Parallel Universes? Contrasting CAN Bus Security in Automotive and Space Domains

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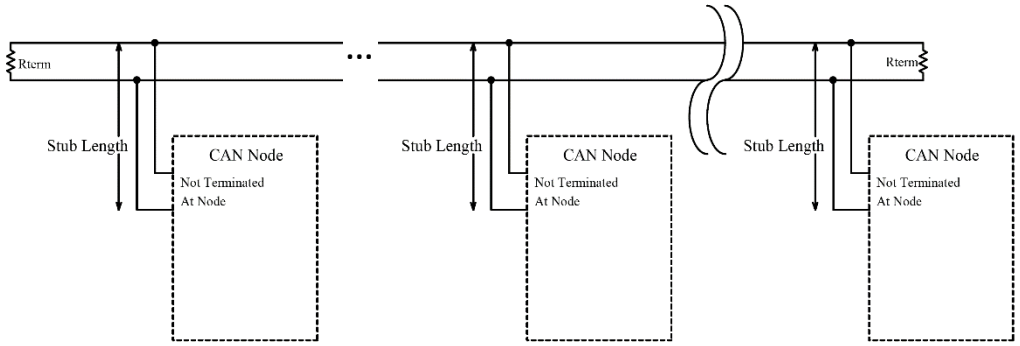
Outline

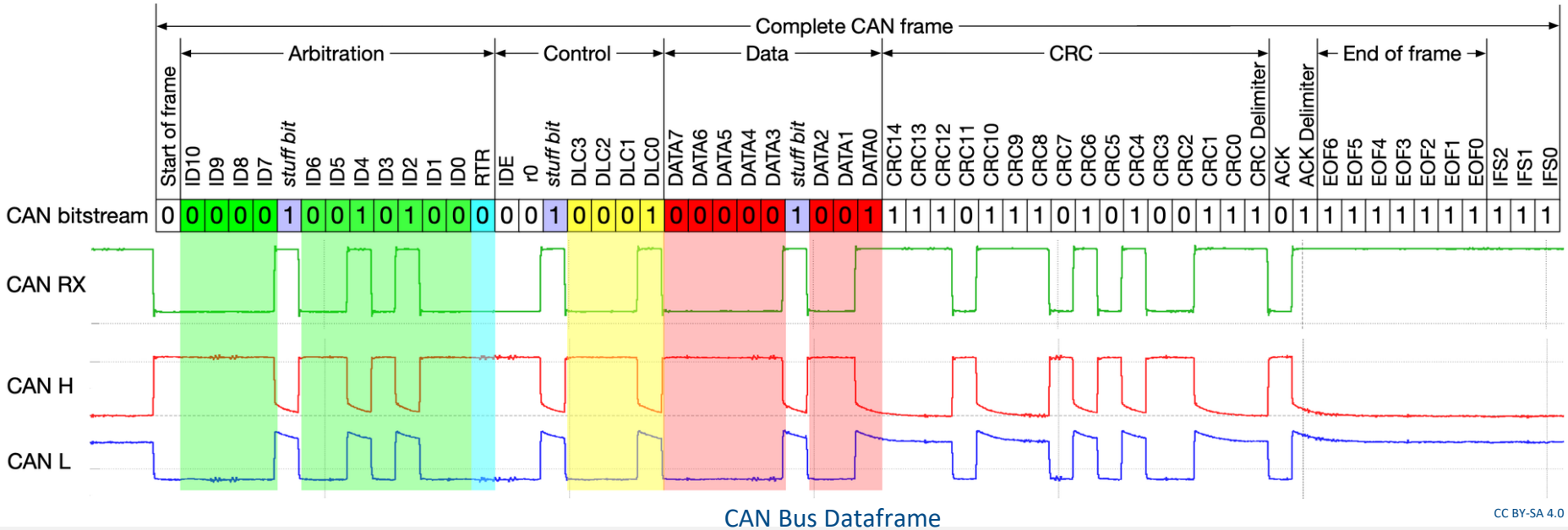
- CAN Bus Intro
- Common Attacks
- Threat Landscape
- Discussion of Space vs Automotive Environments
- Some Security Approaches
- Conclusions

CAN Bus

- Introduced in the 80’s
- Simplistic, but very reliable
- Pair of wires
- Dominant and recessive signals at the physical channel



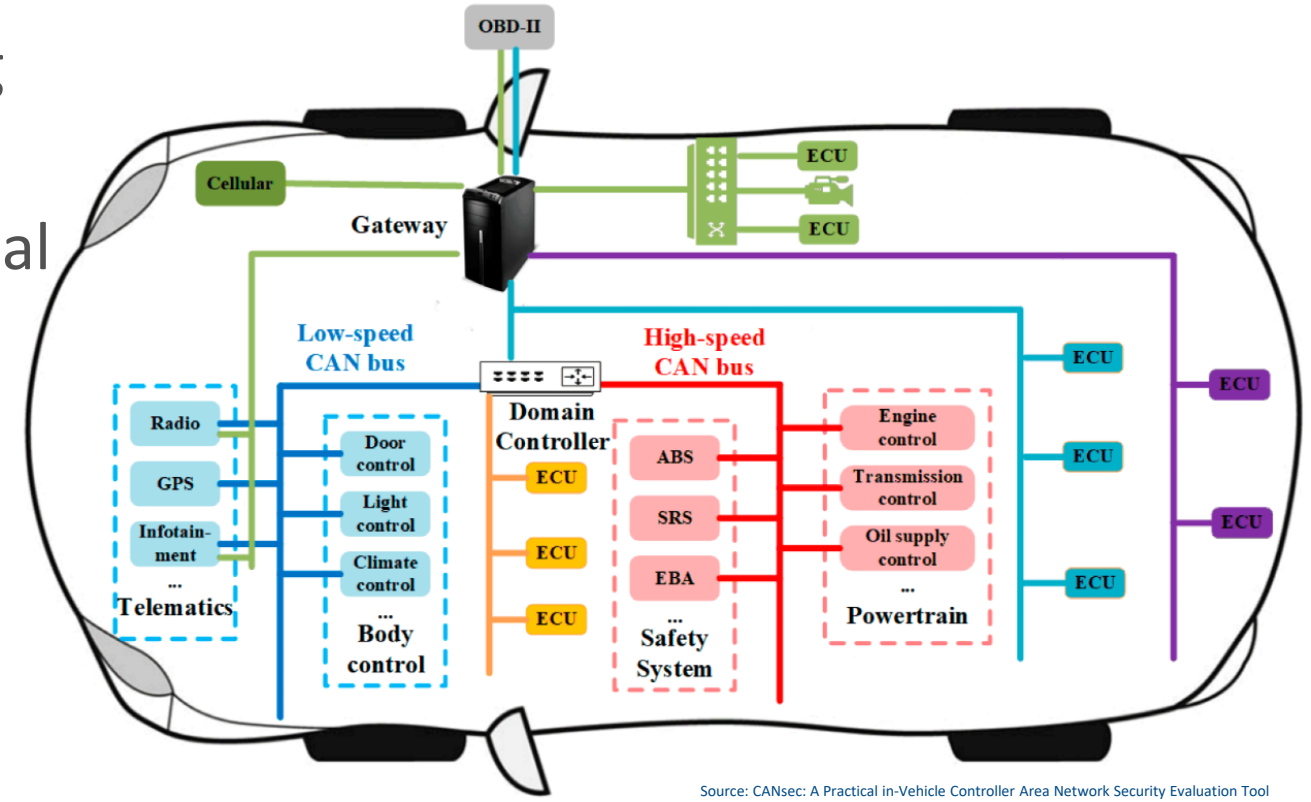
CAN Bus Network



CAN Bus Dataframe

CAN Bus in Automotive

- Controller Area Network (CAN) is a de-facto network in current and upcoming vehicles
- Provides high reliability for safety-critical functions
- ECUs carry out their tasks through reception and broadcast of messages
- Hundreds of ECUs; Several interconnecting buses, including with other networks and external connectivity
- Large attack surface

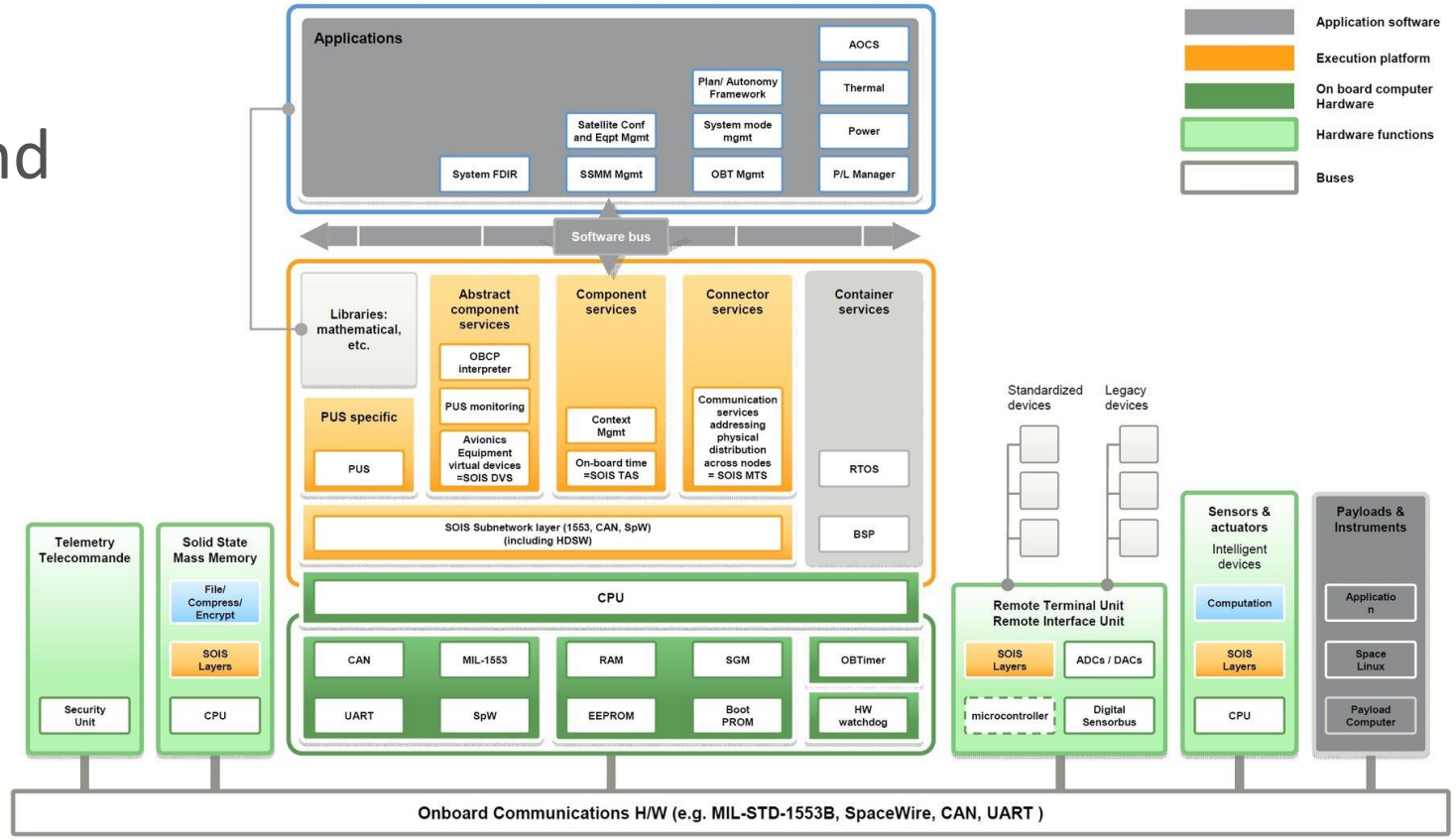


Source: CANsec: A Practical in-Vehicle Controller Area Network Security Evaluation Tool

CAN Bus Architecture

CAN Bus in Space

- CAN bus is being standardized by ESA and the ECSS
  - Covered by ECSS-E-ST-50-15C
- Used for internal command and control buses
- Generally less interconnected components
- Relatively less exposure than Automotive
  (more on that later)



Source: ESA

Onboard Data Systems Architecture

Some Limitations

- Lack of built-in data origin authentication
- Constraints in bandwidth
  - Use of authentication messages is hard due to network bandwidth and load
- Crypto techniques would bring the associated latencies, key management issues, etc.
  - Does not prevent internal attackers from transmitting authenticated malicious messages

Attack Landscape

Compromised Instrument Panel 2010

Jeep 2015

Tesla 2017

Tesla 2016

BMW 2018

Bosch Drivelog 2017

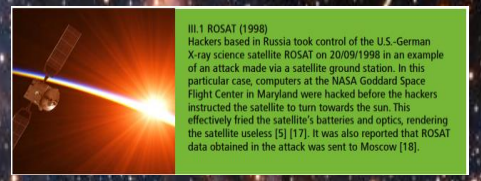
Automotive cybersecurity incidents doubled in 2019, up 605% since 2016

Upstream 2020 Cybersecurity Report

Lexus/Toyota 2020

2020 UN Regulations for Vehicle Cybersecurity Approval

April 1986

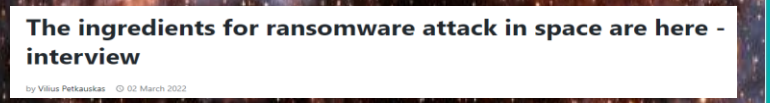


September 1998

November 2021

March 1999

April 2022



March 2022

November 2004

November 2021

October 2007

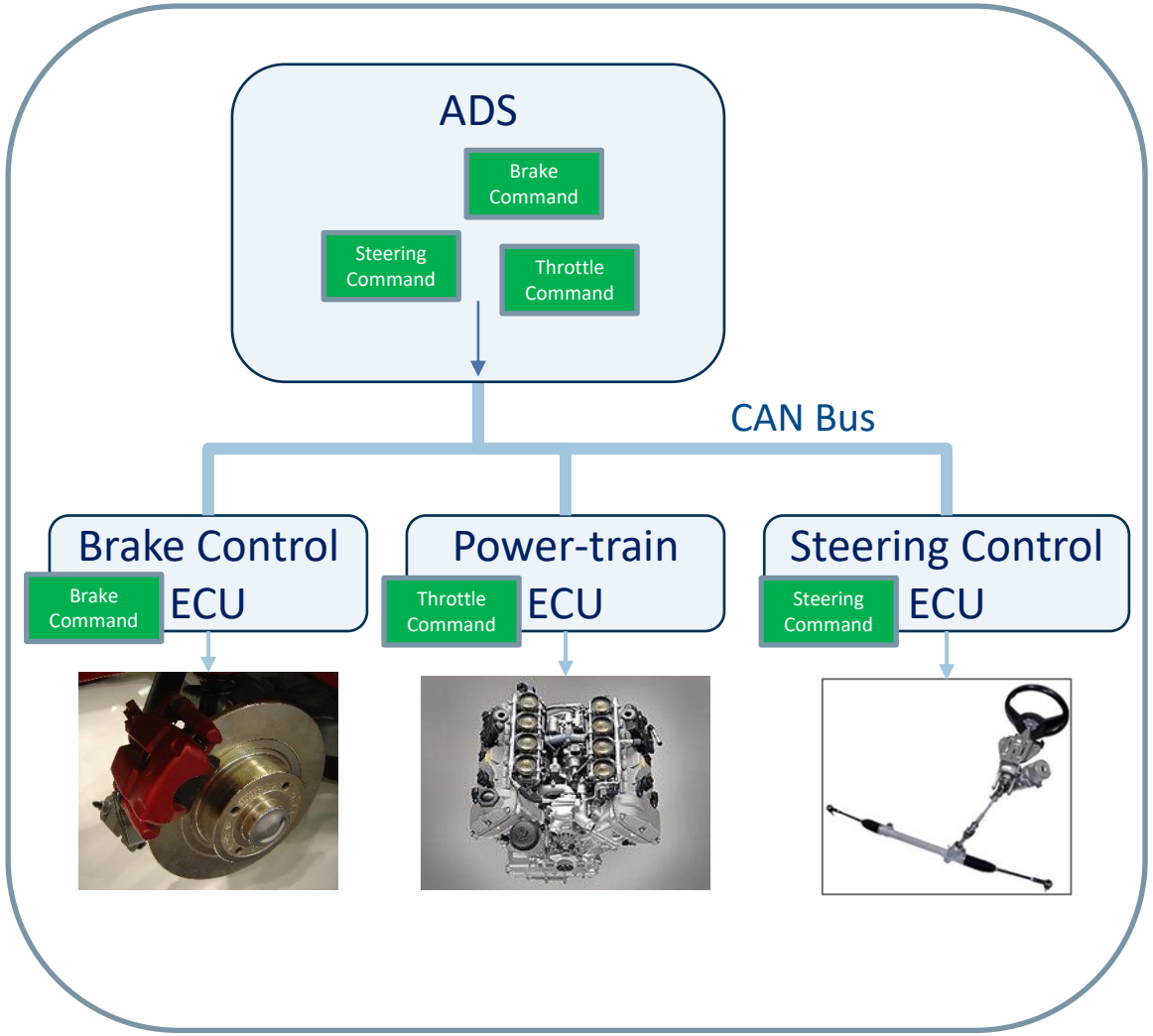
June 2008

Common Attacks against CAN Bus

- Masquerade Attacks
- DoS (Bus-off) Attacks

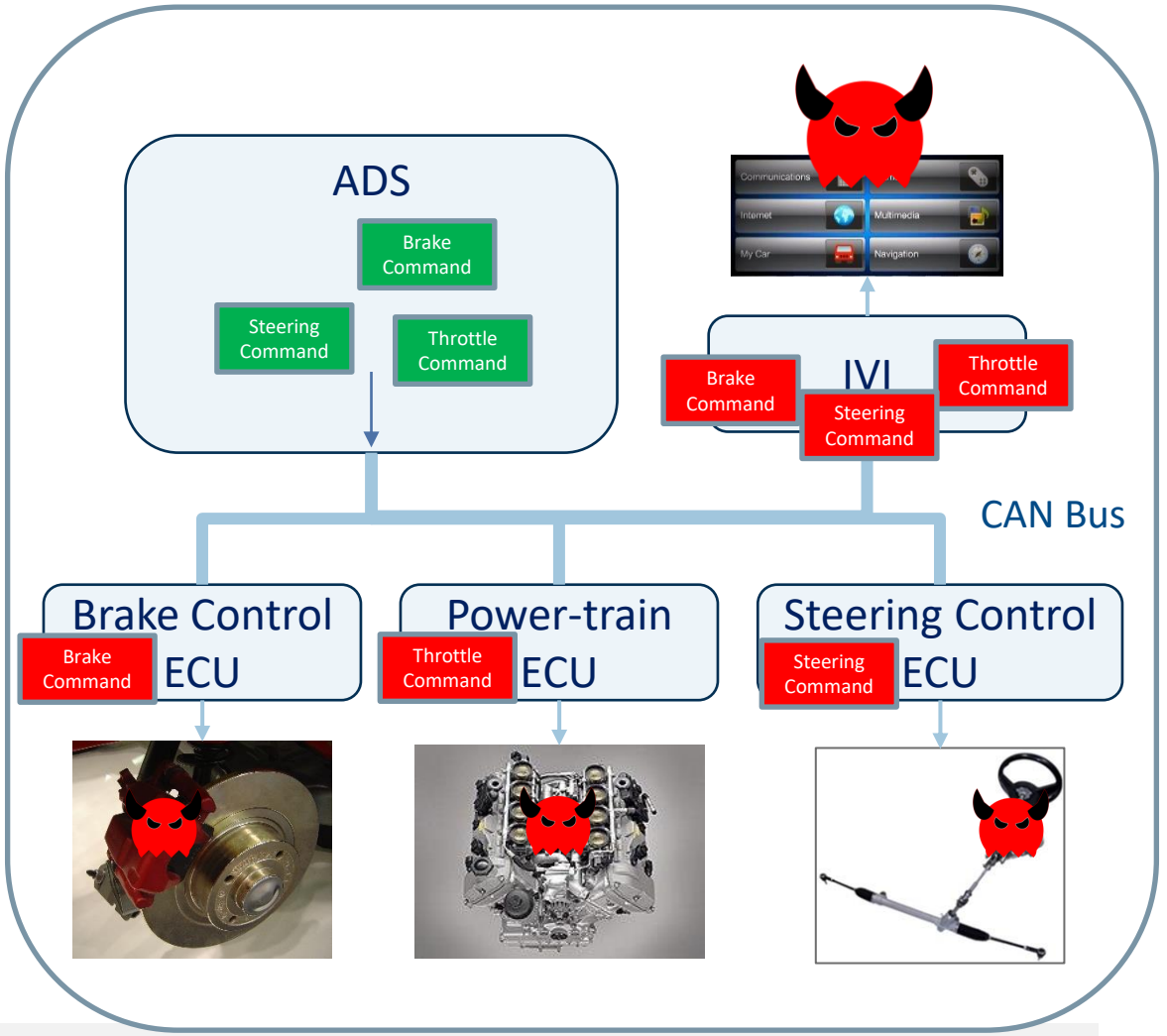
Automotive Example - Actuation

- Autonomous Driving System (ADS) interfaces with the CAN bus to actuate upon the vehicle
- ADS sends control commands to accelerate, brake and steer the vehicle
- Electronic Control Units (ECUs) receives commands and translates them into physical actions
- Similar control architecture and functionality onboard of spacecrafts



Masquerade Attack

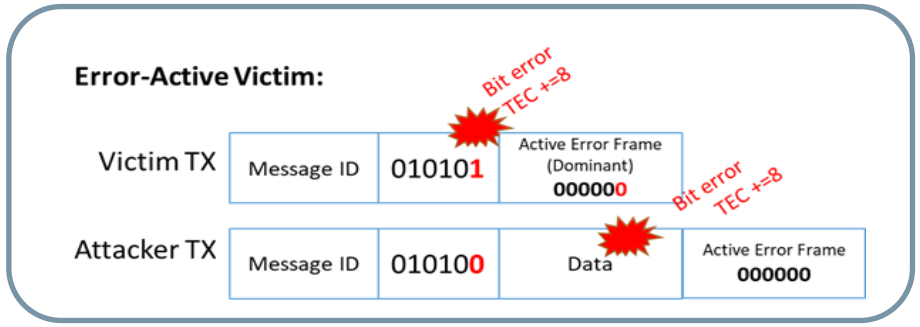
- Attacker gains access of a node (e.g., IVI*)
- Malicious node transmits message identifier (MID) belonging to ADS
- Attacker can fully control the vehicle on behalf of ADS



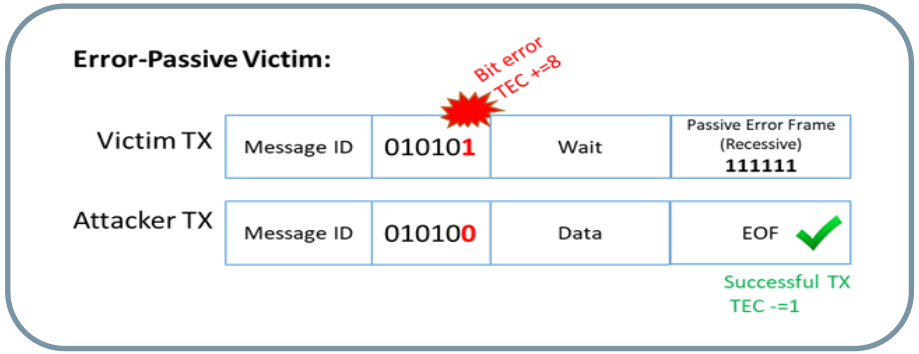
*IVI: In-Vehicle Infotainment

Bus-Off Attack

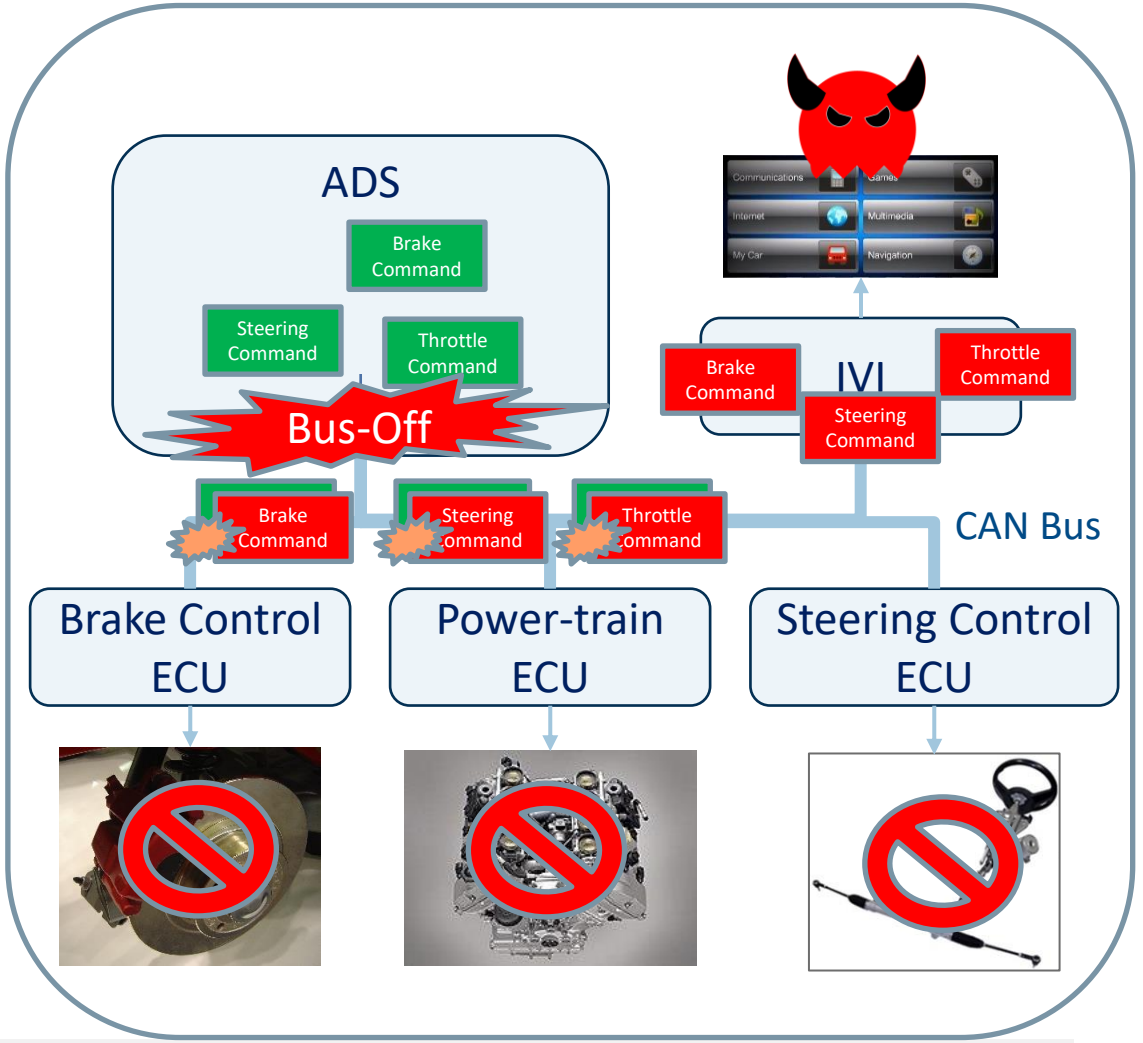
- CCS'16 paper [Cho et al.] introduced bus-off attacks
- Attacker causes controlled collisions to disconnect ADS from CAN bus



Victim and attacker accumulating errors due to the collisions



Victim entering bus-off, while attacker remains active with a successful transmission



Particularities: Automotive

- Local and global threat exposure
  - Physical tampering, including direct access via OBDII port
  - External connectivity via Wi-Fi, Bluetooth, cellular, V2X
- 100’s of ECUs from different manufacturers
- Several co-existing in-vehicle networks
  - CAN, LIN, FlexRay, Ethernet, etc.
- Security solution design constraints:
  - Real-time response and accuracy are critical
  - More relaxed power budget
  - Higher processing capabilities
- Can be brought to a garage for maintenance
- Average age of automobiles in USA: ~13 years*

Source: Kaspersky

OBDII port allow direct access to CAN buses

* Bureau of Transportation Statistics 2023

Particularities: Space

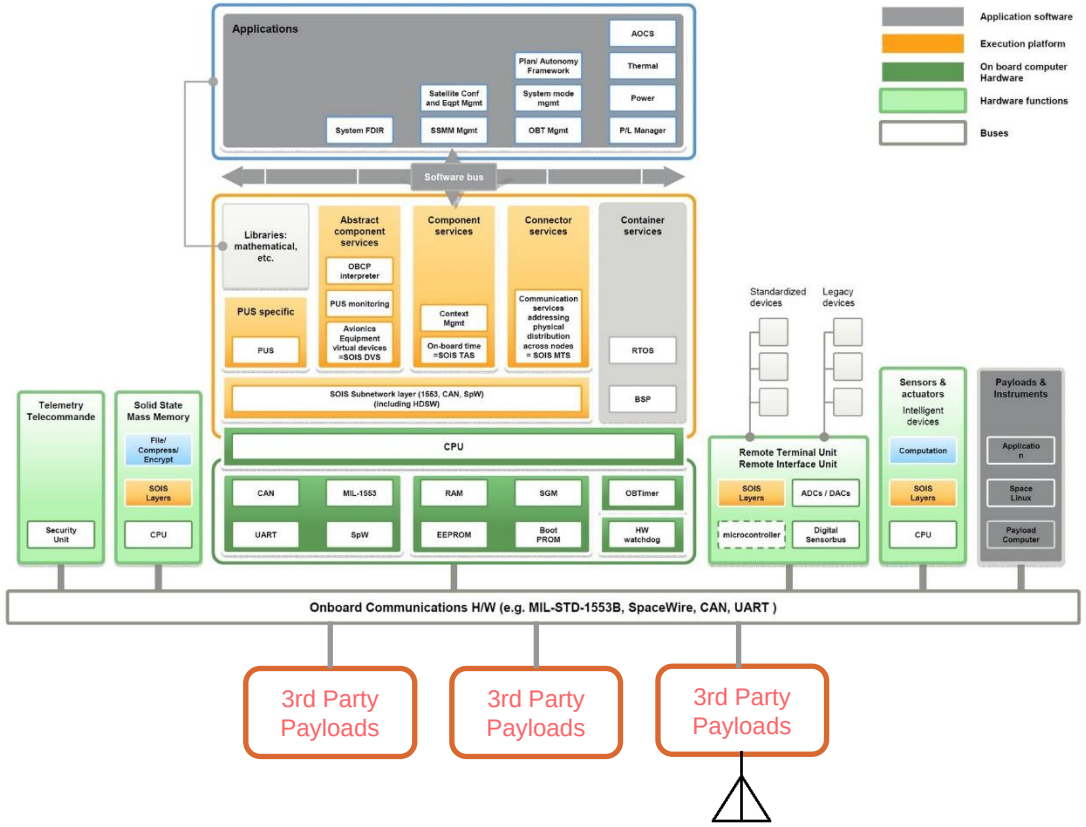
- Global threat exposure
- Physical attacks possible pre-launch, but infeasible post-launch
- Less components from a lesser number of manufacturers
- Relatively small number of components and networks onboard
- Much more constrained environment (power, computational capabilities)
  - Constrains the design space of possible security solutions
- So far, we still don't have a garage in space for maintenance 😀
- Longer lifespan
  - Telecom satellites: 10-15 years
  - International Space Station (ISS) (1998): 25 years
  - Hubble (1990): 34 years
  - Voyager (1977): 47 years
    - Diffie-Hellman paper published in Nov 1976

Source: NASA

Voyager spacecrafts: launched in 1977, currently 14.48 billion miles from Earth

Commonalities

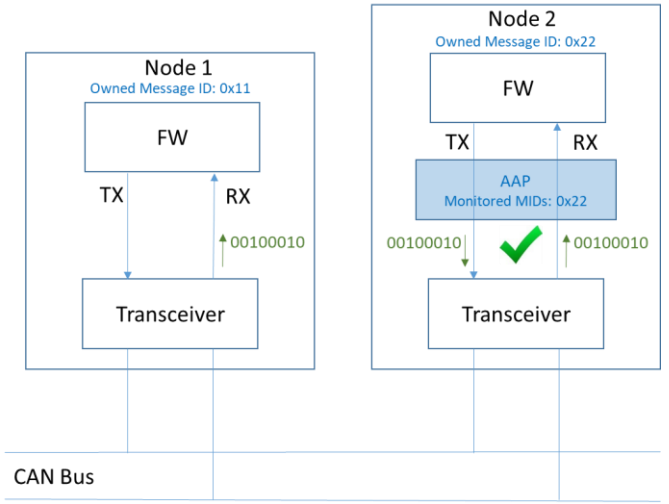
- Real-time systems demanding ultra-low latency of security solutions
- KISS *(“Keep it simple, stupid”)* type of security solutions
  - Complex mechanisms are usually “no-go”
  - Minimal requirements
  - Transparent operations
- External connectivity as entry points for attacks
- Ever-expanding attack surface
  - Especially when hosting 3rd party payloads



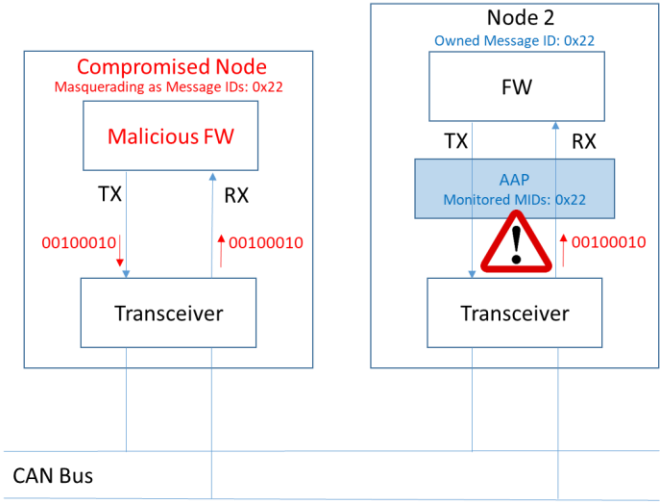
Expansion of attack surface through hosted 3rd party payloads

Real-Time Masquerade Attack Detection and Prevention

- Protect system from impersonation on the CAN bus
- Strategy: Continuous bus monitoring from the perspective of the protected ECU
- Detection of message in the bus owned by the protected ECU when it has not transmitted it
- Remedial action to neutralize the message in real-time
- Avoid consumption of malicious message by the remaining of the system



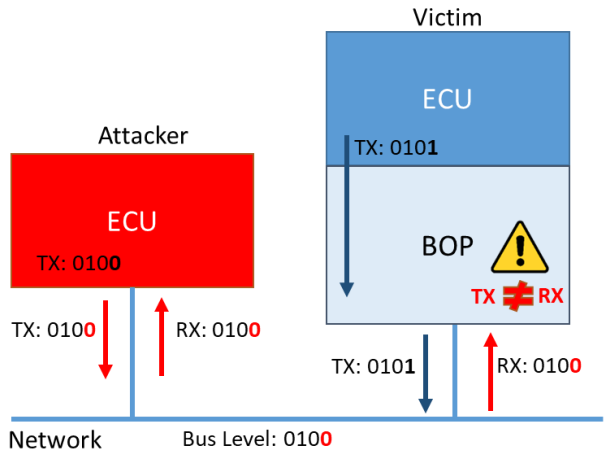
Authentic conditions



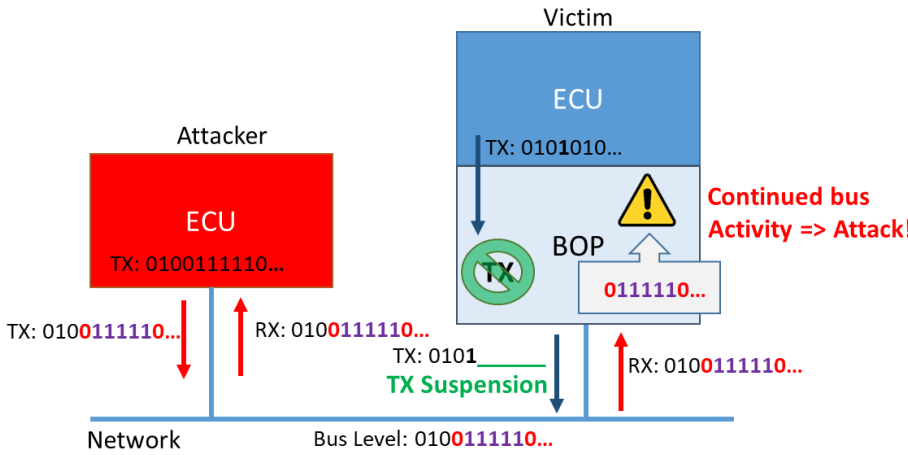
Masquerade attack detected

Real-Time Bus-Off Attacks Detection and Prevention

- Strategy: Not immediately to follow the attacker-induced fault-containment protocol. Rather, differentiate between faults and attacks.
- Detect bit mismatches, temporarily suspend further transmissions of the protected node
- Determine whether bit-mismatch was caused by a fault or attack
- Revert bus-off attack against the attacker
  - Bit corruption of the attacker's messages



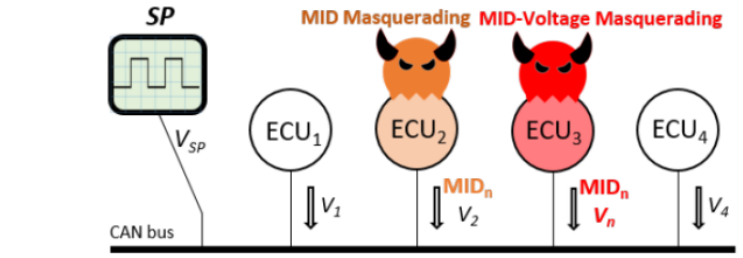
Mismatch detected



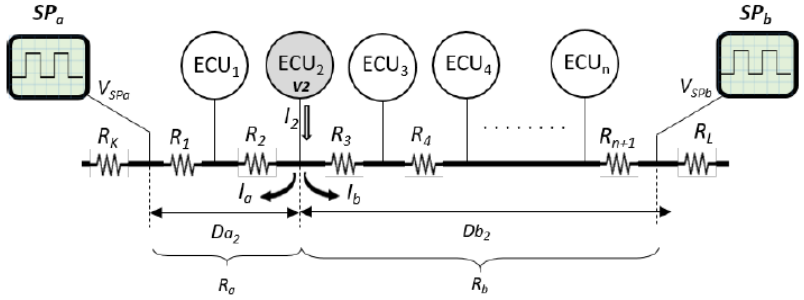
Bus-off attack detected

Masquerade Attack Detection through ECU Voltage Fingerprinting

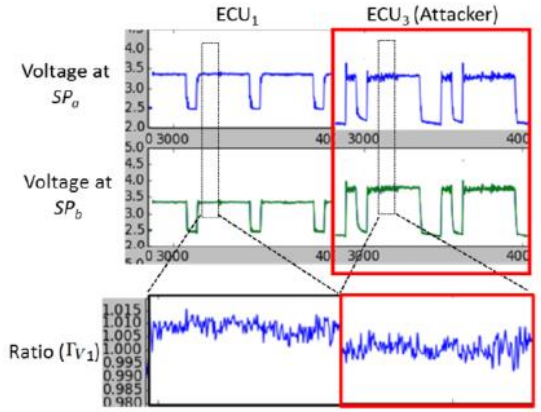
- Focus on masquerading attacks
- Traditional Message Identifier
- Message Identifier+Voltage Masquerading
- Strategy: Prevent masquerading by profiling voltages of transmitting ECUs
- Two voltage sampling points
- Physical location of the ECUs determines specific voltage ratios at the sampling points
- Attacker unable to forge voltages to satisfy both points simultaneously
- Overall F1-score: 99.4%



Attackers on CAN bus



Voltage Sampling



Voltage ratio

Summary

- CAN Bus is widespread and reliable but presents several security challenges.
- Real-time and performant security solutions are hard to build.
- Automotive and Space domains have their own particularities but share a number of commonalities that must be addressed when building a secure system.
- Automotive presents a larger attack surface, in which ML and HW-based solutions can be effective to counteract attacks in real-time.
- Spacecrafts require careful consideration of the expanding threat surface due to 3rd party payloads and may require more efficient solutions due to onboard constraints.

Thank You!