol is composed of 2 bits, also known as a dibit. These dibit symbols can take on one of four values relating to four different frequencies. This style of modulation is called C4FM, or 4-level frequency modulation.

Both voice and data packets can be transmitted and received on the same digital channel, using the 4-level frequency modulation. However, to manage voice and data communications on the same channel, voice packets are granted priority over data packets. This is illustrated in Figure 1. Voice packets take up the full bandwidth of the signal. Data packets can only be transmitted in the silence, between voice messages. The distinction between voice and data packets lies in the control bits present at the beginning of each Common Air Interface voice or data packet.

The reception and transmission of voice and data packets occurs at a base station. The voice and data base station designed in this effort (Figure 2) uses a preexisting commercial voice base station, but adds a custom base station for data transmission.

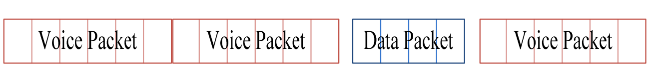

Figure 1 - Voice and Data Packets

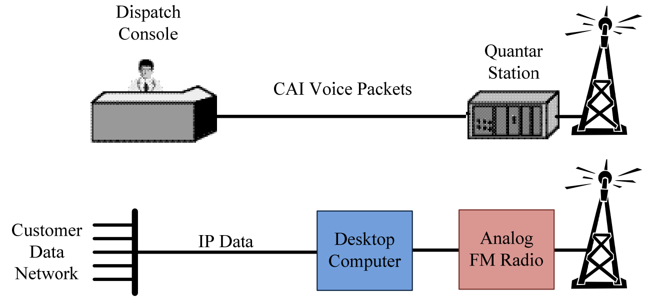

Figure 2 - Designed Voice and Data Base Station

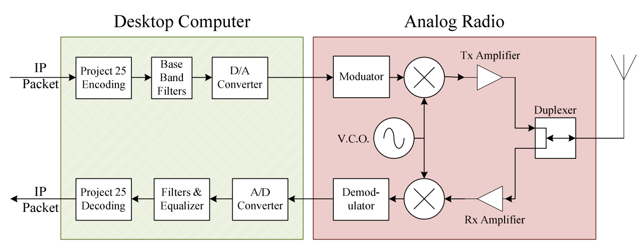

Figure 3 - Project 25 Data Radio System Architecture

The reception and transmission of data packets is performed using an analog radio and a desktop computer (PC) (Figure 3). The analog radio receives both voice and data packet transmissions. The analog version of the digital packet is passed to the computer through the microphone input. This signal is then decoded through software. Voice packets are ignored, while data packets are decoded into IP data packets. The IP data packets are then placed on the customer data network through the computers network card. For the transmission of data packets, IP data packets are received by the computer and encoded into CAI data packets. These CAI data packets are then passed through the speaker output of the computer to the analog radio where they are transmitted. The encoding and transmission of data packets is the main focus of this presentation.

3. The TxRx Application

The TxRx application developed in this project is a central hub for data flow throughout the Project 25 data server. It is a console application which receives an IP packet, encodes and modulates it using definitions set forth by the APCO Project 25 standard, presses the push to talk (PTT) of the radio, and transmits the resulting data packet. A top level flow diagram of the transmission section of the TxRx application is shown in Figure 4.

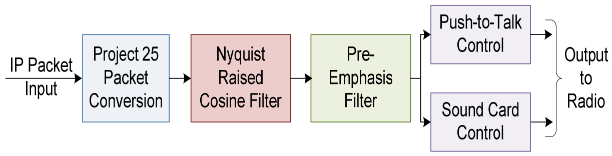

Figure 4 – Top Level flow of TxRx Application

Encoding and Transmission of Digital Data Packets

Digital data messages are handled in the form of IP data packets, which are transferred over the Common Air Interface encapsulated in CAI data packets (Figure 5). Each IP data packet is segmented into blocks of 12 octets, and a header block is added. The header block contains 10 octets of CAI address and control information, followed by 2 octets of a header CRC (cyclic redundancy check). A 32 bit CRC over the entire data contents is added to the end of the last block to allow the recipient to determine if the packet has been received without error.

Each 12 octet block of the CAI packet is protected by a rate ½ trellis code for error correction at the receiver. This FEC code expands the block size from 96 bits to 196 bits (98 dibit symbols). Each block is then interleaved as a final stage of the data error correction coding. The purpose of the interleaver is to spread burst errors due to Rayleigh fading over the 98 dibit block. In the interleaver, the dibit array is rearranged to form another dibit array, set forth by the Project 25 standard.

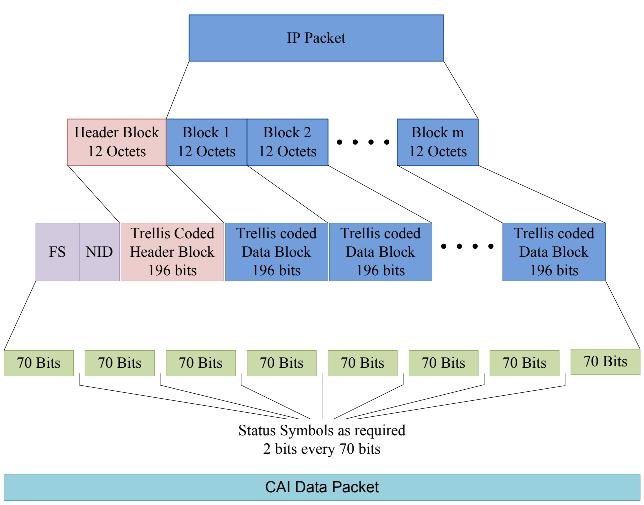

Figure 5 - IP Packet to CAI Data Packet Conversion

Once all the blocks, including the header block, have passed through the data error correction functions, they are placed back together as one long string which will be referred to as the encoded data packet.

A network identifier sequence is placed at the beginning of the encoded data packet. It provides a simple means of addressing radio networks depending on the radio system configuration. The network identifier also has a small field which identifies the type of message, in this case data, so that the proper error correction can be performed to the remainder of the packet. The network identifier encodes 16 bits of information in a 64 bit word to provide robust error correction at the receiver for this information.

The network identifier is preceded by a 64 bit (32 dibit symbols) frame synchronization sequence. This fixed symbol sequence serves to identify the start of a new data packet. The accumulated symbol stream (frame synchronization, network identifier, and encoded data packet) is then broken into segments of 35 symbols (70 bits), separated by 1 status symbol. Each symbol is composed of one dibit. This results in four different values related, through C4FM, to four different FM frequency deviations. Finally, a fixed repeating clock synchronization symbol sequence is placed before the frame synchronization in order to initialize the receiver's symbol clock.

The frequency deviation symbols are to be transmitted at 4800 symbols per second. The symbol stream is up-sampled to 48000 samples per second and shaped using a Nyquist raised cosine low-pass filter followed by a pre-emphasis filter. These are both implemented as linear phase FIR filters (121 and 39 filter coefficients, respectively). The output of the pre-emphasis filter is a fully encoded and modulated Project 25 Data Packet in the form of an analog signal sampled at 48000 samples per second. The sampled data packet is passed to a digital to analog (D/A) converter (PC sound card) and the resulting analog signal is input to the modulation input of a commercial analog VHF transceiver which performs the FM modulation.

Push-to-Talk

Before the Project 25 waveform can be transmitted through the analog radio, the push-to-talk (PTT) of the radio must be pressed. The PTT is an internally powered, normally high, 5V, signal. This is an active low signal, meaning that the PTT is triggered when the signal is grounded. To ground this signal, one of the RS-232 standard control lines was used. The control line used was the Data Terminal Ready (DTR) line. Since the radio PTT input is designed for an open circuit or ground, rather than an active drive of +9V or -9V, the input was protected using a simple passive circuit.

4. TESTING

Testing was a crucial part to the completion of the Project 25 CAI base station. It occurred during key points of the software and hardware development. The equipment test configuration is shown in Figure 6.

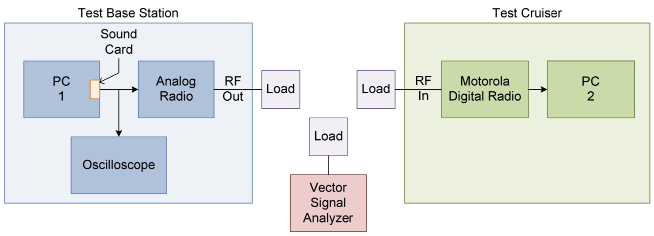

Figure 6 – The configuration for testing basic Project25 waveform compliance and end-to-end Project25 data radio interoperability.

The test configuration can be segmented into three main sections. These sections are only connected through radio frequency (RF) transmissions. The first section is the test base station. The test base station is comprised of a PC, with a sound card, and an analog radio. The sound card used is a Creative Sound Blaster X-Fi card. This specific sound card was used because of its ability to play audio at the desired rate of 48 KHz, its high signal to noise ratio, and its linear response. The output of the sound card is attached to the input of an analog radio. The radio frequency output of the analog radio is attached to a load.

Another section of the test configuration is the Vector Signal Analyzer (VSA). The VSA used was an Agilent 89441A with an Intermediate Frequency (IF) unit and a Radio Frequency (RF) unit. For this setup, a specific Agilent module (Option AYA) was installed. This option added vector modulation analysis for characterizing digital modulation schemes, in particular APCO 25. The VSA was tied to the rest of the setup through a load attached to the RF Section.

The final section of the test configuration is the test cruiser section. The test cruiser section mimics the setup found in a New Hampshire local police cruiser. It has a Motorola XTL5000 Project 25 compliant digital radio attached to a PC running Windows XP. The digital radio communicates with the PC through the Project54's Project25PPP service over an RS-232 connection.

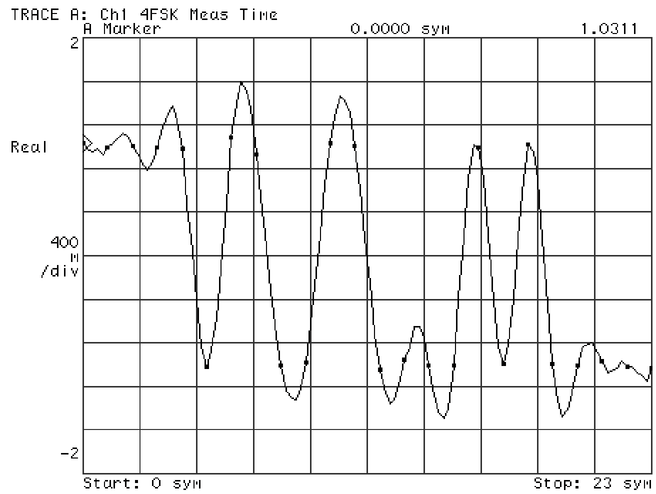

Figure 7 - APCO 25 waveform compliance testing using the VSA.

Compliance of generated CAI waveforms with the Project 25 standard specifications was tested using the VSA. Using the built-in Project25 waveform analysis and demodulation capabilities, the VHF signals generated were tested for depth of modulation, symbol timing, and so forth (Figure 7).

Basic end-to-end data interoperability was tested by passing IP packets successfully from one PC to the other via the VHF connection from the software defined Project25 data base station radio to the commercial Project25 mobile data radio.

5. CONCLUSIONS

The primary goal of this project was to design and develop a cost effective way for local departments to transmit information from headquarters to cruisers. The result was the Project 25 SDR Base Station. Using the pre-existing radio network infrastructure, which is standardized across all local departments in the state of New Hampshire, IP packets were transmitted in the form of CAI data packets. The source of the transmissions was a desktop computer attached to an analog radio. These two components make up the Project 25 SDR Base Station as shown in figure 3.

The desktop computer runs a custom application, designed and written for this project, called the TxRx Application. The TxRx Application receives IP Packets from the IP Reflector Service, encodes the packet as the data block of a CAI data packet, filters with a Nyquist Raised Cosine filter and a Pre-Emphasis filter, and then transmits the waveform through the computer's sound card. The output of the sound card is then fed through a custom cable and used as the audio input of an analog radio. The analog radio transmits the audio on a pre-determined CAI digital channel. A digital radio is tuned to this frequency and receives the CAI Data packet. The digital radio demodulates and decodes the data packet which results in the IP Packet which was first sent to the TxRx Application.

The system developed in this project implements the transmission half of a Project 25 base station data radio (Figure 3). A separate effort to develop the receive portion is ongoing. Another necessary development is to implement collision avoidance with the voice base station and with mobile radio transmissions. Since all of the tests were conducted on one radio transmitting on a specific frequency, there was no need to wait for the channel to be available. However, if the desire is to perform mixed voice and data on the same channel, there is a possibility of lost CAI Data packets. The loss of packets would be caused by transmission collisions between the data and voice base station radios. This improvement would be used to increase the robustness of the system. Development of the collision avoidance subsystem is also ongoing.

Once the base station is able to receive requests for information and can coexist safely in parallel to the voice radio system, it can be used for textual record queries and other low bandwidth data communications, such as CAD messaging, by local police. This would result in a safer, more time efficient method of requesting vehicle and driver information. Since all local police agencies in New Hampshire already have Project 25 data capable mobile radios in their cruisers, this approach would be cost effective as well. The overall cost of the data base station should be under $5000 depending on the choice of computer and analog VHF transceiver (excluding antenna installation costs which will vary by agency).

References

[1] Telecommunications Industry Association. *Project 25 FMA Common Air Interface New Technology Standards Project Digital Radio Technical Standards*. Arlington : Telecommunications Industry Association, 1998. TIA/EIA-102.BAAA.

[2] Andrew L. Kun, W. Thomas Miller, III and William H. Lenharth, *Computers in police* cruisers, IEEE Pervasive Computing, Volume 3, Issue 4, Pages: 34 - 41, October-December 2004

[3] Eric Ramsey, *A Software Based APCO Project 25 Data Transmission Base Station For Local Police Headquarters,* M.S. Thesis, University of New Hampshire, September, 2007.

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