

FRC Advanced Control System Development: Part I

CAN Diagnostic Stream & CCSDSification

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1 Introduction

This paper will cover a method of capturing CAN traffic on the RoboRIO, as well as encapsulating the CAN frames using the CCSDS Space Packet Protocol and transmitting them over the robot network. Later papers in this series will address how to capture, analyze, visualize, and log the resulting data streams.

2 Monitoring CAN Traffic

Since so much of the communication on the robot occurs over the CAN bus (all PDP voltage/current telemetry, PCM status and commands, smart motor controller data, etc.), being able to monitor and process CAN frames immediately provides a wealth of telemetry and diagnostic information. A basic way of doing this is to simply use a device API to read the CAN data of interest, and then relay that data to a remote machine, using for example NetworkTables. However, this technique has several limitations. First, the telemetry is restricted to that data which can be accessed through existing API calls. Second, adding statements to poll effectively all APIs for all devices in use, and then publish that data, results in a tremendous amount of code cluttering up the user program. Finally, since a certain amount of decoding would have to be done by the RoboRIO, this would steal precious CPU cycles.

Therefore, it is preferable to relay raw CAN frames to a remote machine, and process them on a more capable platform. There are several ways to do this. One would be to use some kind of CAN bridge physically connected to the bus, and to a data channel to the remote machine. The [PiCAN2](#) and [Microchip CAN Bus Analyzer Tool](#) come to mind. However, since the RoboRIO already has a built-in CAN interface, as well as an Ethernet connection, it seems preferable to stream CAN frames from the RoboRIO, over Ethernet, across the WiFi link, to a telemetry computer. This allows realtime monitoring of all data that transits the CAN bus, in realtime, with minimal burden to the RoboRIO.

First, a brief overview of the RoboRIO/Athena/WPIlib CAN stack is in order. The actual CAN interface on the RoboRIO PCBA is routed to the Zynq Z-7020 processor¹. Linux instantiates the CAN port as character device `/dev/ni/niembcanzynqk:0\niembcan.ucan\0`. This device is accessed exclusively by `/usr/local/frc/bin/FRC_NetCommDaemon`, commonly known as FRCNetComm. This binary, as far as I can tell, is a black box; only the header is publicly available. User software then interacts with the FRCNetComm interface (either directly or via JNI). More specifically, CAN traffic is handled with the `CANSessionMux` framework. This allows multiple processes to send and receive packets through a single physical interface. WPIlib provides a C++ wrapper around the FRCNetComm calls, as well as a JNI. Higher-level objects (motor controller instances, etc.) eventually call the WPIlib interface to send and receive CAN frames. `CANSessionMux.h` is reproduced in Appendix A.

Nearly all of the CAN communication commonly seen at the user level uses only the `sendMessage` and `receiveMessage` functions. The latter essentially monitors the incoming

¹I don't know if the CAN interface is routed directly to the ARM core, or if it goes through the FPGA.

CAN traffic for a frame matching the ID parameter, and returns it when found. Unfortunately, this cannot be used to sniff CAN traffic, because `receiveMessage` “steals” frames²; that is, if a process were set up to receive all frames, they would be consumed by that process and never reach the actual destination (robot code). However, the `*StreamSession` functions provide a much more flexible interface for inspecting CAN traffic. Essentially, user code merely sets up the stream session, optionally with an ID mask to exclude unneeded frames, and polls it occasionally. When polled, the stream returns all of the received CAN messages, *without* affecting the normal reception of those frames in user code. Note that the `*StreamSession` functions are apparently so rarely used that they are not exposed in the CAN JNI.

3 CCSDS Encapsulation

CCSDS, the Consultative Committee for Space Data Systems, maintains a Space Packet Protocol which is specifically designed for remote command and telemetry. The CCSDS header contains data to identify packet type, sequencing, and context. However, there are very few restrictions placed on the encapsulated data; the header is simply prepended to a block of data, from 1 to 65536 bytes (see Appendix B for the summary of the CCSDS header; the full standard is publicly available). For these reasons, it is ideal for conveying robot telemetry to the remote machine.

Most fields of the header are explicitly described in the CCSDS standard. I have chosen not to use the secondary header capability in the proof-of-concept code, although it may be useful to convey metadata such as CAN frame receipt time. Other future work includes documenting an APID dictionary for FRC use; this application should have an APID defined as “RoboRIO CAN Stream” or similar. Many different sources of telemetry are possible in the FRC ecosystem, each of which should have its own APID. For example, the RoboRIO code could also send telemetry packets regarding its status: memory usage, temperature, power rails, etc. These streams should have their own APIDs. Similarly, other devices, such as coprocessors, could have their own telemetry streams. It is important that APIDs identify the *provenance* as well as the *intent* of data. For example, both the PDP and PCM transmit their measured bus voltage. However, while these data are nominally the same, they should be kept separate since they are in fact two different measurements of (hopefully) the same physical quantity.

In order to pass the CCSDS packets over WiFi, in the proof-of-concept implementation, they are simply sent as UDP datagrams. As such, the address of the telemetry computer (separate from the driver station computer, although that need not be the case) was hard-coded into the telemetry-sending software.

²As described on a Chief Delphi post: <https://www.chiefdelphi.com/t/how-to-detect-missing-can-devices-from-java/147675/10>

4 Future Work

An example implementation of architecture to receive and process telemetry has been completed, and will be described in a following paper. Other items for future work include:

- Implement the CAN streaming code as a standalone binary, so that it doesn't need to be in the normal robot code;
- Allow switching the CAN stream on or off (to reduce bandwidth usage) via CCSDS telecommand packet;
- Define CCSDS APIDs for FRC use;
- Use UDP broadcast or multicast so that telemetry computer IP is not hardcoded;
- Investigate running telemetry over a second radio, or possibly a non-802.11 data channel, to avoid bandwidth consumption.

A CANSessionMux.h

```
#ifndef __CANSessionMux_h__
#define __CANSessionMux_h__

#include <stdint.h>

#define CAN_SEND_PERIOD_NO_REPEAT 0
#define CAN_SEND_PERIOD_STOP_REPEATING -1

/* Flags in the upper bits of the messageID */
#define CAN_IS_FRAME_REMOTE 0x80000000
#define CAN_IS_FRAME_11BIT 0x40000000

#define ERR_CANSessionMux_InvalidBuffer -44086
#define ERR_CANSessionMux_MessageNotFound -44087
#define WARN_CANSessionMux_NoToken 44087
#define ERR_CANSessionMux_NotAllowed -44088
#define ERR_CANSessionMux_NotInitialized -44089
#define ERR_CANSessionMux_SessionOverrun 44050

struct tCANStreamMessage{
    uint32_t messageID;
    uint32_t timeStamp;
    uint8_t data[8];
    uint8_t dataSize;
};

#ifdef __cplusplus
namespace nCANSessionMux{
    void sendMessage_wrapper(uint32_t messageID, const uint8_t *data,
                             uint8_t dataSize, int32_t periodMs,
                             int32_t *status);
    void receiveMessage_wrapper(uint32_t *messageID, uint32_t messageIDMask,
                                uint8_t *data, uint8_t *dataSize,
                                uint32_t *timeStamp, int32_t *status);
    void openStreamSession(uint32_t *sessionHandle, uint32_t messageID,
                            uint32_t messageIDMask, uint32_t maxMessages,
                            int32_t *status);
    void closeStreamSession(uint32_t sessionHandle);
}
```

```

void readStreamSession(uint32_t sessionHandle,
                      struct tCANStreamMessage *messages,
                      uint32_t messagesToRead, uint32_t *messagesRead,
                      int32_t *status);
void getCANStatus(float *percentBusUtilization, uint32_t *busOffCount,
                  uint32_t *txFullCount, uint32_t *receiveErrorCount,
                  uint32_t *transmitErrorCount, int32_t *status);
}
#endif

#ifdef __cplusplus
extern "C"{
#endif

void FRC_NetworkCommunication_CANSessionMux_sendMessage(
    uint32_t messageID, const uint8_t *data, uint8_t dataSize,
    int32_t periodMs, int32_t *status);
void FRC_NetworkCommunication_CANSessionMux_receiveMessage(
    uint32_t *messageID, uint32_t messageIDMask, uint8_t *data,
    uint8_t *dataSize, uint32_t *timeStamp, int32_t *status);
void FRC_NetworkCommunication_CANSessionMux_openStreamSession(
    uint32_t *sessionHandle, uint32_t messageID, uint32_t messageIDMask,
    uint32_t maxMessages, int32_t *status);
void FRC_NetworkCommunication_CANSessionMux_closeStreamSession(
    uint32_t sessionHandle);
void FRC_NetworkCommunication_CANSessionMux_readStreamSession(
    uint32_t sessionHandle, struct tCANStreamMessage *messages,
    uint32_t messagesToRead, uint32_t *messagesRead, int32_t *status);
void FRC_NetworkCommunication_CANSessionMux_getCANStatus(
    float *percentBusUtilization, uint32_t *busOffCount,
    uint32_t *txFullCount, uint32_t *receiveErrorCount,
    uint32_t *transmitErrorCount, int32_t *status);

#ifdef __cplusplus
}
#endif

#endif // __CANSessionMux_h__

```

B CCSDS Space Packet Protocol (Excerpt)

4 PROTOCOL SPECIFICATION

4.1 PROTOCOL DATA UNIT

4.1.1 SPACE PACKET

NOTE – The protocol data unit of the Space Packet Protocol is the Space Packet. In this Recommendation, the Space Packet is also called the Packet.

4.1.1.1 A Space Packet shall encompass the major fields, positioned contiguously, in the following sequence:

- a) Packet Primary Header (6 octets, mandatory);
- b) Packet Data Field (from 1 to 65536 octets, mandatory).

4.1.1.2 A Space Packet shall consist of at least 7 and at most 65542 octets.

NOTES

- 1 The maximum Packet length allowed by a particular spacecraft or ground implementation may be less than the maximum specified here.
- 2 A Space Packet that contains Idle Data in its Packet Data Field is called an Idle Packet.
- 3 Idle Packets are generated by the Telemetry (TM) and Advanced Orbiting Systems (AOS) Space Data Link Protocols (references [B6] and [B8], respectively) when needed to maintain synchronization of the data transport processes.

4.1.1.3 The structural components of the Space Packet are shown in figure 4-1.

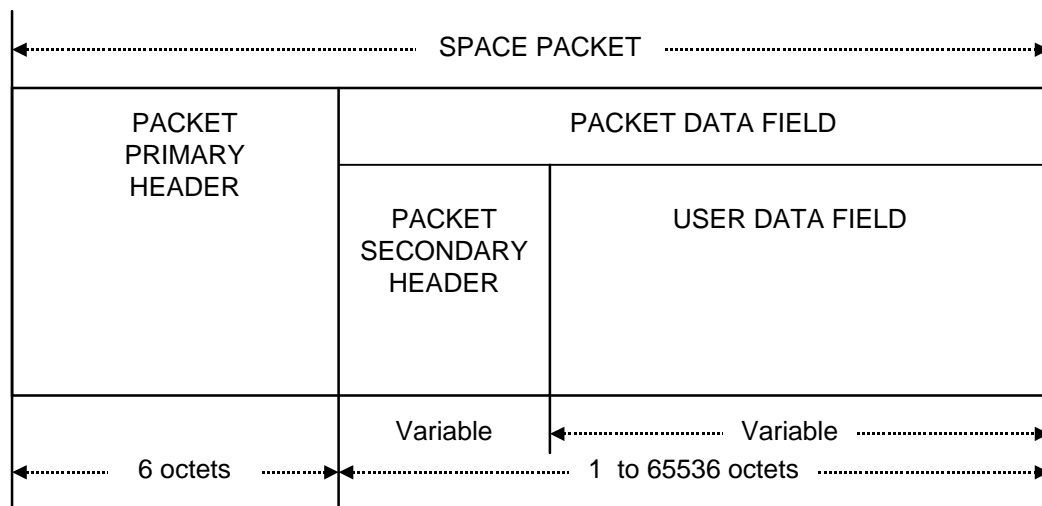


Figure 4-1: Space Packet Structural Components

4.1.2 PACKET PRIMARY HEADER

4.1.2.1 General

The Packet Primary Header is mandatory and shall consist of four fields, positioned contiguously, in the following sequence:

- a) Packet Version Number (3 bits, mandatory);
- b) Packet Identification Field (13 bits, mandatory);
- c) Packet Sequence Control Field (16 bits, mandatory);
- d) Packet Data Length (16 bits, mandatory).

The format of the Packet Primary Header is shown in figure 4-2.

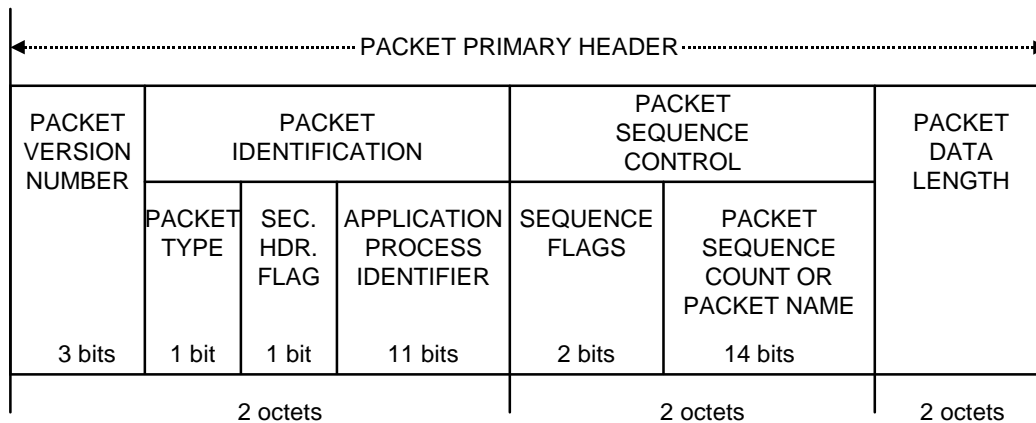


Figure 4-2: Packet Primary Header

4.1.2.2 Packet Version Number

4.1.2.2.1 Bits 0–2 of the Packet Primary Header shall contain the (binary encoded) Packet Version Number.

4.1.2.2.2 This 3-bit field shall identify the data unit as a Space Packet defined by this Recommendation; it shall be set to ‘000’.

NOTE – The Version Number is used to reserve the possibility of introducing other packet structures. This Recommendation defines Version 1 CCSDS Packet whose binary encoded Version Number is ‘000’.

C Proof-Of-Concept Implementation

C.1 Robot.cpp

```
#include <frc/TimedRobot.h>
#include <hal/CAN.h>
#include "CCSDS/CCSDS.h"
#include <stdlib.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <arpa/inet.h>
#include <netinet/in.h>

#define PORT      8080

uint8_t bytebuffer[14];
class Robot : public frc::TimedRobot {
public:

void RobotPeriodic() override{
    uint32_t messagesRead=0;
    uint8_t i;
    uint8_t j;
    HAL_CAN_ReadStreamSession (canStreamHandle, messages, 100,
                                &messagesRead, &canStreamStatus);
    for(i=0; i<messagesRead; i++){
        //Process CAN messages
        create_CCSDS_header(false, 0, UNSEGMENTED, CCSDS_count++,
                            messages[i].dataSize+4, bytebuffer);
        bytebuffer[6] = (messages[i].messageID >> 24);
        bytebuffer[7] = (messages[i].messageID >> 16);
        bytebuffer[8] = (messages[i].messageID >> 8);
        bytebuffer[9] = (messages[i].messageID);
        memcpy(bytebuffer+10, messages[i].data, messages[i].dataSize);
        sendto(sockfd, bytebuffer, 10+messages[i].dataSize, MSG_CONFIRM,
                (const struct sockaddr *) &cliaddr, sizeof(cliaddr));

        //for(j=0; j<(10+messages[i].dataSize); j++){
        //  printf("%x", bytebuffer[j]);
        //}
    }

    printf("%d\n", messagesRead);
}
```

```

    //printf("%x\n", messages[0].messageID);
}

void RobotInit() override{
    HAL_CAN_OpenStreamSession(&canStreamHandle, 0, 0, 100, &canStreamStatus);
    // Creating socket file descriptor
    if((sockfd = socket(AF_INET, SOCK_DGRAM, 0)) < 0 ){
        exit(EXIT_FAILURE);
    }

    memset(&servaddr, 0, sizeof(servaddr));
    memset(&cliaddr, 0, sizeof(cliaddr));

    //Server information
    servaddr.sin_family    = AF_INET;
    servaddr.sin_addr.s_addr = INADDR_ANY;
    servaddr.sin_port = htons(PORT);

    //Client information
    cliaddr.sin_family     = AF_INET;
    cliaddr.sin_addr.s_addr = inet_addr("10.6.96.5");
    cliaddr.sin_port = htons(PORT);

    // Bind
    if(bind(sockfd, (const struct sockaddr *)&servaddr, sizeof(servaddr)) < 0){
        exit(EXIT_FAILURE);
    }
}

private:
    uint32_t canStreamHandle;
    int32_t canStreamStatus;
    HAL_CANStreamMessage messages[100];
    uint16_t CCSDS_count = 0;
    int sockfd;
    struct sockaddr_in servaddr, cliaddr;
};

#ifdef RUNNING_FRC_TESTS
int main() { return frc::StartRobot<Robot>(); }
#endif

```

C.2 CCSDS.h

```
#include <stdint.h>

#define CCSDS_PROTOCOL_VERSION 0

enum CCSDS_sequence_type {
    CONTINUATION = 0b00,
    FIRST = 0b01,
    LAST = 0b10,
    UNSEGMENTED = 0b11
};

void create_CCSDS_header(bool isCommand, uint16_t APID,
                        CCSDS_sequence_type seq_type,
                        uint16_t count, uint16_t length,
                        uint8_t* destination);
```

C.3 CCSDS.cpp

```
#include "CCSDS/CCSDS.h"

void create_CCSDS_header(bool isCommand, uint16_t APID,
                        CCSDS_sequence_type seq_type,
                        uint16_t count, uint16_t length,
                        uint8_t* destination){
    APID &= 0x7ff; //Sanitize APID to 11 bits
    destination[0] = 0;
    destination[0] |= CCSDS_PROTOCOL_VERSION << 5;
    destination[0] |= ((isCommand ? 1 : 0) << 4);
    //destination[0] |= 0b00001000; //Sec hdr flag
    destination[0] |= (APID >> 8);
    destination[1] = (APID & 0xff);
    destination[2] = 0;
    destination[2] |= (seq_type << 6);
    destination[2] |= (count >> 8);
    destination[3] = (count & 0xff);
    destination[4] = (length >> 8);
    destination[5] = (length & 0xff);
    return;
}
```