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It's Easier to Br(e)ak(e) Than to Patch:

A Stealthy DoS attack against CAN

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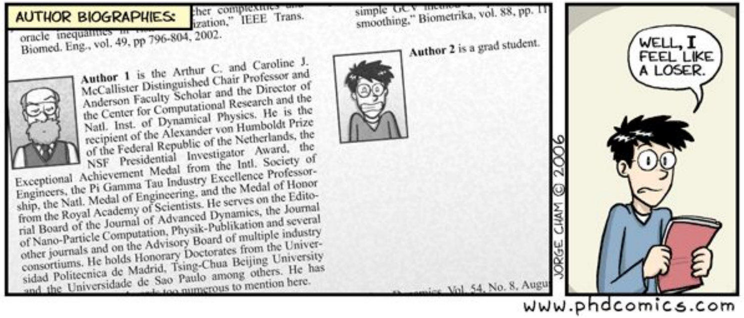
Acknowledgments: Matteo Penco, Michele Carminati, Andrea Palanca, Eric Evenchick, Federico Maggi

$whoami

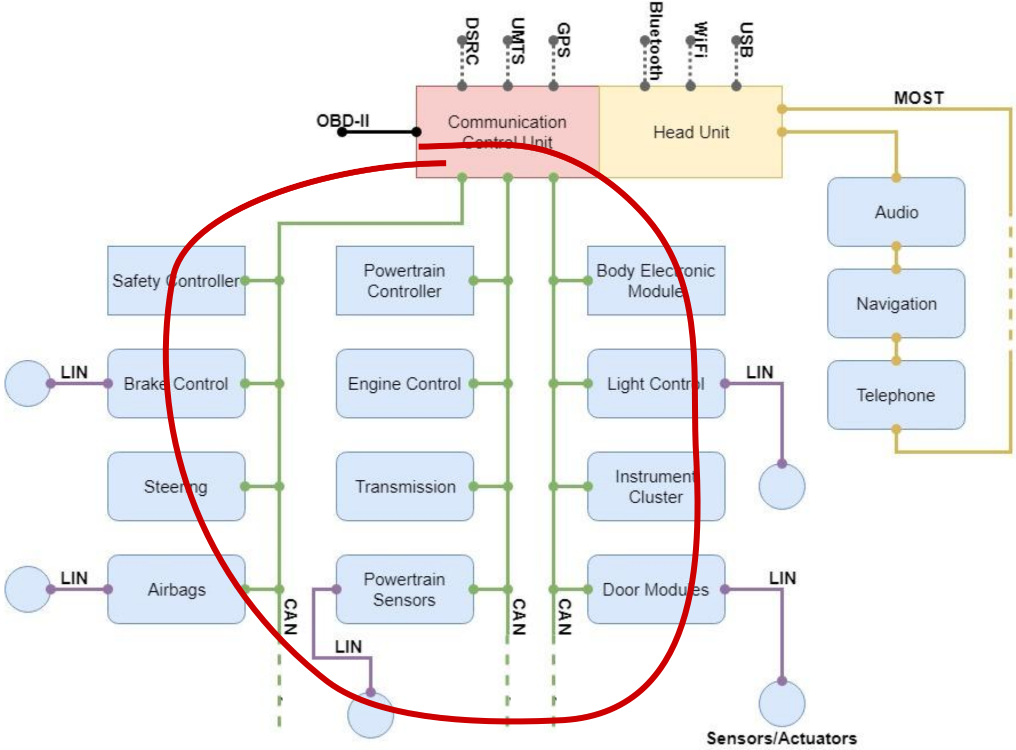
Stefano Longari is a PhD student at Politecnico di Milano, his research focuses on automotive on-board security.



Stefano Zanero is an associate professor at Politecnico di Milano, and has over 20 years of experience in the security field. He has founded a security services company that delivers security assessment services worldwide.

Controller Area Network

De-facto standard in the automotive World



Is CAN key to automotive attacks?

AUTO TECH

Tesla hackers explain how they did it at Defcon

At the digital security conference, Kevin Mahaffey and Marc Rogers explain how they hacked a Tesla Model S -- and why you shouldn't be too alarmed.

BY ANTUAN GOODWIN | AUGUST 9, 2015 2:09 PM PDT

Note: *As stated below, Tesla has already patched many of the vulnerabilities discussed here in a recent patch.*

LAS VEGAS -- It is very difficult to hack a Tesla Model S, but it's not impossible. Last week, researchers Kevin Mahaffey and Marc Rogers demonstrated that they were able to remotely unlock the Model S' doors, start the vehicle and drive away. They were also able to issue a

At Defcon, Rogers and Mahaffey (left to right) explain what Tesla does right and where it was weak in designing the Model S' information systems.

Antuan Goodwin/CNET

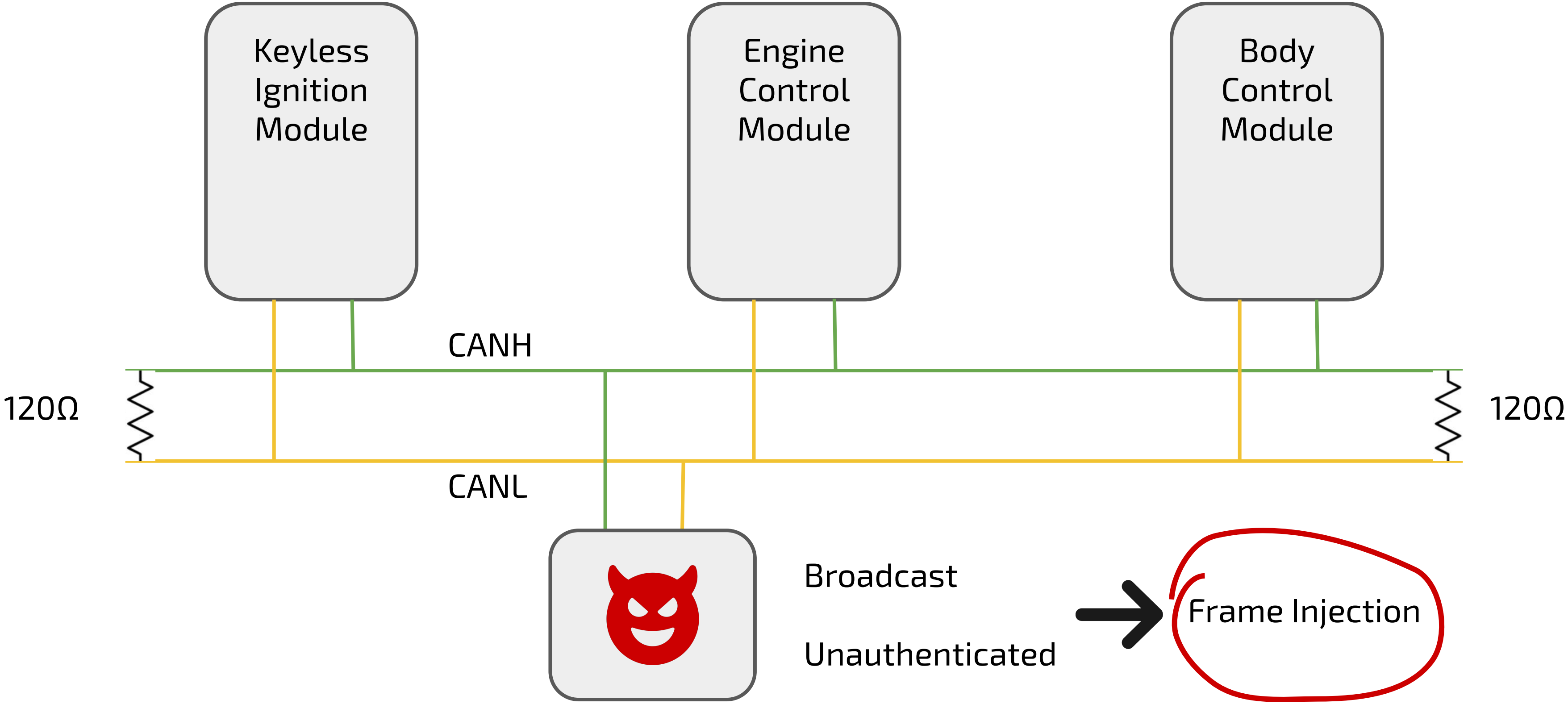
The Jeep Hackers Are Back to Prove Car Hacking Can Get Much Worse

ANDY GREENBERG SECURITY 08.01.16 03:30 PM

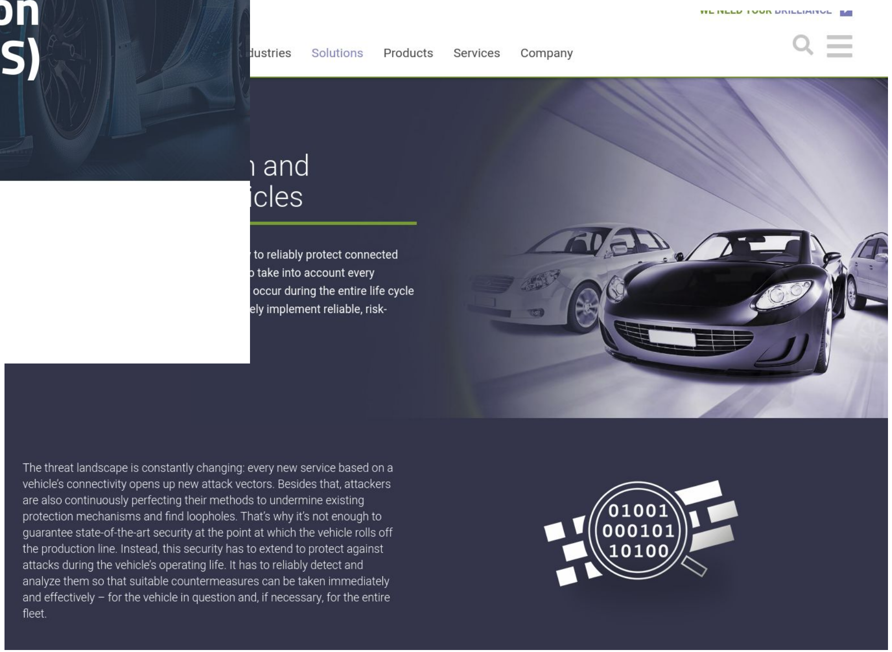
THE JEEP HACKERS ARE BACK TO PROVE CAR HACKING CAN GET MUCH WORSE

Security researchers Charlie Miller and Chris Valasek. WHITNEY CURTIS FOR WIRED

What weaknesses are commonly abused?



Can we detect these attacks?

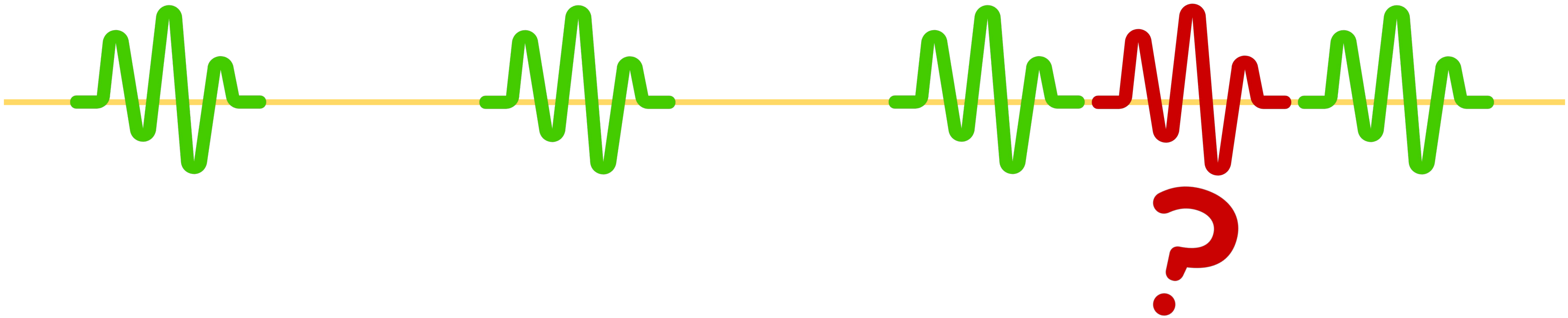


How do automotive IDS work?

Industrial secret, however we can make an educated guess at some methods

- Frequency based
  - CAN messages are usually periodic
- Specification based
  - Set rules for the data field of the message
  - Potentially dynamic depending from message history
- Machine Learning based
  - Generally similar to specification based ones
  - Mainly Academic

How to evade an automotive IDS



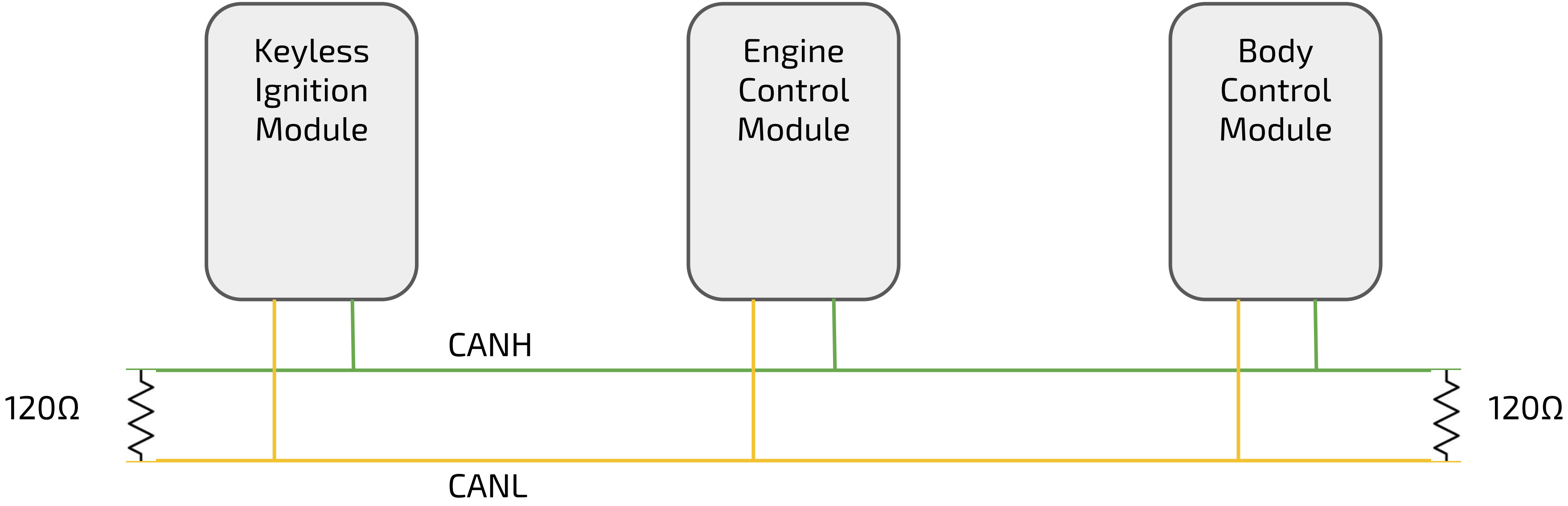
- Specification based: Comply with the rules
- Frequency based: Comply with the frequency
- ML based: different forms of mimicry attacks

The perfect crime

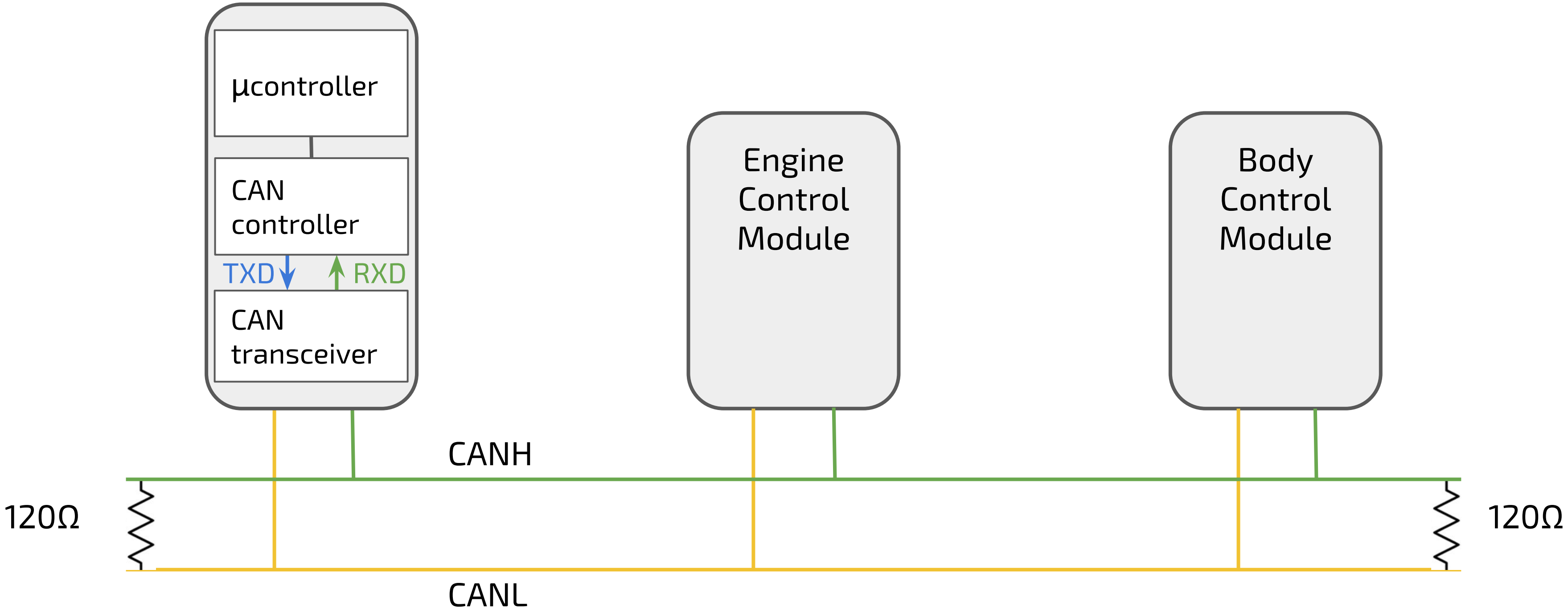
What if we manipulate/substitute a real frame?

- Specification based: Comply with the rules
- Frequency based: Comply with the frequency
- ML based: different forms of mimicry attacks

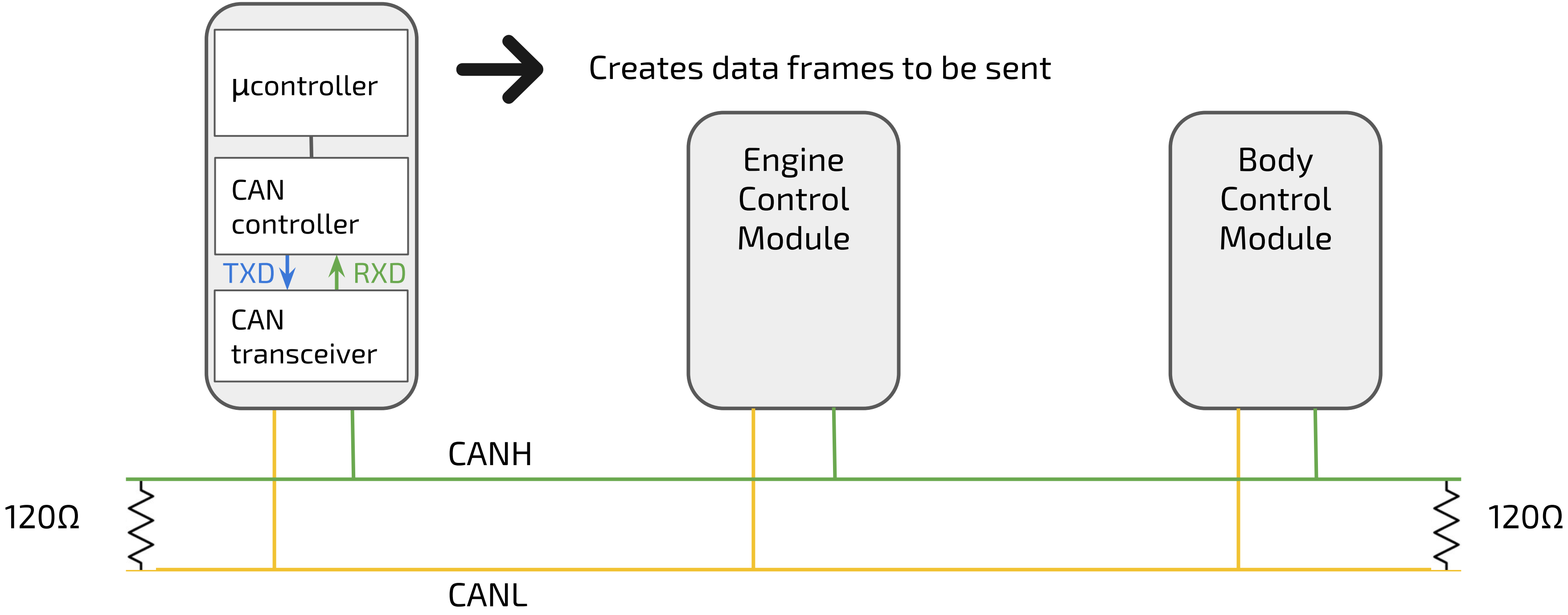
How could you possibly do that?



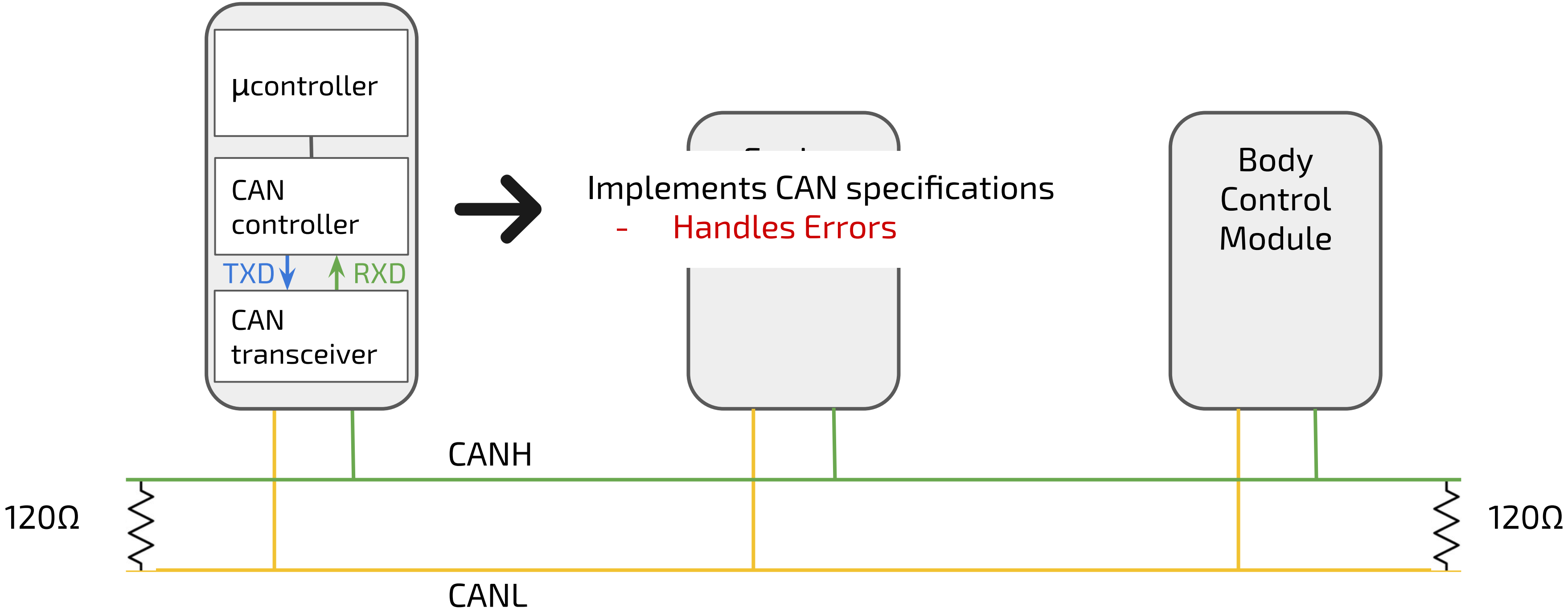
CAN specs overview



CAN specs overview



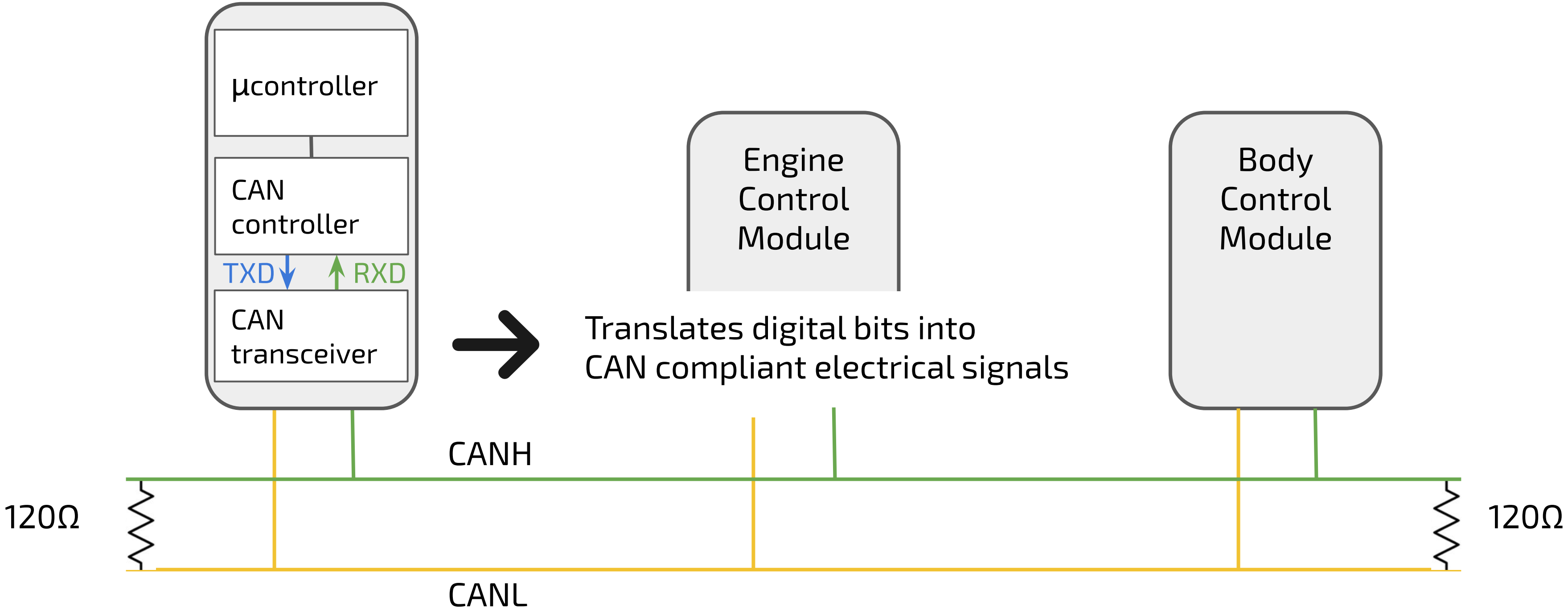
CAN specs overview



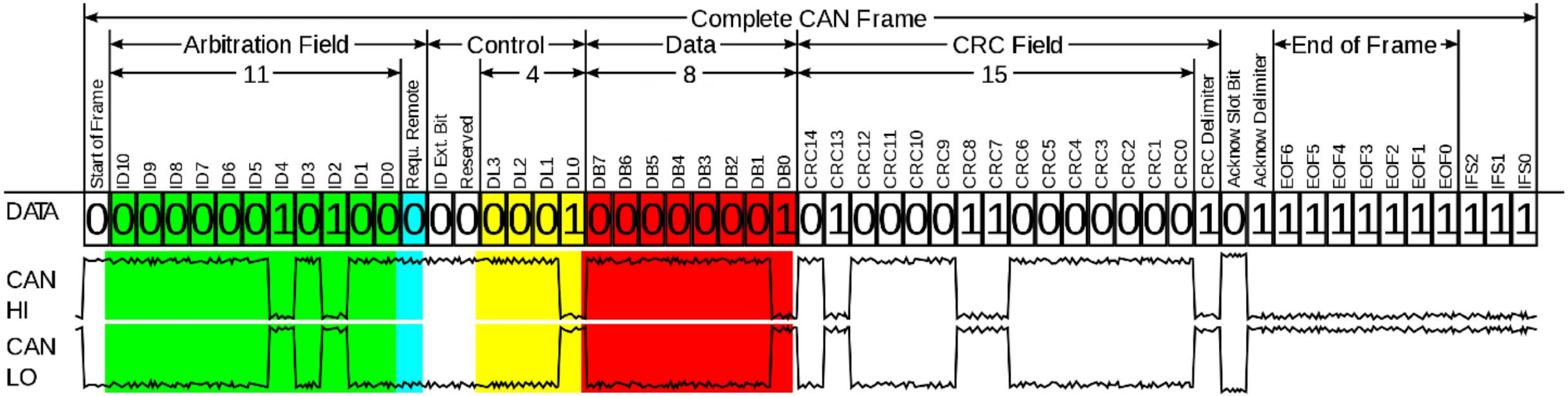
Implements CAN specifications

- Handles Errors

CAN specs overview

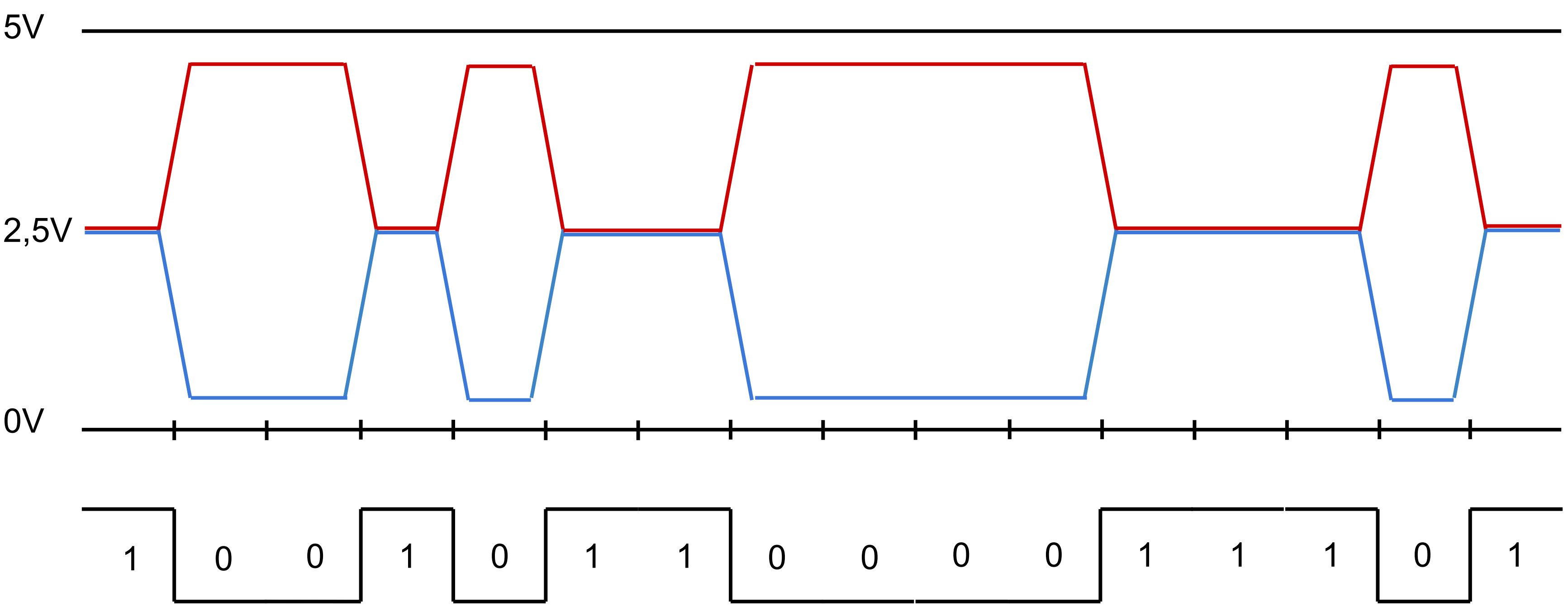


Data frames

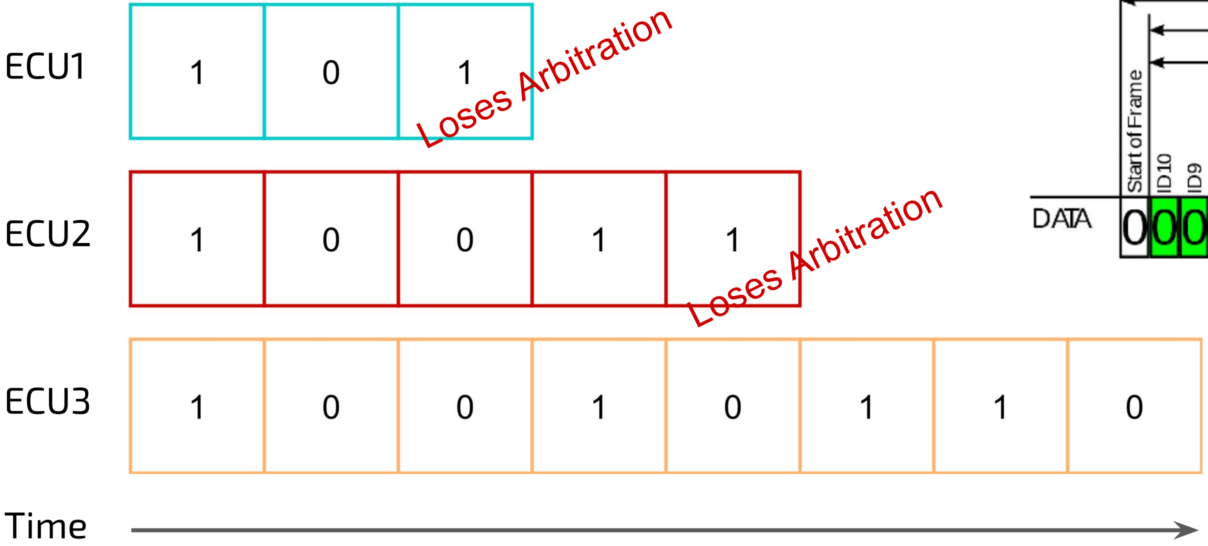


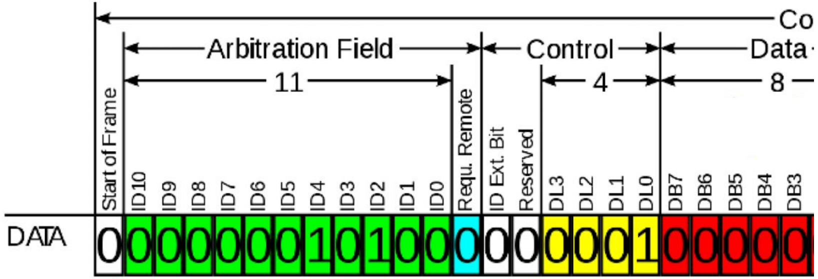
Complete CAN Frame
Arbitration Field
Control
Data
CRC Field
End of Frame
11
4
8
15
Start of Frame
ID10 ID9 ID8 ID7 ID6 ID5 ID4 ID3 ID2 ID1 ID0
Requ. Remote
ID Ext. Bit
Reserved
DL3 DL2 DL1 DL0
DB7 DB6 DB5 DB4 DB3 DB2 DB1 DB0
CRC14 CRC13 CRC12 CRC11 CRC10 CRC9 CRC8 CRC7 CRC6 CRC5 CRC4 CRC3 CRC2 CRC1 CRC0
CRC Delimiter
Acknow Slot Bit
Acknow Delimiter
EOF6 EOF5 EOF4 EOF3 EOF2 EOF1 EOF0
IFS2 IFS1 IFS0
DATA
0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 1 0 0 0 0 0 0 0 1 0 1 1 1 1 1 1 1 1 1 1 1
CAN HI
CAN LO

CAN bus values

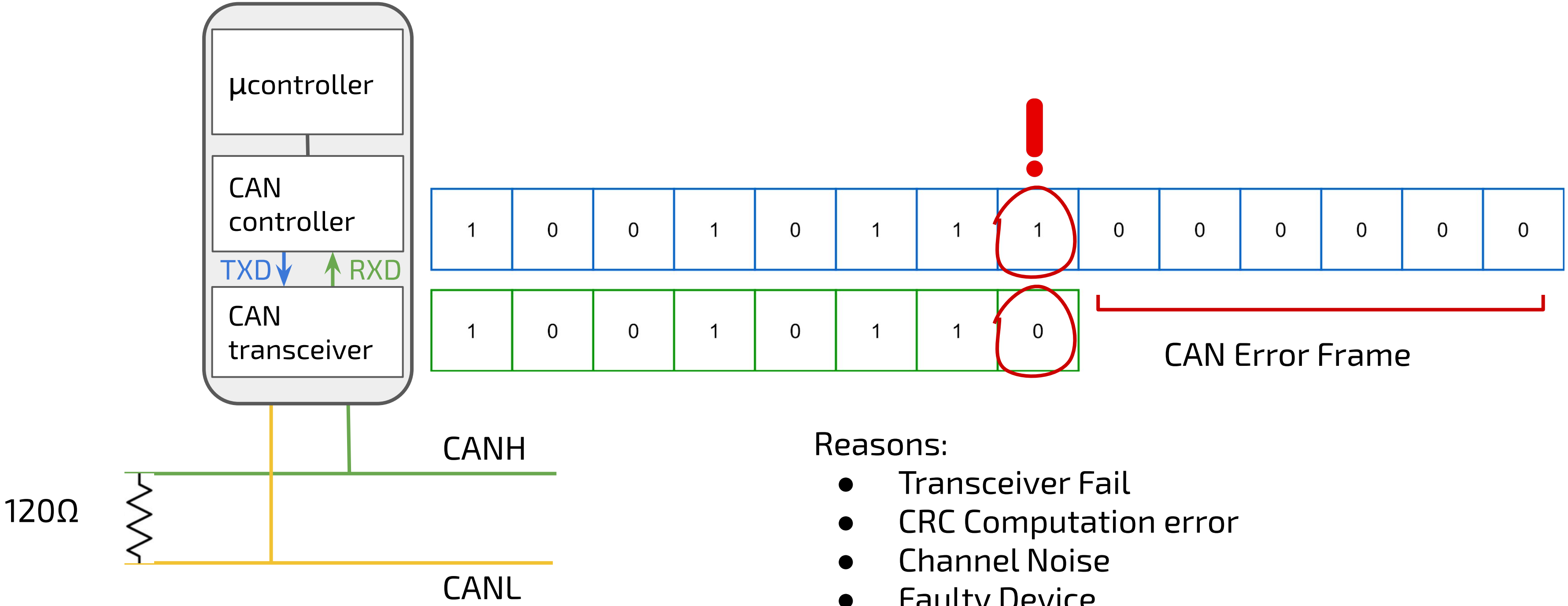


Dominant beats recessive - arbitration





CAN error handling

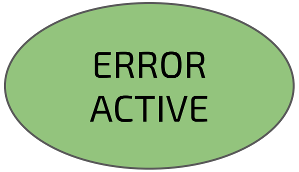


Reasons:

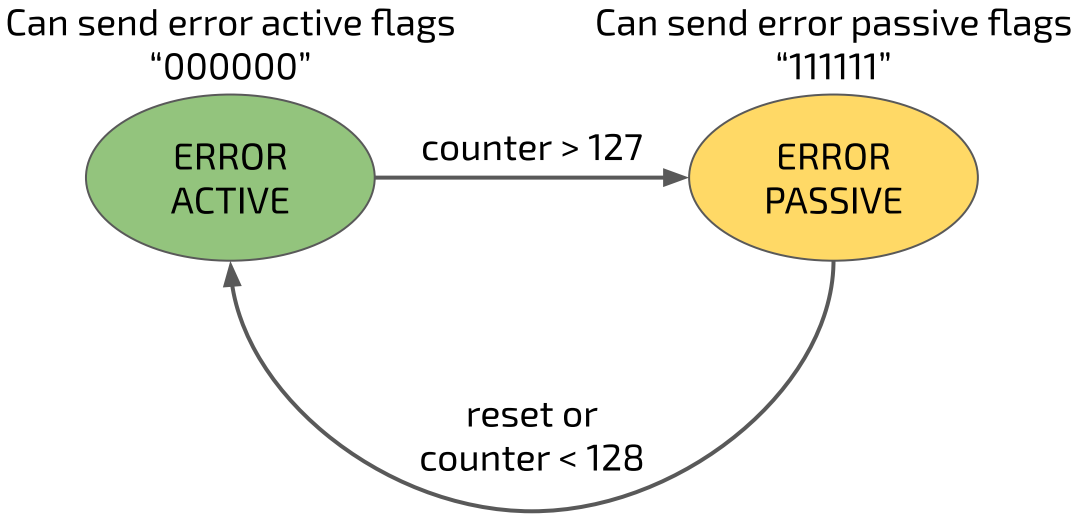
- Transceiver Fail
- CRC Computation error
- Channel Noise
- Faulty Device
- ...

CAN fault confinement

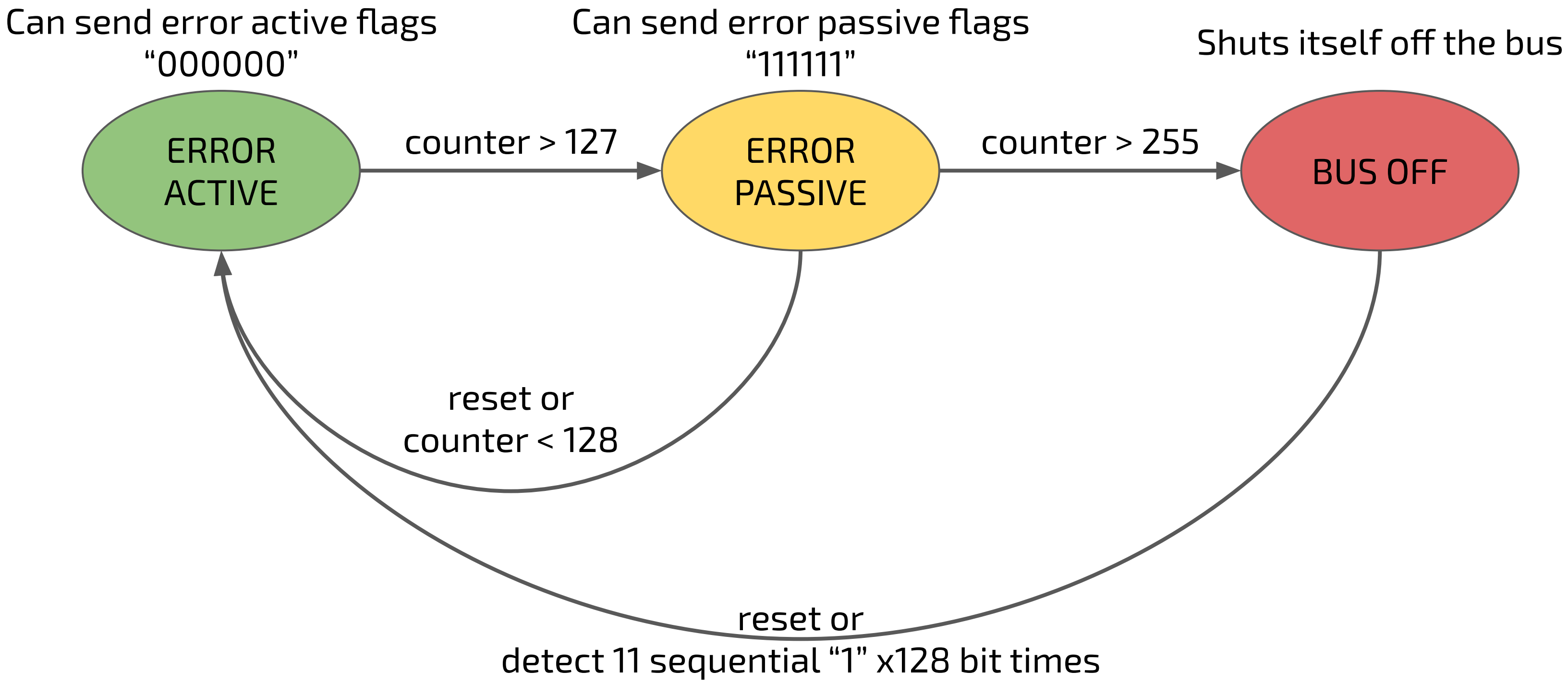
Can send error active flags
“000000”



CAN fault confinement

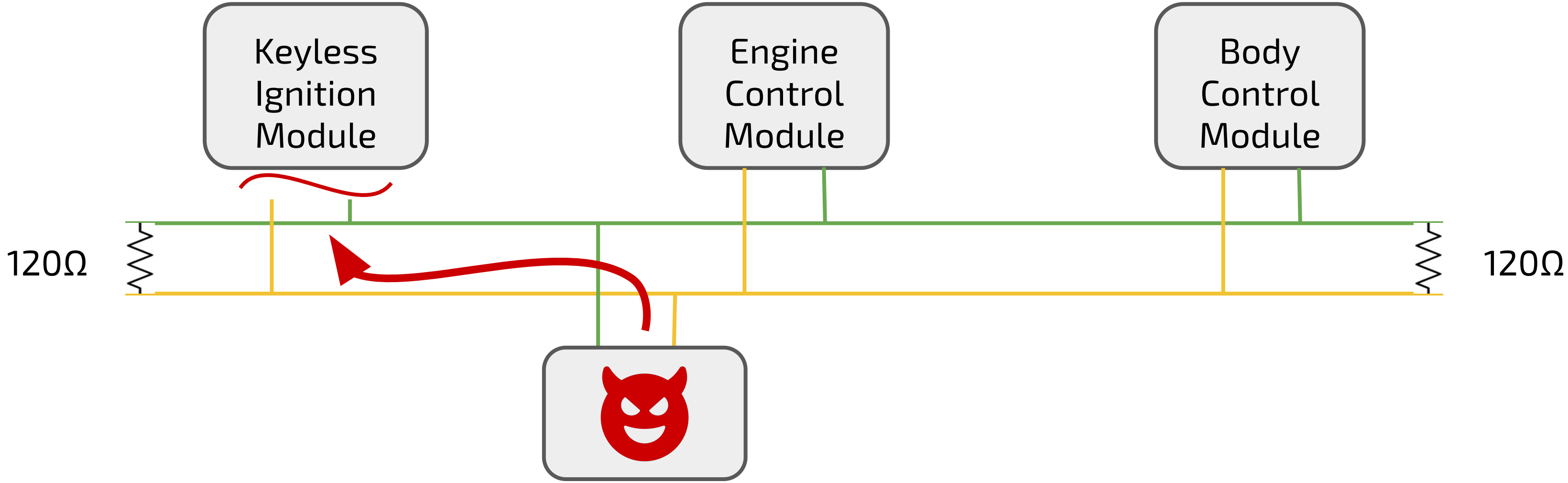


CAN fault confinement

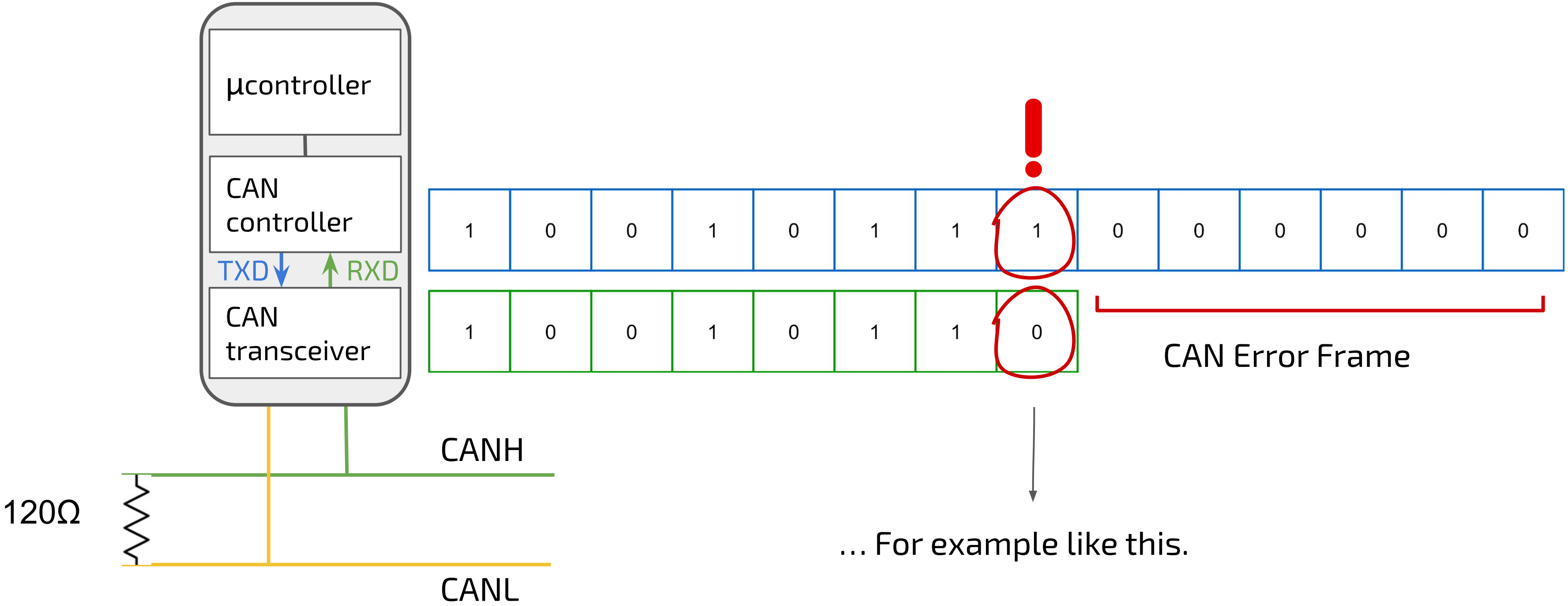


How do we Exploit this?

How do we convince the target ECU to kick itself off the network?



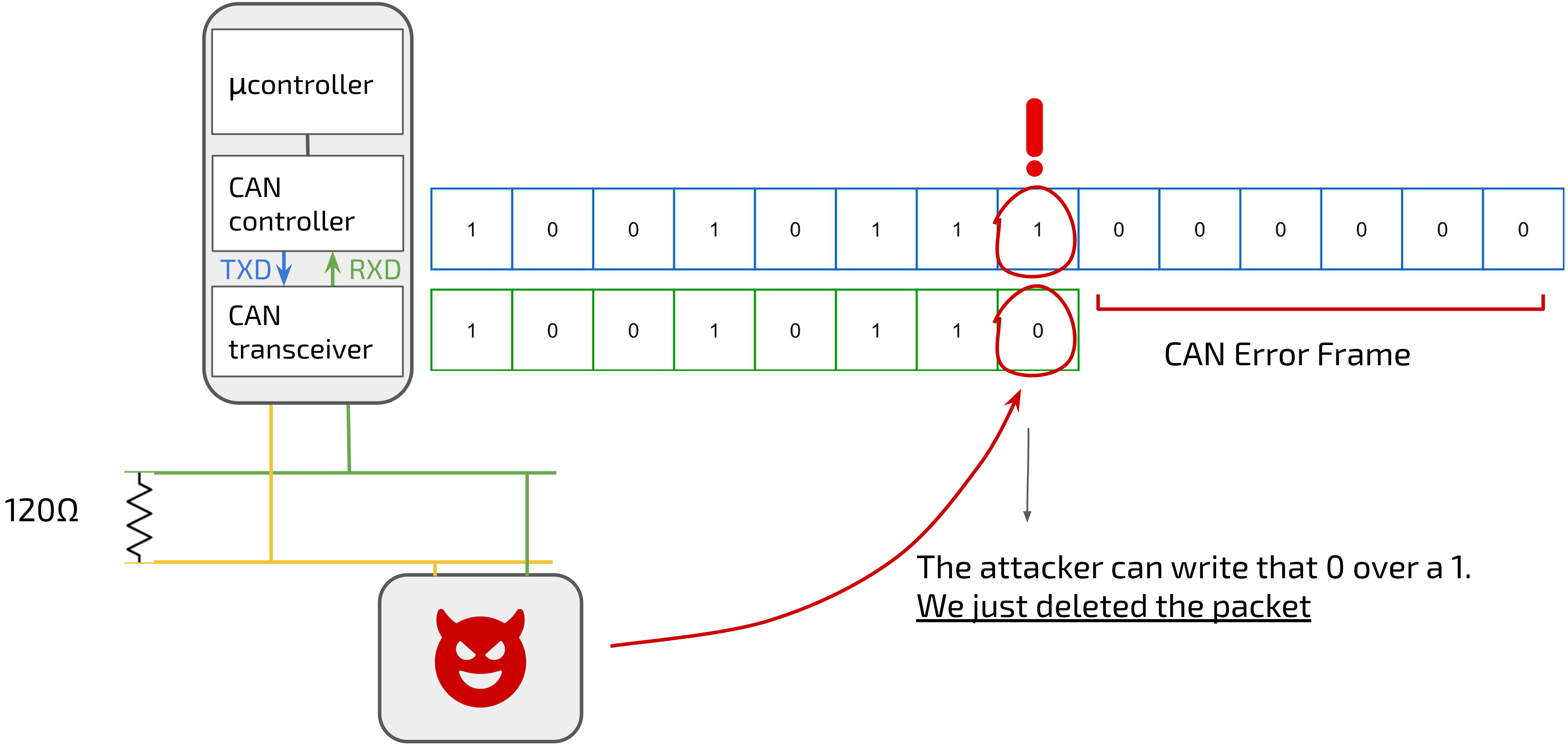
How do we Exploit this?



… For example like this.

<u>0 overwrites 1.</u>

How do we Exploit this?



The attacker can write that 0 over a 1.
<u>We just deleted the packet</u>

Steps

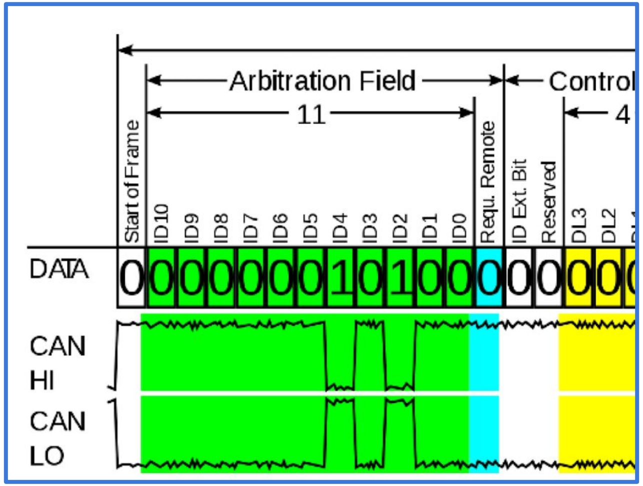
1) Discover the ID of the victim
2) Detect the ID of the victim on the bus
3) Find a “1” (recessive) bit in the packet
4) Overwrite it with a 0
5) Repeat 32 consecutive times

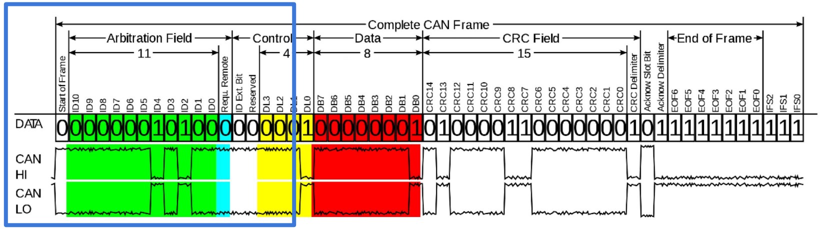
e.g., Reverse engineer the CAN IDs of an identical vehicle

Steps

1) Discover the ID of the victim
2) <u>Detect</u> the ID of the victim on the bus
3) Find a “1” (recessive) bit in the packet
4) Overwrite it with a 0
5) Repeat 32 consecutive times

e.g., read all IDs passing on the bus





Steps

1) Discover the ID of the victim

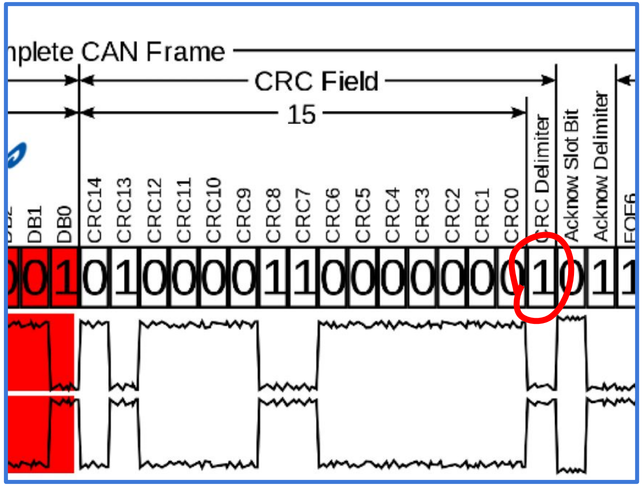
2) Detect the ID of the victim on the bus

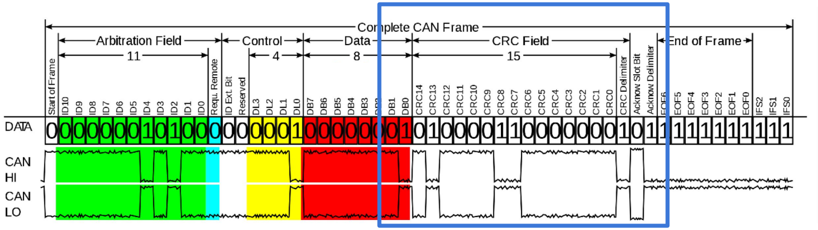
3) Find a "1" (recessive) bit in the packet

4) Overwrite it with a 0

5) Repeat 32 consecutive times

<u>CRC delimiter</u> is "1" by design





Steps

1) Discover the ID of the victim

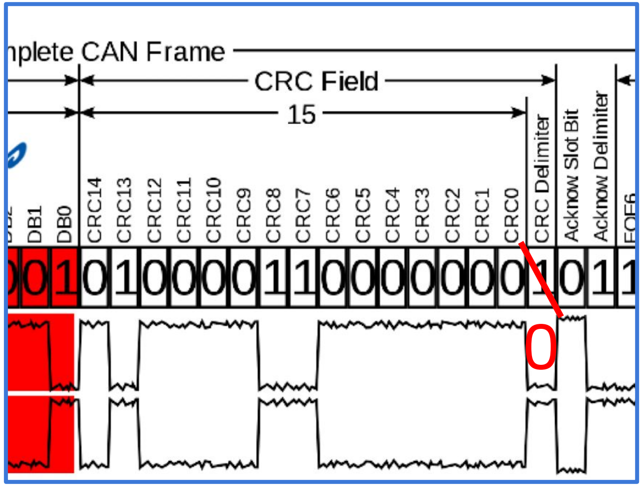
2) Detect the ID of the victim on the bus

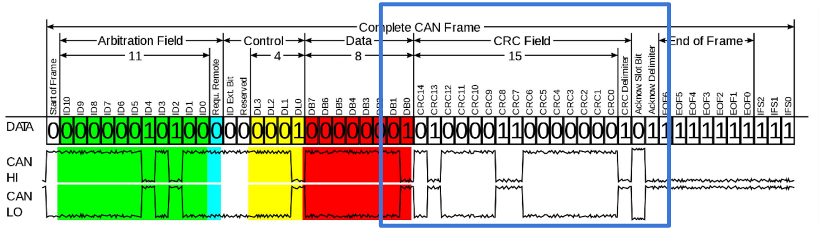
3) Find a "1" (recessive) bit in the packet

4) Overwrite it with a 0

5) Repeat 32 consecutive times

This triggers an <u>error</u> generated by the victim





Steps

1) Discover the ID of the victim
2) Detect the ID of the victim on the bus
3) Find a "1" (recessive) bit in the packet
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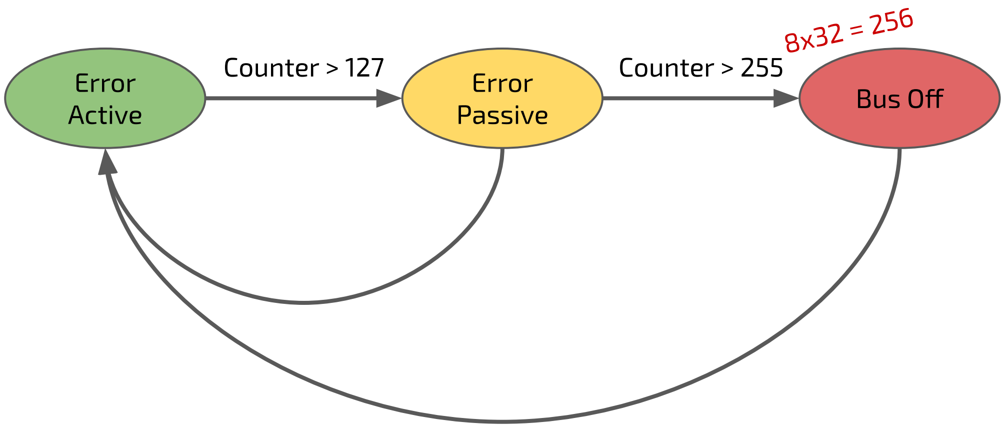
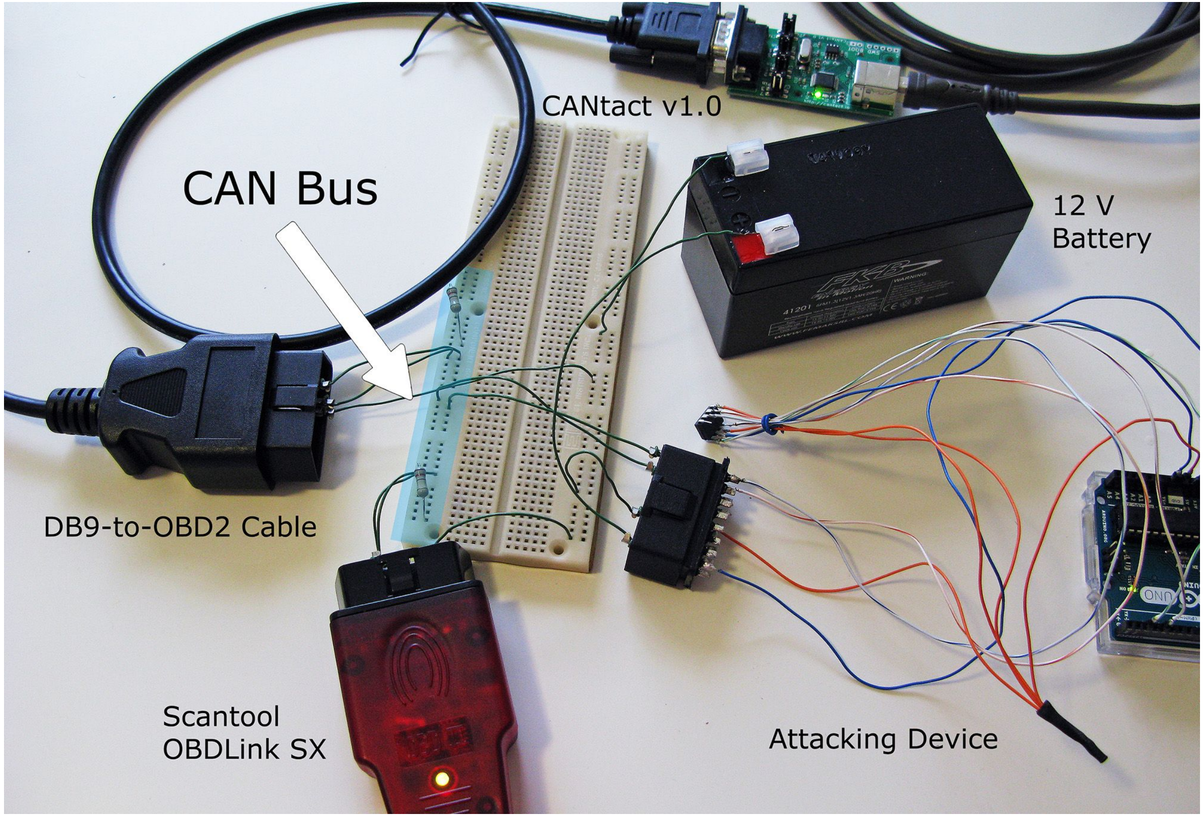
This kind of error adds +8 to the counter of the victim



Proof of Concept Implementation

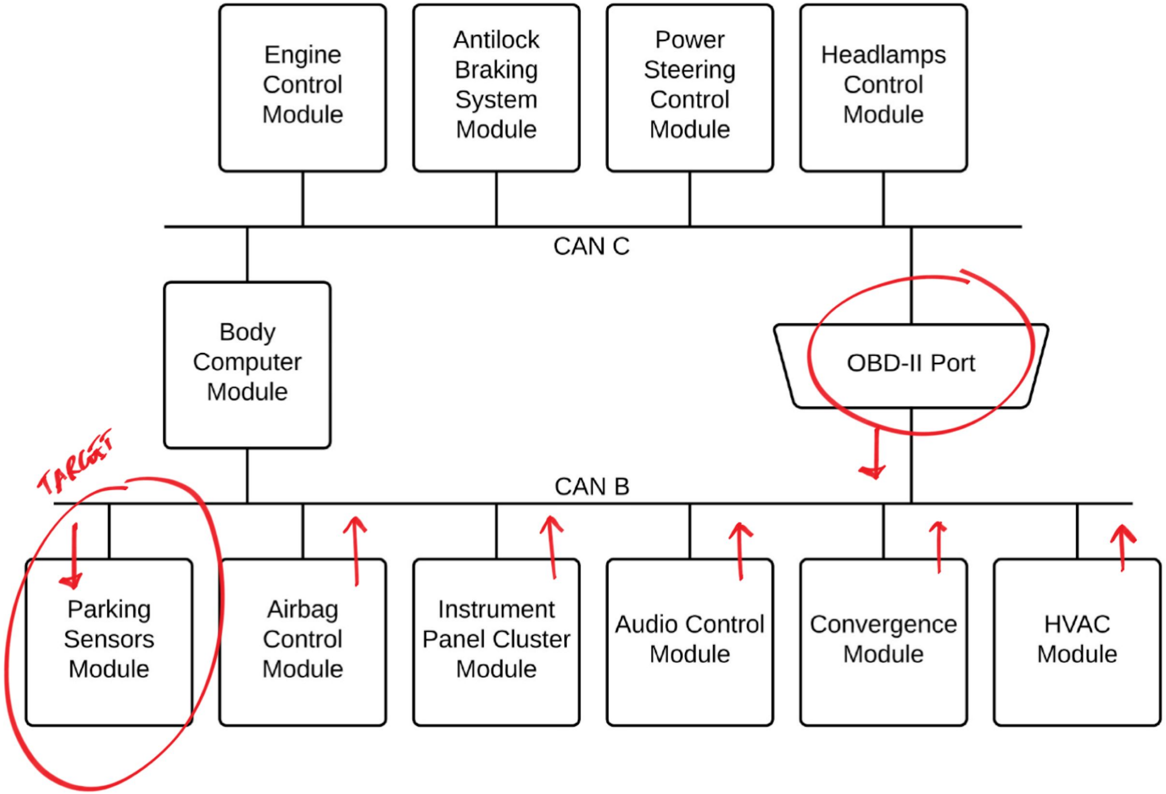


Testbed Experiment

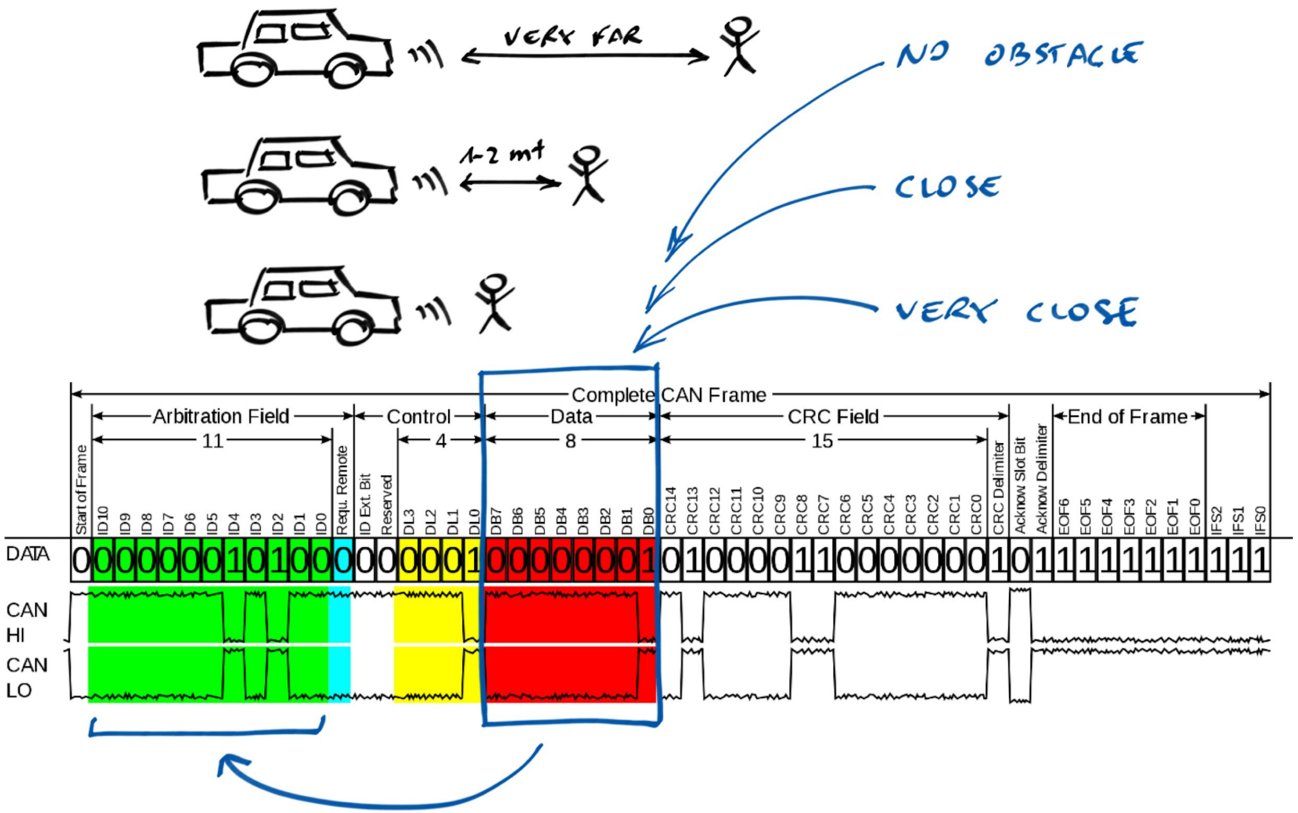
Description	Value
Test Duration	24 hours
Total Number of Frames Sent	9,403,842 frames
Average Throughput	108.84 frames/s
Average Frame Length	101 bits
Average CAN Utilization	0.21985834
Number of Correctly Processed Frames	9,403,598 frames
Number of False Positives	0 frames
Number of False Negatives	244 frames
Accuracy	**0.99997405**

Proof of Concept Implementation

Alfa Giulietta Exploited



Alfa Giulietta Exploited



Alfa Giulietta Exploited

https://is.gd/candos

Is it preventable?

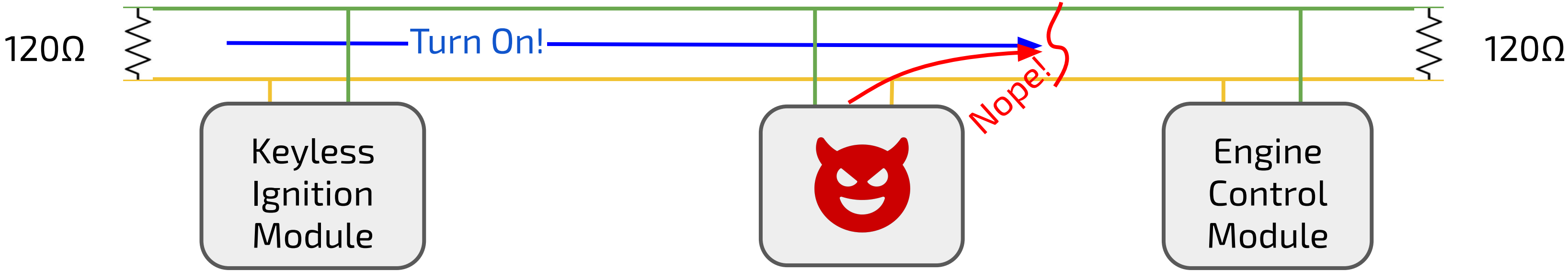
Not really…

- Based on the protocol specs
- Hard to retrieve logs to distinguish between real failures and attacks

Attack scenarios

Denial of Service for the sake of Denial of Service

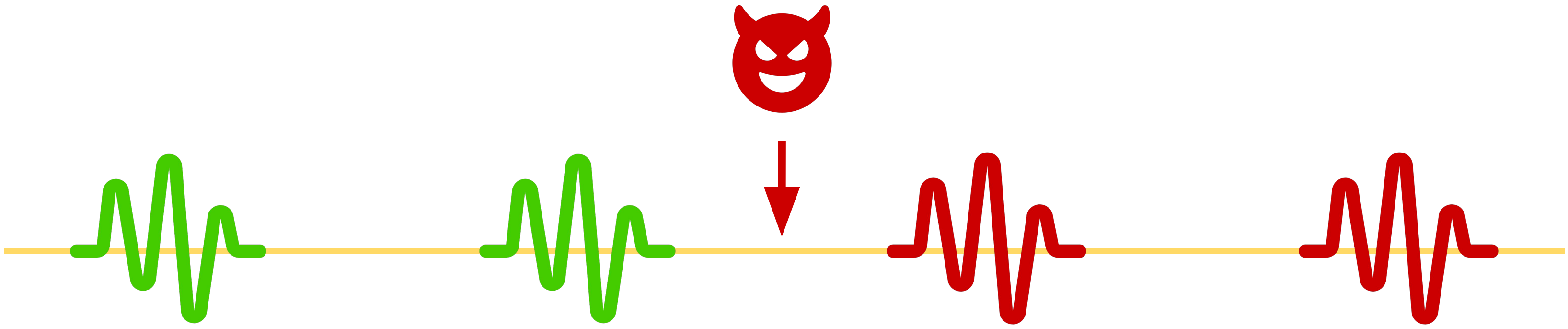
e.g. Ransomware



Attack scenarios

Detection avoidance for spoofing attacks

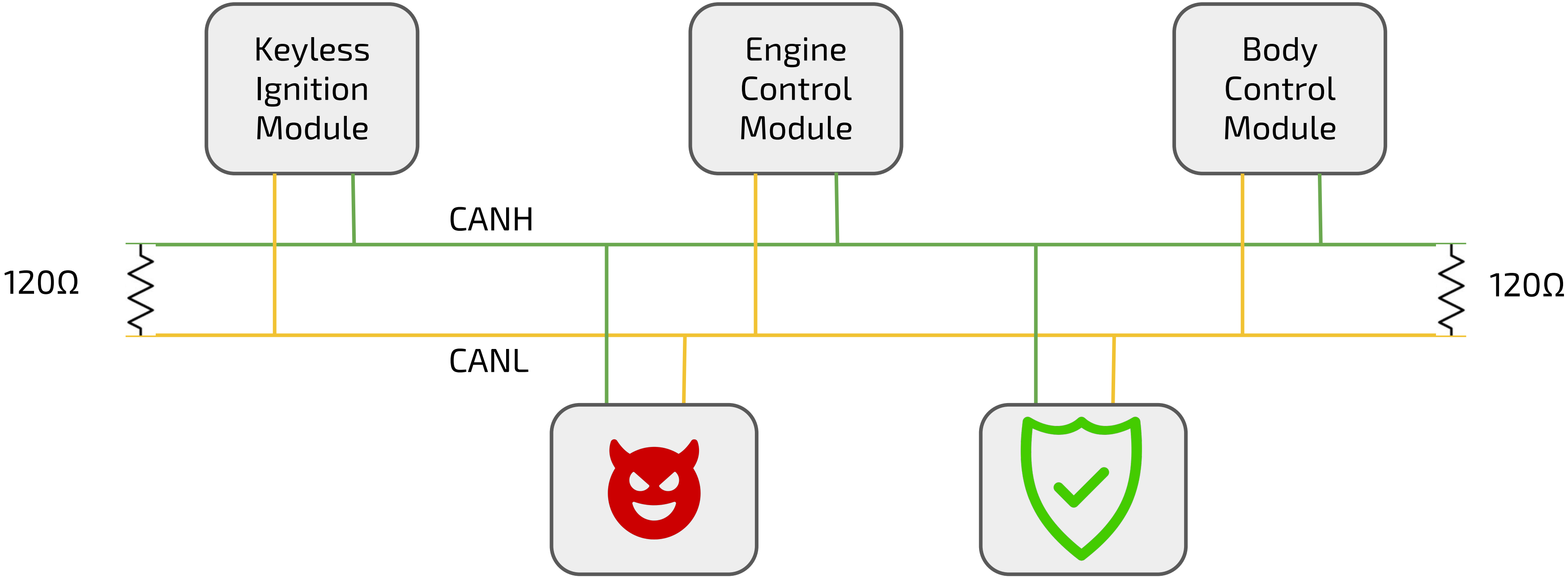
- Shut down the victim ECU
- Send spoofed data



Can we detect the DoS?

We can read data from the bus

We can detect the attacker once he tries to spoof data after the DoS



We need to study more CAN specs! :(

List of rules that change the counters:

1. When a RECEIVER detects an error, the RECEIVE ERROR COUNT will be increased by 1, except when the detected error was a BIT ERROR during the sending of an ACTIVE ERROR FLAG or an OVERLOAD FLAG.

2. When a RECEIVER detects a 'dominant' bit as the first bit after sending an ERROR FLAG the RECEIVE ERROR COUNT will be increased by 8.

3. When a TRANSMITTER sends an ERROR FLAG the TRANSMIT ERROR COUNT is increased by 8.

   Exception 1:
   If the TRANSMITTER is 'error passive' and detects an ACKNOWLEDGMENT ERROR because of not detecting a 'dominant' ACK and does not detect a 'dominant' bit while sending its PASSIVE ERROR FLAG.

   Exception 2:
   If the TRANSMITTER sends an ERROR FLAG because a STUFF ERROR occurred during ARBITRATION, and should have been 'recessive', and has been sent as 'recessive' but monitored as 'dominant'.

   In exceptions 1 and 2 the TRANSMIT ERROR COUNT is not changed.

4. If an TRANSMITTER detects a BIT ERROR while sending an ACTIVE ERROR FLAG or an OVERLOAD FLAG the TRANSMIT ERROR COUNT is increased by 8.

5. If an RECEIVER detects a BIT ERROR while sending an ACTIVE ERROR FLAG or an OVERLOAD FLAG the RECEIVE ERROR COUNT is increased by 8.

6. Any node tolerates up to 7 consecutive 'dominant' bits after sending an ACTIVE ERROR FLAG, PASSIVE ERROR FLAG or OVERLOAD FLAG. After detecting the 14th consecutive 'dominant' bit (in case of an ACTIVE ERROR FLAG or an OVERLOAD FLAG) or after detecting the 8th consecutive 'dominant' bit following a PASSIVE ERROR FLAG, and after each sequence of additional eight consecutive 'dominant' bits every TRANSMITTER increases its TRANSMIT ERROR COUNT by 8 and every RECEIVER increases its RECEIVE ERROR COUNT by 8.

7. After the successful transmission of a message (getting ACK and no error until END OF FRAME is finished) the TRANSMIT ERROR COUNT is decreased by 1 unless it was already 0.

8. After the successful reception of a message (reception without error up to the ACK SLOT and the successful sending of the ACK bit), the RECEIVE ERROR COUNT is decreased by 1, if it was between 1 and 127. If the RECEIVE ERROR COUNT was 0, it stays 0, and if it was greater than 127, then it will be set to a value between 119 and 127.

9. A node is 'error passive' when the TRANSMIT ERROR COUNT equals or exceeds 128, or when the RECEIVE ERROR COUNT equals or exceeds 128. An error condition letting a node become 'error passive' causes the node to send an ACTIVE ERROR FLAG.

10. A node is 'bus off' when the TRANSMIT ERROR COUNT is greater than or equal to 256.

11. An 'error passive' node becomes 'error active' again when both the TRANSMIT ERROR COUNT and the RECEIVE ERROR COUNT are less than or equal to 127.

12. An node which is 'bus off' is permitted to become 'error active' (no longer 'bus off') with its error counters both set to 0 after 128 occurrence of 11 consecutive 'recessive' bits have been monitored on the bus.

Not all of them…

List of rules that change the counters:

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Rule 6

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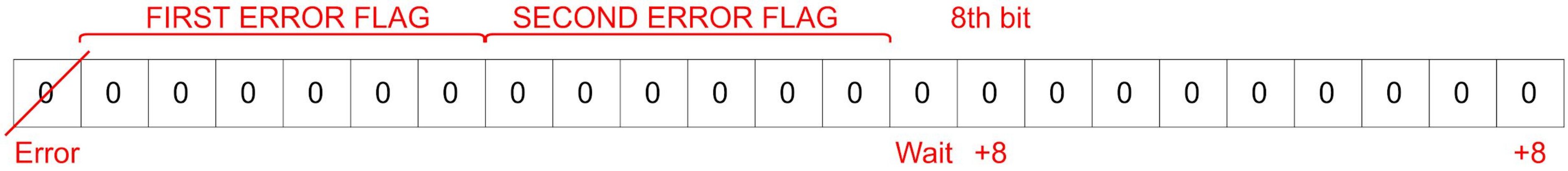
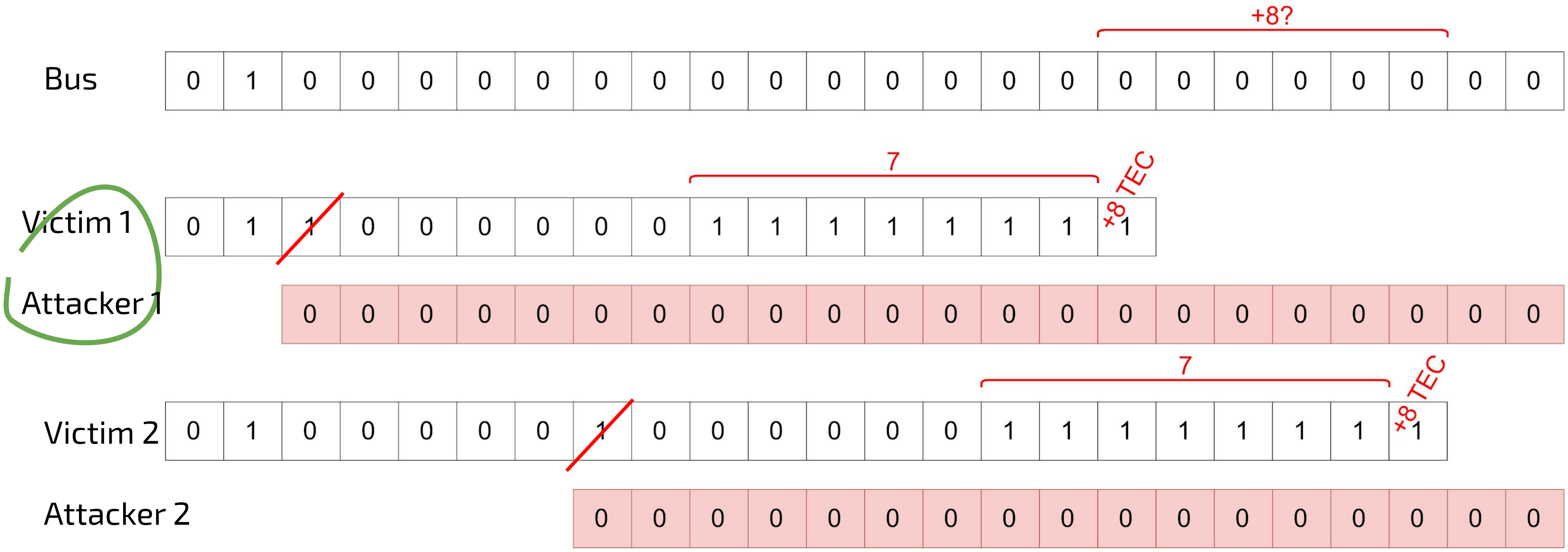
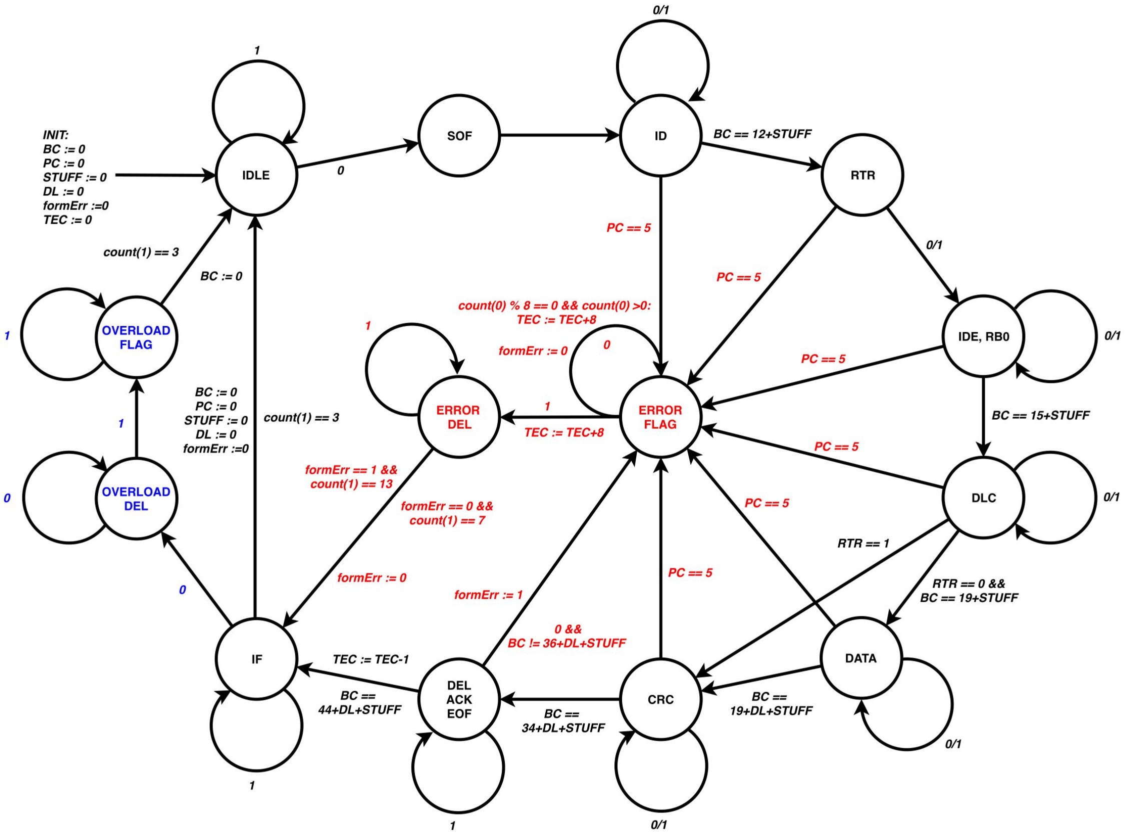


Rule 6

Cannot let the attacker <u>bypass</u> the whole IDS,
so we always consider case 1



Modify the CAN Controller



Complete IDS process: CopyCAN

1) Define which ECUs/IDs to defend
2) Monitor the bus from the beginning of communication
3) Count the TEC (Transmit Error Counter) of each ECU
4) Detect when the ECU goes Bus Off
5) If the ECU writes on the bus again, flag as attack.
6) React?

CopyCAN: An Error-Handling Protocol based Intrusion Detection System for Controller Area Network
Stefano Longari, Matteo Penco, Michele Carminati and Stefano Zanero
CPS-SPC 2019 (ACM Workshop on Cyber-Physical Systems Security & Privacy) - To Appear
ascarecrowhat.github.io for the draft

Reactions

- Switch to safe/degraded driving mode + Alert driver

- Analyze log to prevent attack next time (swarm defense)

- “Attack” the attacker?

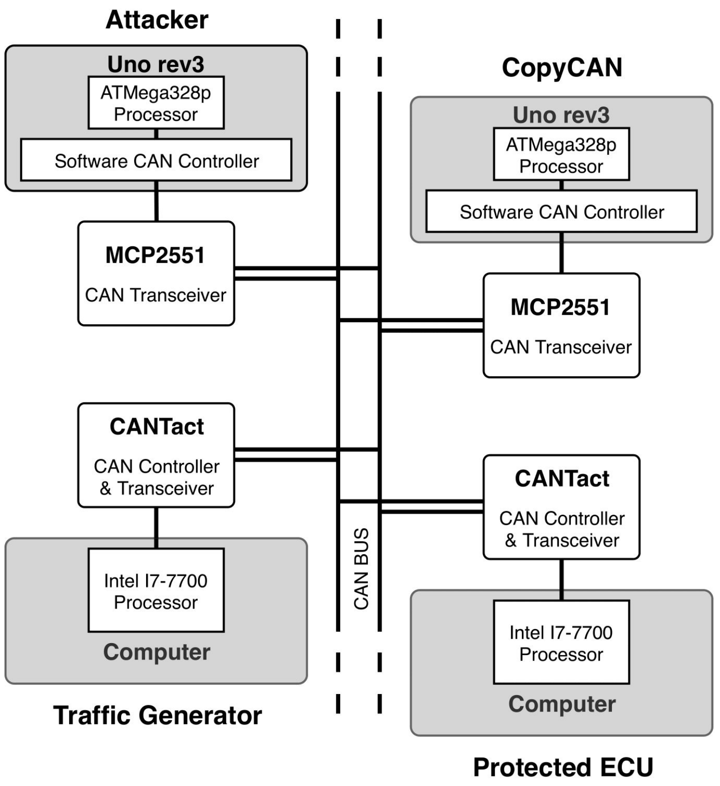
Reactions

“Attack” the attacker?

Con: Really small chance to kill the ECU with a false positive

Pro: Completely denies the attack, degrading it into a DoS

Proof of Concept implementation:



Testbed to detect rules 4 and 6 "in the wild":

Tests done	50
Frames sent per test	15000

IDS Never failed

Conclusions

DoS for CAN is not preventable…

… but the goals of the attacker may be!

Thanks!

For any questions:

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< stefano.zanero@polimi.it > @raistolo