CAN decoder warns for malicious attacks

The open-source Sigrok project is a set of drivers and tools. It provides a desktop oscilloscope and logic analyzer UI (user interface) that can control different instruments (from Siglent, Rigol, and others).

The UI runs on Mac OS, Windows and Linux and is called Pulseview. Integrated is also a command-line tool for batch decoding, useful in an automated test environment. Pulseview has an API (application programming interface) for protocol decoders. Recently, a decoder for CAN has been introduced.

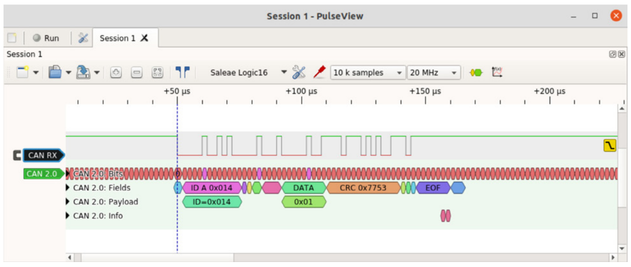


Figure 1: Decoder screenshot of a CAN frame (Source: Canis Automotive Labs)

Figure 1 is a screenshot of the decoder showing a CAN frame. Here, the Pulseview interface runs on Ubuntu Linux. The logic analyzer hardware used here is a 16-channel Saleae Logic16. But the available USB logic analyzers that cost less than 10 US $ with eight channels and a sample rate of up to 20 MHz are also suitable for use with CAN. A falling-edge trigger condition is typically used with CAN (this is the sync point for the protocol). A pre-trigger buffer enables the decoder to see at least ten recessive bits to know that the next dominant bit is a new frame.

The decoder shows four lines of details about a CAN frame:

- The raw bitstream (including stuff bits)
- The decoded CAN fields
- The decoded CAN-ID and payload bytes
- An information line showing protocol events and warnings

View of details

Pulseview shows as much details as fits into an item for a given time scale, but a tooltip appears with the full data if the mouse pointer hovers over an item. For example, the value of the 4-bit DLC (data length code) field with a tooltip is shown in Figure 2.

The decoder also checks the frame for valid fields and marks when an error is detected. For example, it will show in the warning line when the received CRC (cyclic redundancy check) does not match with the calculated CRC, when

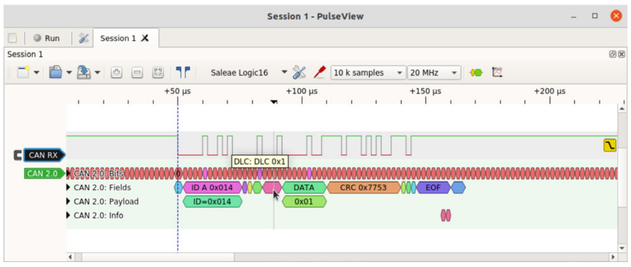


Figure 2: Value of the 4-bit DLC field shown with a tooltip (Source: Canis Automotive Labs)

the ACK (acknowledge) field is not 0, when a stuff error has been detected, and so on. It also shows an active error frame including the superposition, the error delimiter, and the IFS

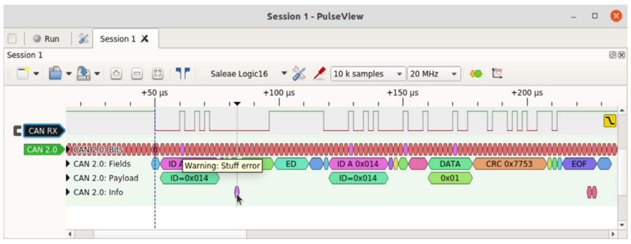


Figure 3: Warning about a stuff error (Source: Canis Automotive Labs)

(interframe space) field following an error frame.

The warning as shown in Figure 3 is a stuff error – the result of an error being signaled by another CAN controller. The decoder shows the error flag (which includes the superposition of dominant bits from many controllers) and the error delimiter. The trace also shows the frame being re-transmitted successfully.

The double-receive event is a particularly interesting property of CAN. Because a frame is received one bit-time before it is transmitted, it is possible that an error in the last bit of the EOF (end of frame) causes the transmitter to detect an error and retransmit the frame, leading to it being received twice. This is not a bug in the CAN protocol: it is an inevitable consequence of implementing an atomic broadcast protocol (something that most other communication protocols do not even attempt to provide, which is one reason why CAN is such a superbly reliable fieldbus protocol).

As seen in Figure 4, the decoder warns of this specific event (double receive). This event should happen rarely (a bit error must occur exactly at the last bit of EOF). But it can be engineered to occur by an attack on the bus: by deliberately injecting a dominant bit at the last bit of EOF, an attacker can force the frame to be retransmitted and ▷

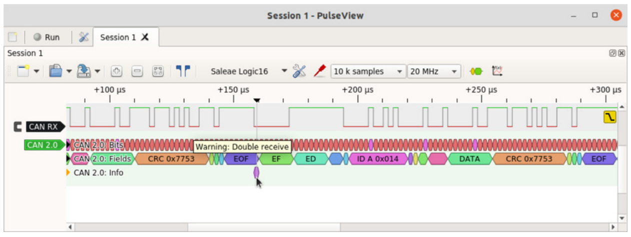


Figure 4: Warning about a double receive (Source: Canis Automotive Labs)

received twice. If the frame being targeted contains an event data, then that event will be acted upon twice by receivers, which could cause all kinds of things to go wrong – the very purpose of a malicious attack.

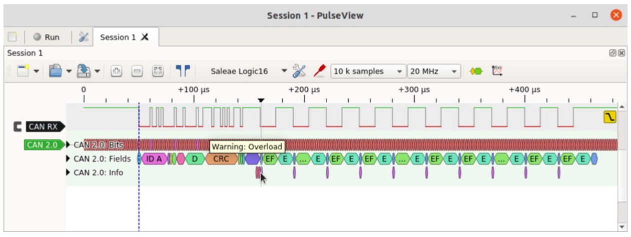


Figure 5: Warning about an overload frame (Source: Ian Tabor)

The decoder also shows when there is an overload frame – something that should never be seen since modern CAN controllers never generate these frames. The screenshot in Figure 5 shows a frame that is sent, but then a sequence of overload frames is injected to hold all the CAN controllers in an overload loop. This is a clear indication of a type of denial-of-service attack on the CAN network. In this case it was carried out by the CANhack toolkit. The CANhack toolkit is an open-source library for demonstrating attacks on the CAN protocol: github.com/kentindell/canhack.

The protocol decoder is designed to help spot these events from a logic analyzer trace – it can see things that a simple list of received CAN frames would not show. But it also can interface to CAN frame logging tools. The decoder has an option to export CAN frames in a packet capture format (called "pcapng") that tools such as Wireshark can process. A trace of many frames can be shown in Wireshark as a conventional list of frames. For example, the screenshot in Figure 6 shows the trace of a pair of CAN frames sent roughly every 100 ms.

When the exported packet capture file is read in to the Wireshark tool, it is shown as a simple list of frames (see Figure 7).

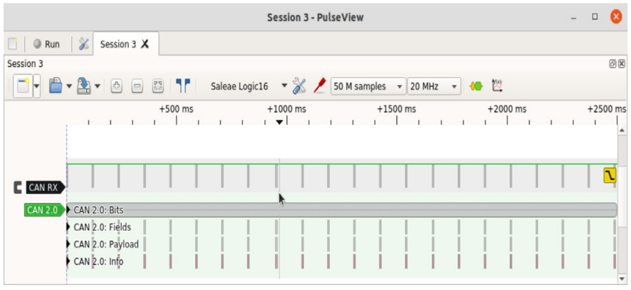
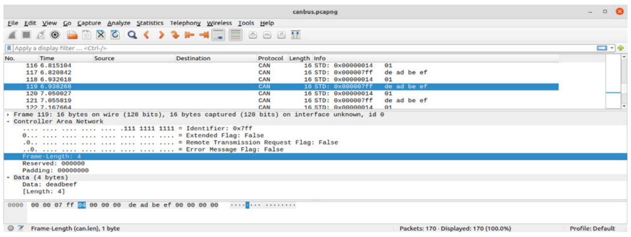


Figure 6: Trace of a pair of CAN frames sent roughly every 100 ms (Source: Ian Tabor)


canbus.pcapng

```
No.   Time       Source   Destination   Protocol  Length  Info
  116 6.815104                          CAN           16 STD: 0x00000014   01
  117 6.820842                          CAN           16 STD: 0x000007ff   de ad be ef
  118 6.932618                          CAN           16 STD: 0x00000014   01
  119 6.938268                          CAN           16 STD: 0x000007ff   de ad be ef
  120 7.050027                          CAN           16 STD: 0x00000014   01
  121 7.055819                          CAN           16 STD: 0x000007ff   de ad be ef
  122 7.167664                          CAN           16 STD: 0x00000014   01
▸ Frame 119: 16 bytes on wire (128 bits), 16 bytes captured (128 bits) on interface unknown, id 0
▾ Controller Area Network
    .... .... .... .... .... .111 1111 1111 = Identifier: 0x7ff
    0... .... .... .... .... .... .... .... = Extended Flag: False
    .0.. .... .... .... .... .... .... .... = Remote Transmission Request Flag: False
    ..0. .... .... .... .... .... .... .... = Error Message Flag: False
    Frame-Length: 4
    Reserved: 000000
    Padding: 00000000
▾ Data (4 bytes)
    Data: deadbeef
    [Length: 4]
0000  00 00 07 ff 04 00 00 00  de ad be ef 00 00 00 00   ........ ........
Frame-Length (can.len), 1 byte          Packets: 170 · Displayed: 170 (100.0%)          Profile: Default
```

Figure 7: The exported packet capture file is shown as a frame list in Wireshark (Source: Canis Automotive Labs)

The timestamps attached to the CAN frames in the packet stream are very accurate. These are useful when hunting for a particular incident in the frame view of the Wireshark (or other tools) to navigate within Pulseview to find details of what was happening on the wire around an incident.

Unveiling hidden problems

The decoder has already helped one developer to solve a problem with their system. Ian Tabor (@mintynet on Twitter) is a car hacker who has developed a low-cost "car in a box" system for people to practice hacking. The hardware includes the ability to send CAN frames from three different buses to a monitoring bus via an MCP2515 CAN controller from Microchip. The driver was running very slowly and unable to sustain throughput that was needed. But Pulseview was able to show where the time was going: the CAN protocol decoder showed the CAN frames and the Pulseview SPI decoder (serial peripheral interface) showed where the SPI transactions were taking place. The screenshot in Figure 8 shows the situation before.

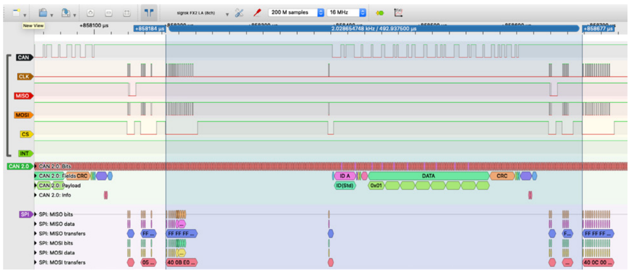


Figure 8: CAN traffic before driver optimization (Source: Ian Tabor)

The screenshot in Figure 9 shows the situation after the drivers were optimized, reducing the time between frames from nearly 500 μs to just over 300 μs.

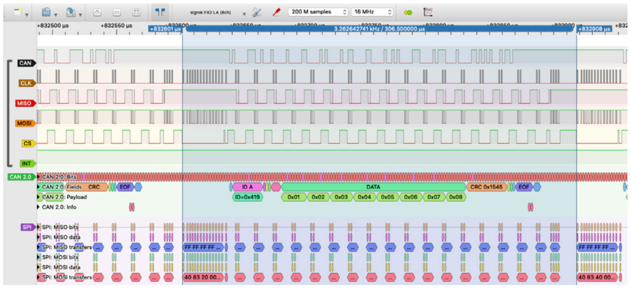


Figure 9: CAN traffic after driver optimization reducing the time between frames (Source: Ian Tabor)

The tool's availability

The source code to the CAN protocol decoder is available in the CANhack toolkit repository on Github at github.com/kentindell/canhack. The decoder is in the folder src/can2. The best way to install the Sigrok tools (Pulseview and Sigrok-cli) is to download them directly from Sigrok. More details on setting up the decoder can be found here. ◀

CAN board for Raspberry Pi Pico

The CANPico board has been recently released by Canis Automotive Labs. It integrates a Microchip MCP2517/18FD CAN controller with a 2-KiB buffer and the Microchip MCP2562FD CAN transceiver. Jumpers are available for connection of a 120-Ω CAN termination resistor and for disabling of transmit access to the CAN network (listen-only access). There is also a 6-pin header for connection of a logic analyzer (e.g. the CAN2 protocol decoder) or oscilloscope. The included Trig pin can be set in order to trigger the logic analyzer on a specific CAN-ID or a CAN error frame.

Along with the board is a pre-built Micropython SDK (start development kit) firmware, with a CAN API that includes priority-inversion-free drivers, time-stamping (both send and receive), control of CAN-ID filters, and a CAN bit-rate setup. The board is ready for order online from SK Pang. It is shipped with a Raspberry Pi Pico and the pre-installed firmware. More detailed information is available here.

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