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Passive and Active Attacks on TPMS systems

Threats of Long-term surveillance and fast attacks to Tire Pressure Monitoring Systems

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Introduction

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Working at the intersection of AI and Cybersecurity

Experience in Spectrum Sensing Networks and Localization

Also worked with Autonomous vehicles



What are we talking about?

- **Tire Pressure Monitoring Systems (TPMS):**
  - Designed to increase vehicle safety
  - Have been mandatory for more than a decade
- Cars have complex software stacks:
  - **Cyberattacks** on them are very common nowadays
  - Since **July 2022**: Europe requires cybersecurity certificates
  - Against attacks that: reveal identity, location, and so on
  - TPMS not included in this



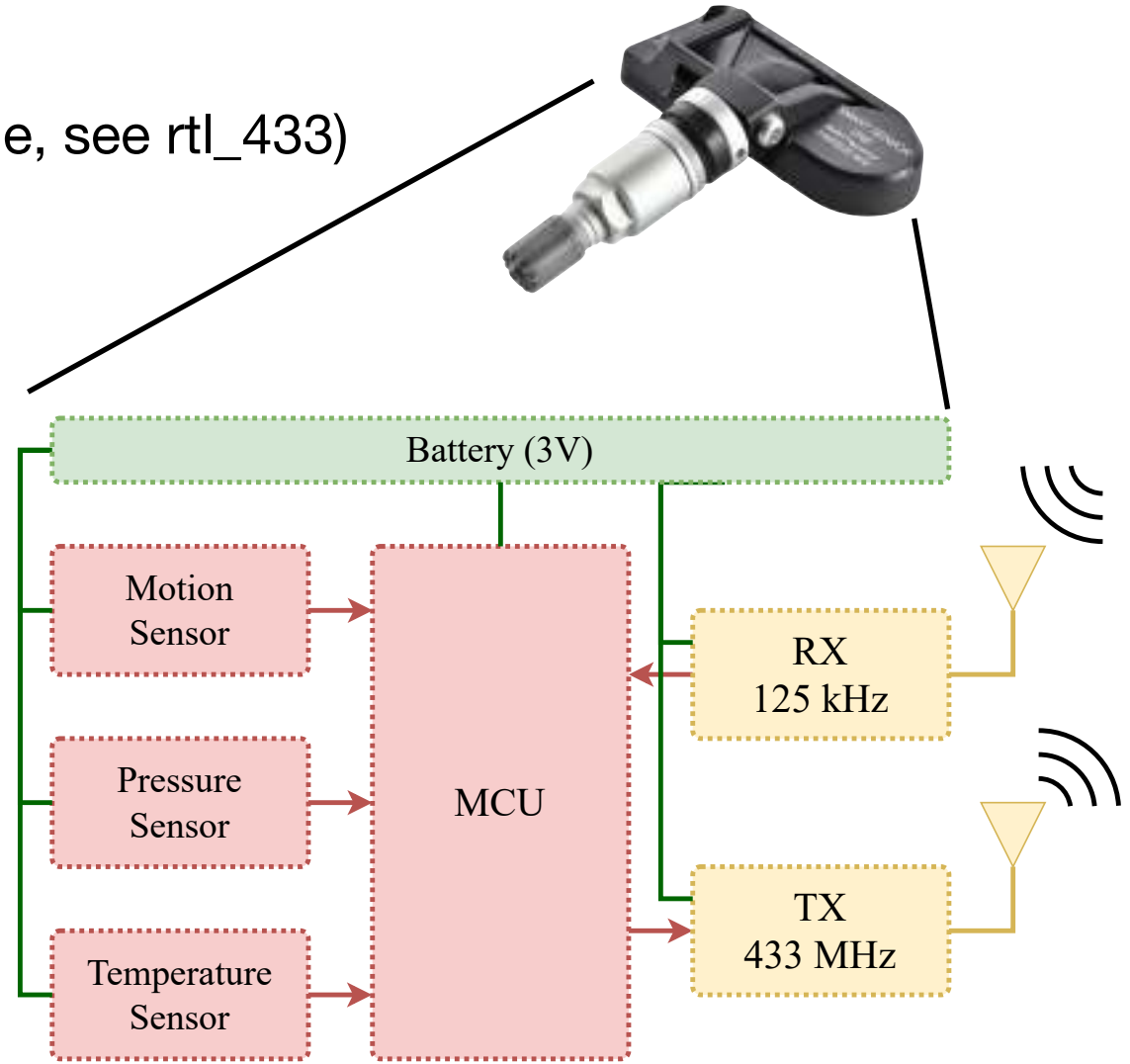
TPMS Families

- **Indirect TPMS (iTPMS):**
  - Based on rotation of wheel
  - Less accurate
  - Favored by: VW Group, GM
- **Direct TPMS (dTPMS):**
  - Pressure and Temperature
  - More accurate
  - Favored by: Toyota, Ford, OEM
- **Other:**
  - Bluetooth-based
  - More accurate
  - Favored by: Tesla, Pirelli

Direct TPMS Primer

- On the **inside** of a TPMS sensor:
  - Battery-powered devices
  - Protocols are proprietary (but easily reversible, see rtl_433)
  - Simple modulations (ASK/FSK @ 433 MHz)

- They have **different modes** of operation:
  - In theory, many only transmit when car movement starts. Then every 30-60 seconds
  - When parked they should not transmit
  - By sending a 125 kHz signal, it is possible to trigger a transmission

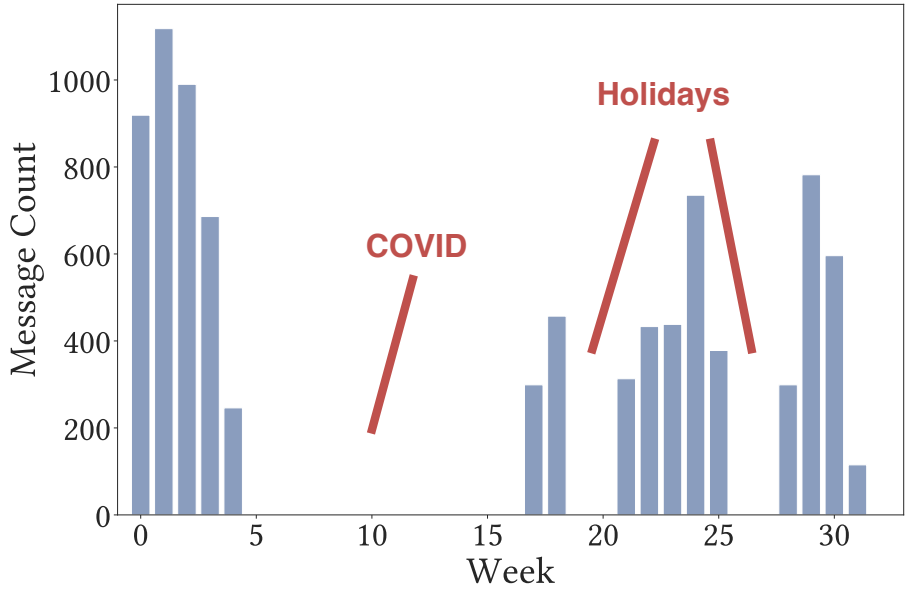


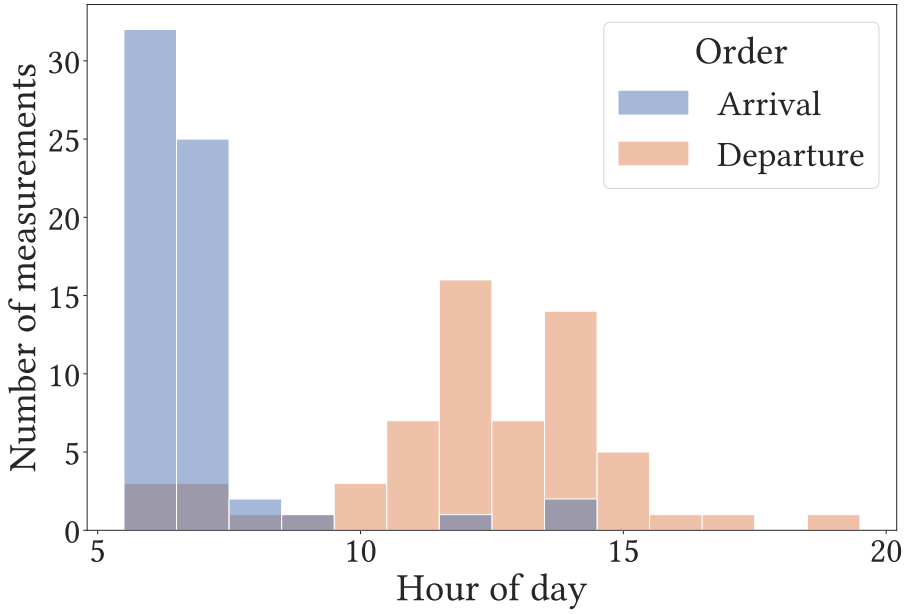
Sensor ID (32 bit) | Pressure (kPa) | Temperature (C)

From Passive Monitoring…

Why did we start with this

- IT Director and a Toyota
- Doing unrelated measurements we noticed some things:
  - We could easily track our director's schedule
  - After some time, we could learn when he had holidays, random absences, …
- We asked ourselves:
  - Is it actually feasible to track cars with dTPMS?
  - What patterns can we learn?

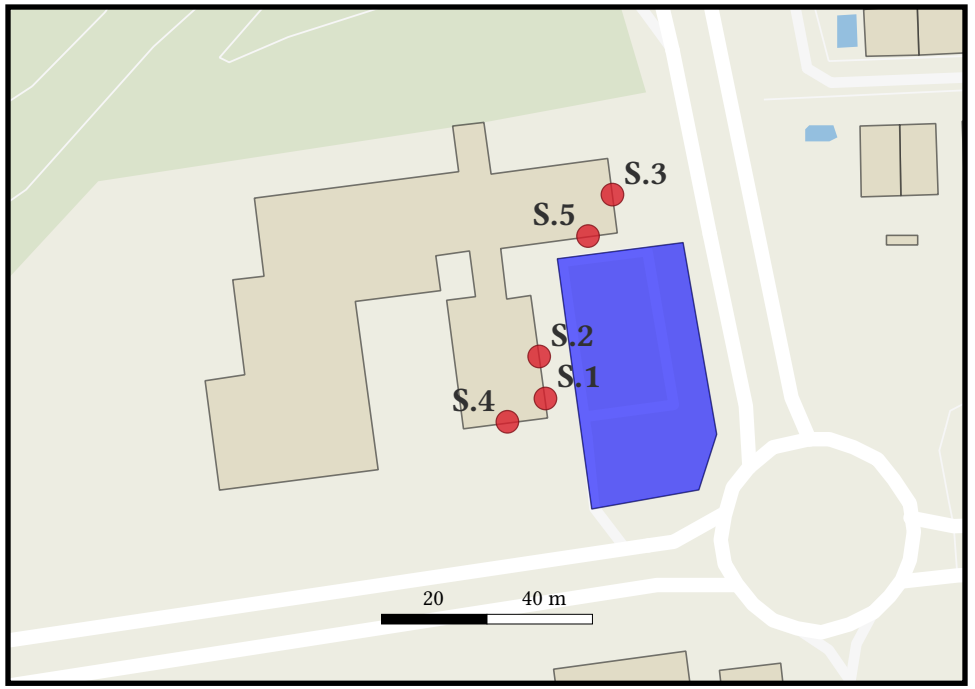




Setup

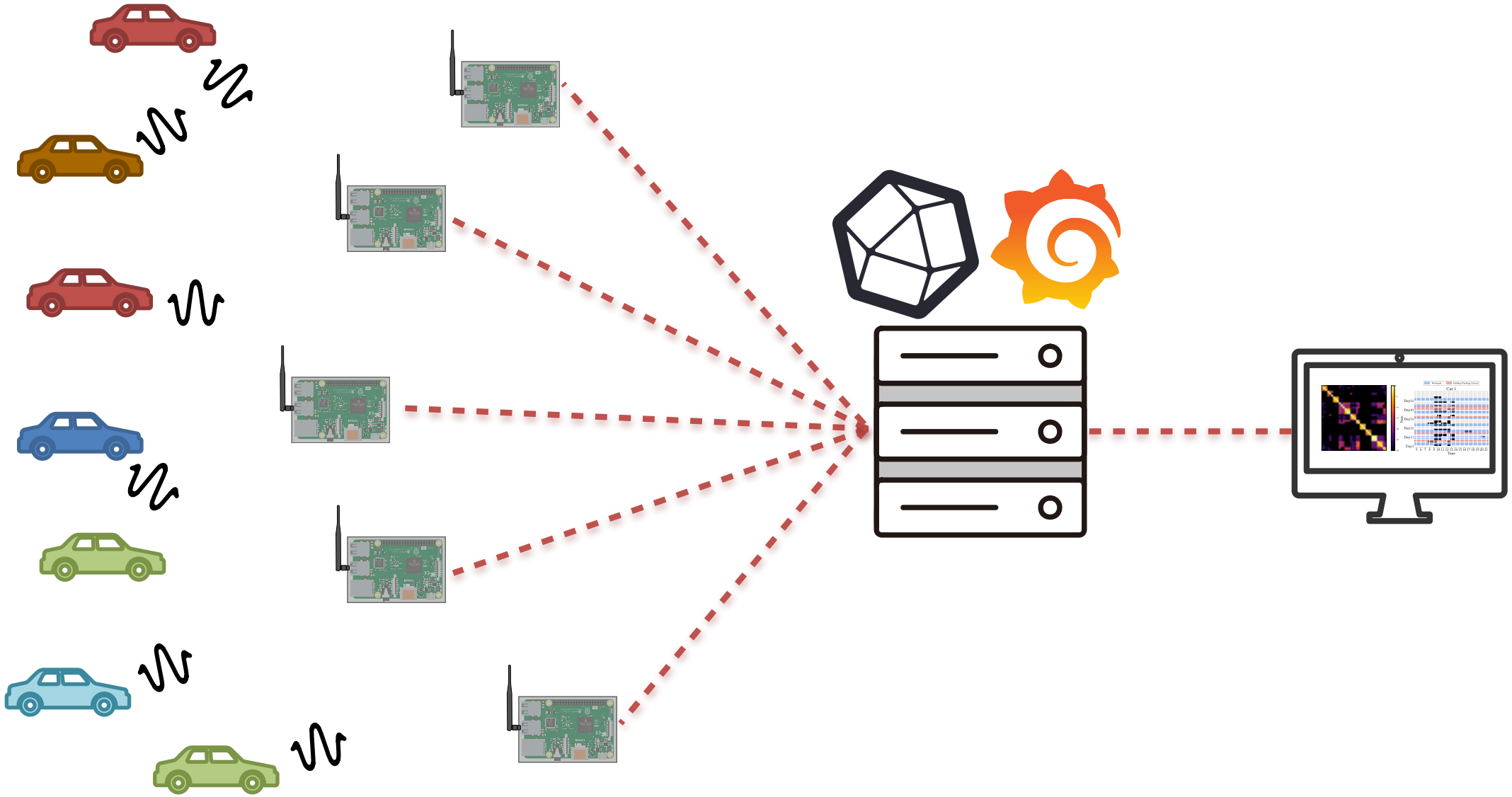
- Hardware:
  - RTL-SDR + 433 MHz Antenna
  - Raspberry Pi
  - Internet Connectivity + Power
- Software:
  - **rtl_433** + custom modules
- Infrastructure:
  - Sensors send data to Database
- We can now capture millions of messages





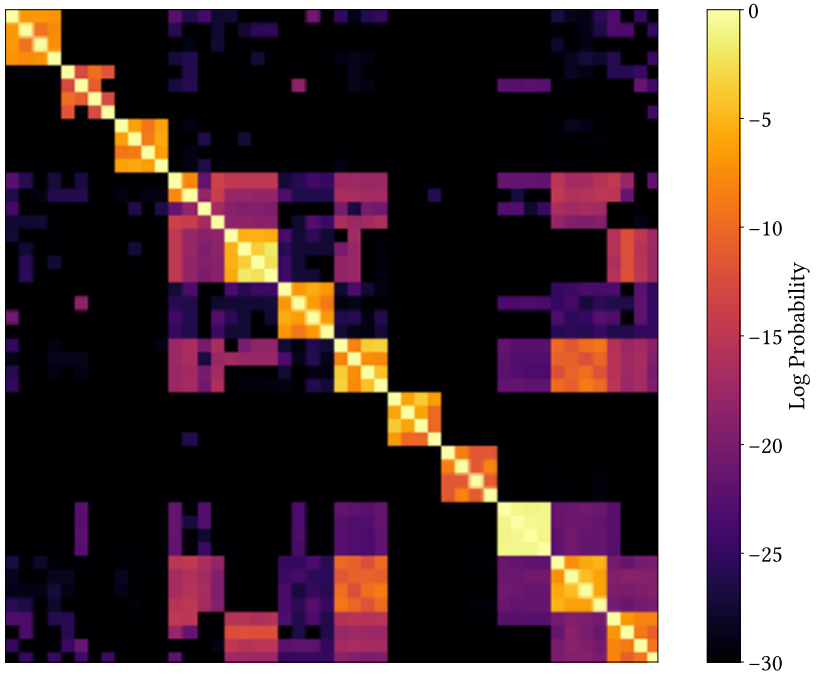
Site name	Recording Hours	Measured IDs	Recorded IDs
Receiver 1	655	476248	17621
Receiver 2	655	412905	22706
Receiver 3	655	514484	3230
Receiver 4	653	753327	7708
Receiver 5	362	356526	24123

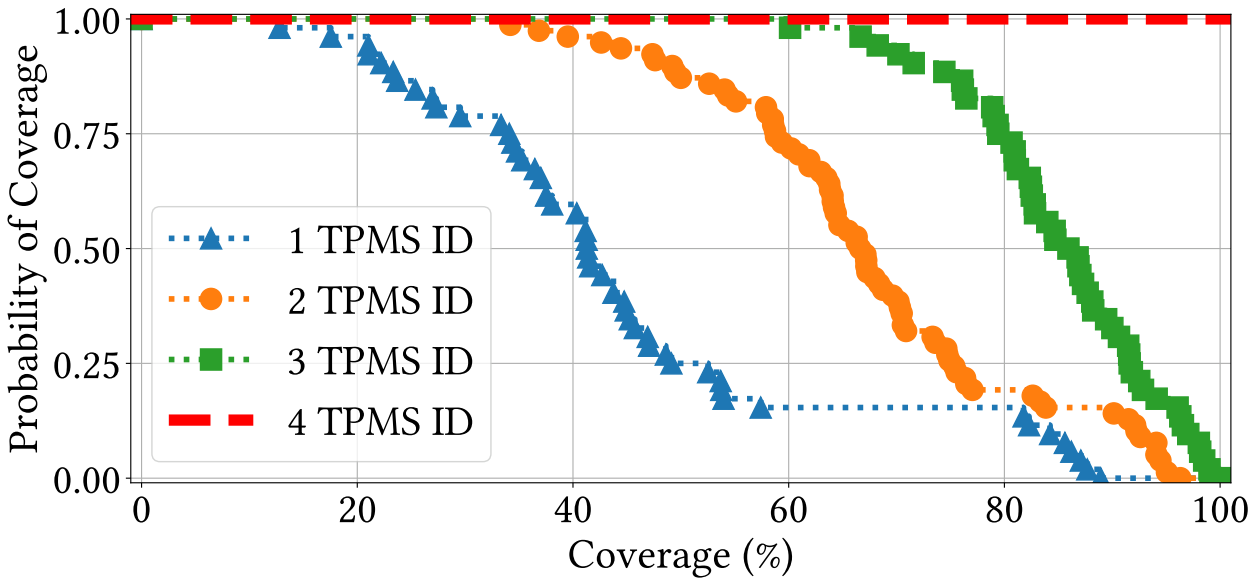
Infrastructure



Car Matching

- If we just capture a single ID:
  - We cannot capture all the times a car passes by
- We develop methods to correlate IDs of same car:
  - Cross-Correlation
  - **Jaccard Index**
- We design a robust matching:
  - To capture transitivity between IDs
  - Even in narrow time windows we capture cars

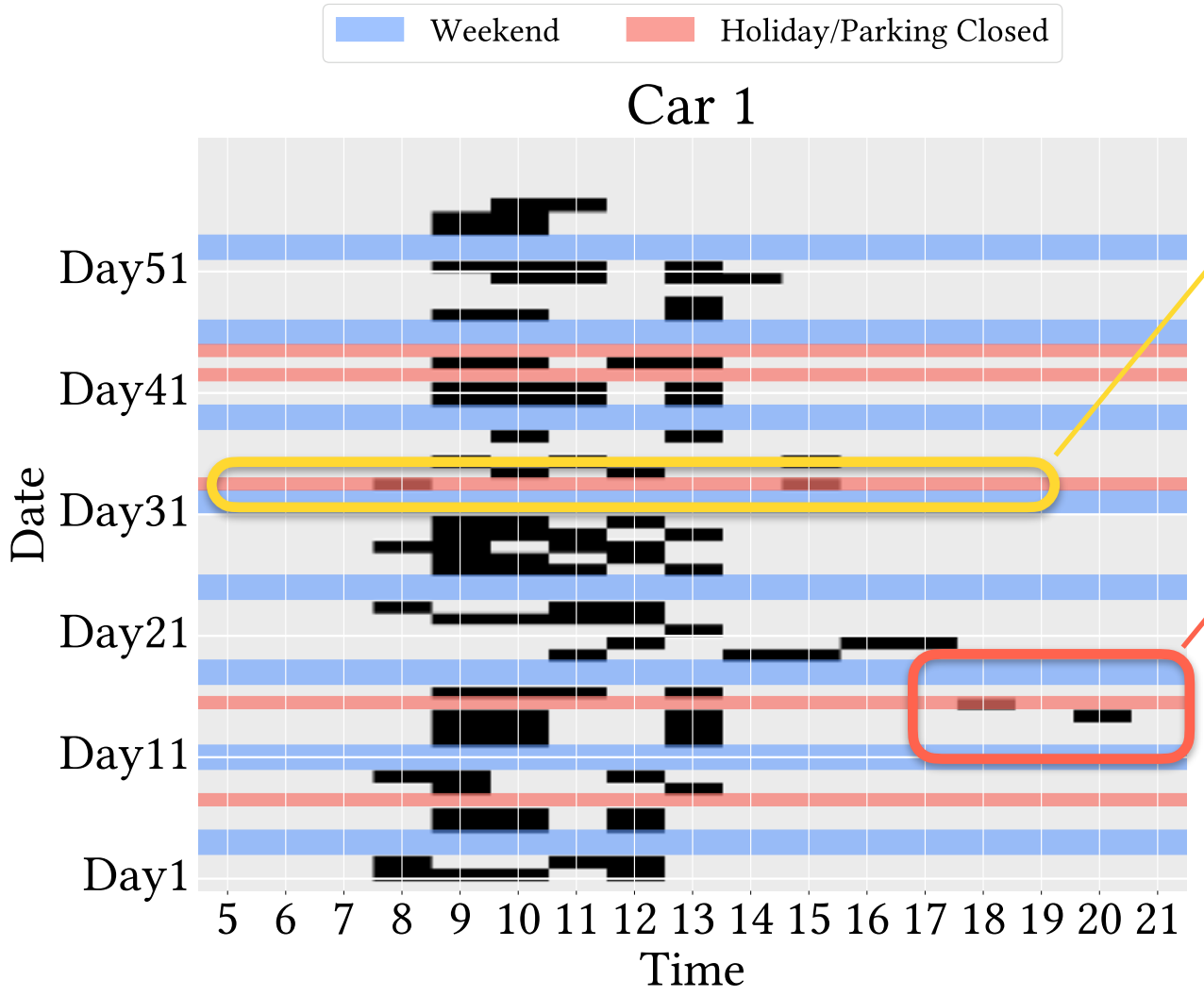




Method	Agg. (s)	Naive Match	Robust Match	Comp. Time (s)
Xcorr	5 sec.	5	9	2.0970
	10 sec.	6	10	1.5616
	30 sec.	8	11	1.1017
	1 min.	8	12	0.8708
	2 min.	10	12	0.6534
Jaccard	5 sec.	7	10	34.1570
	10 sec.	9	12	23.7702
	30 sec.	10	12	21.1729
	1 min.	11	12	19.1987
	2 min.	11	12	18.2871

Long-Term Patterns (I)

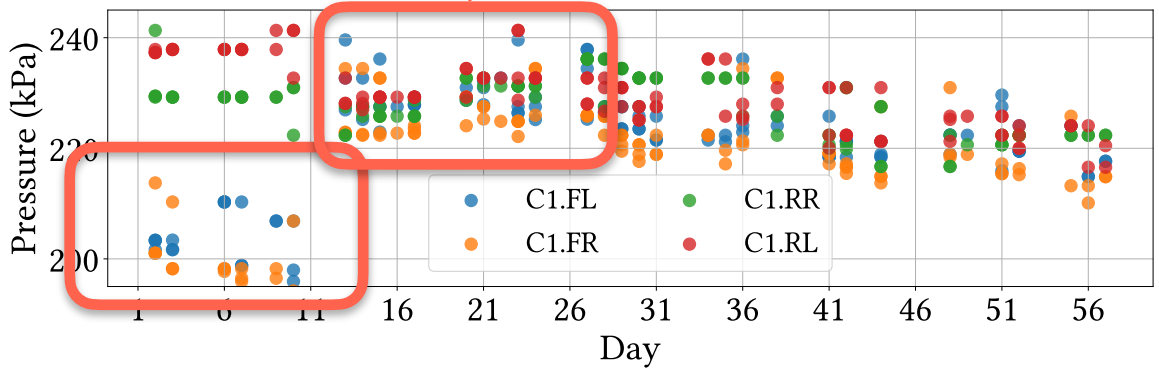
- Car 1: Part-Time Student



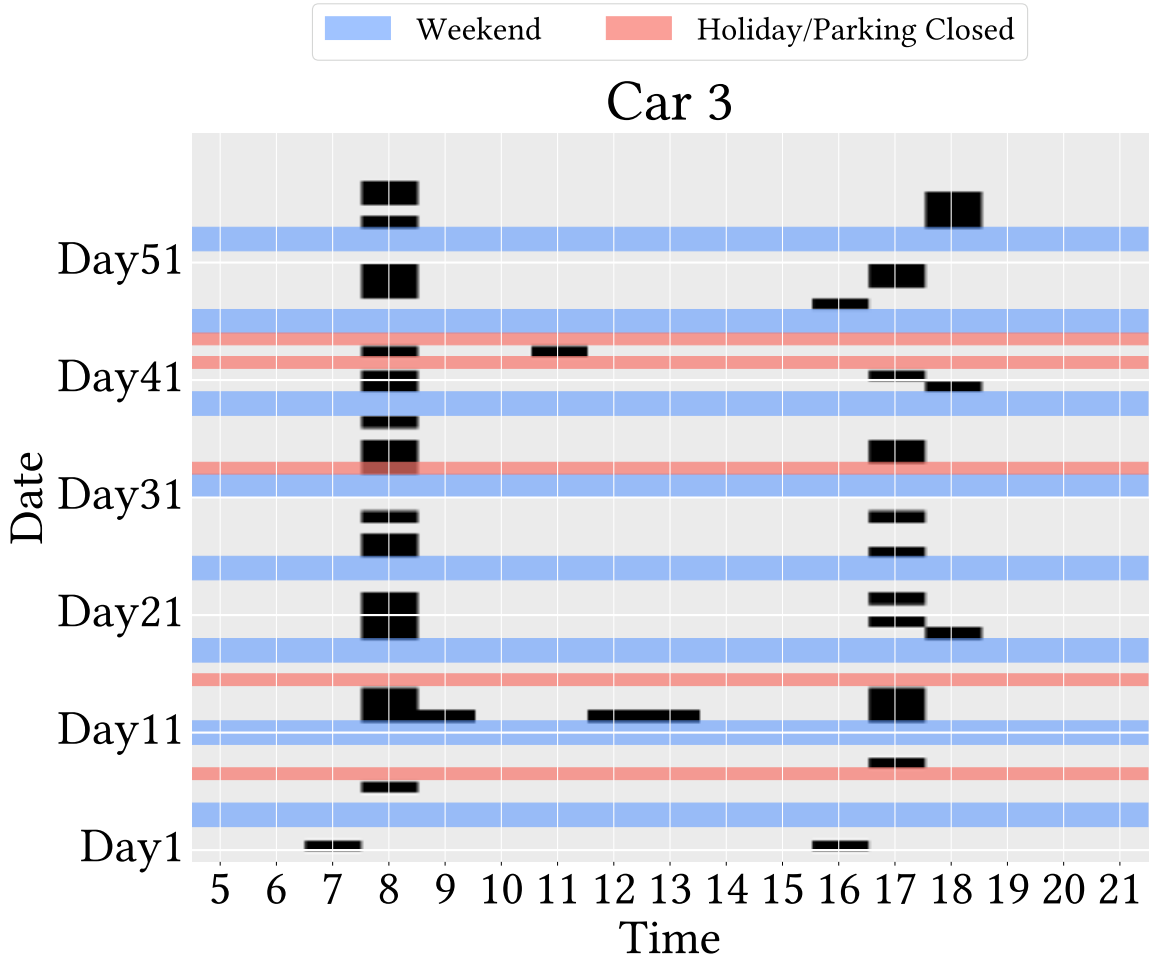
No Holidays

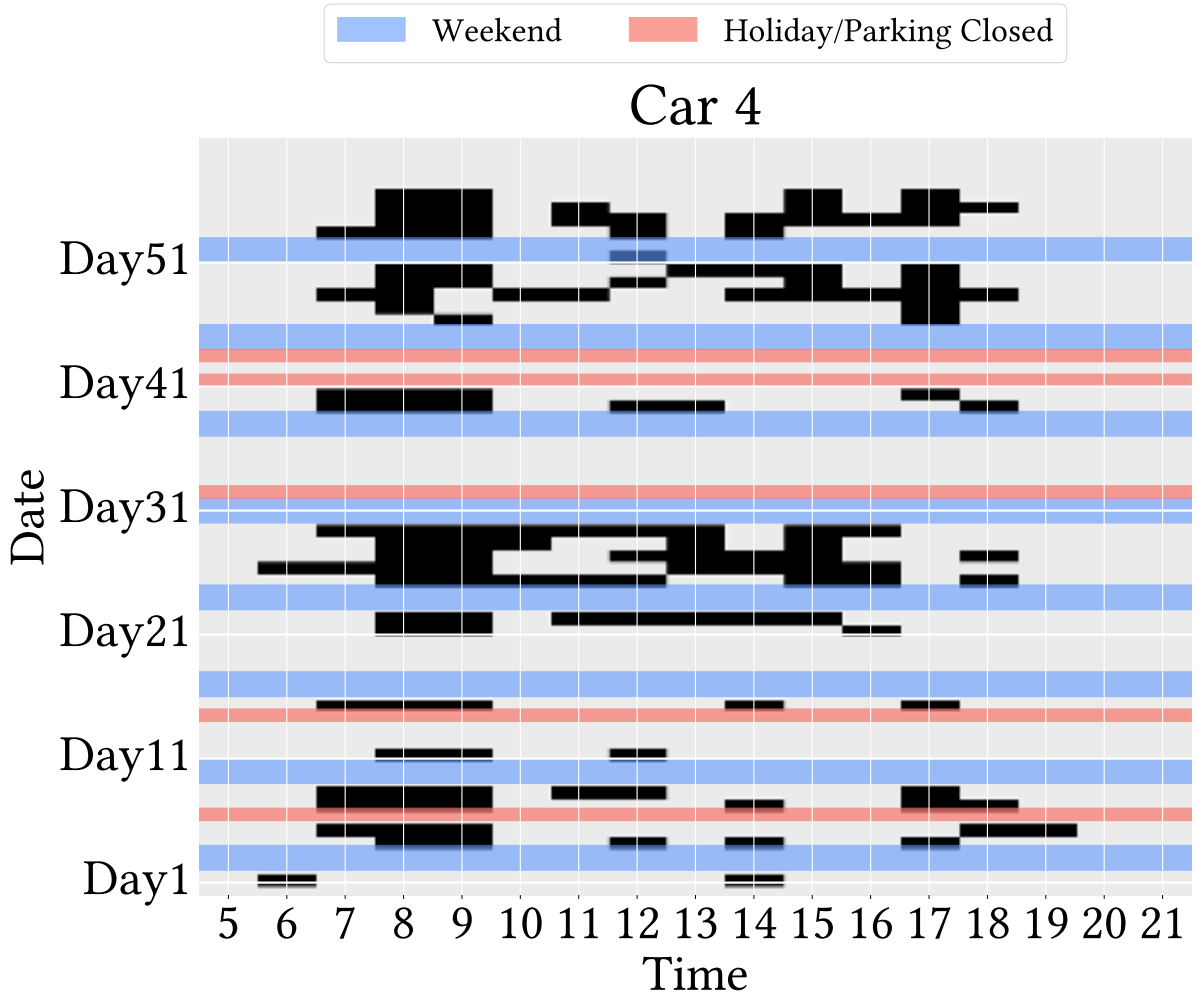
University Course

Taking care of our participants



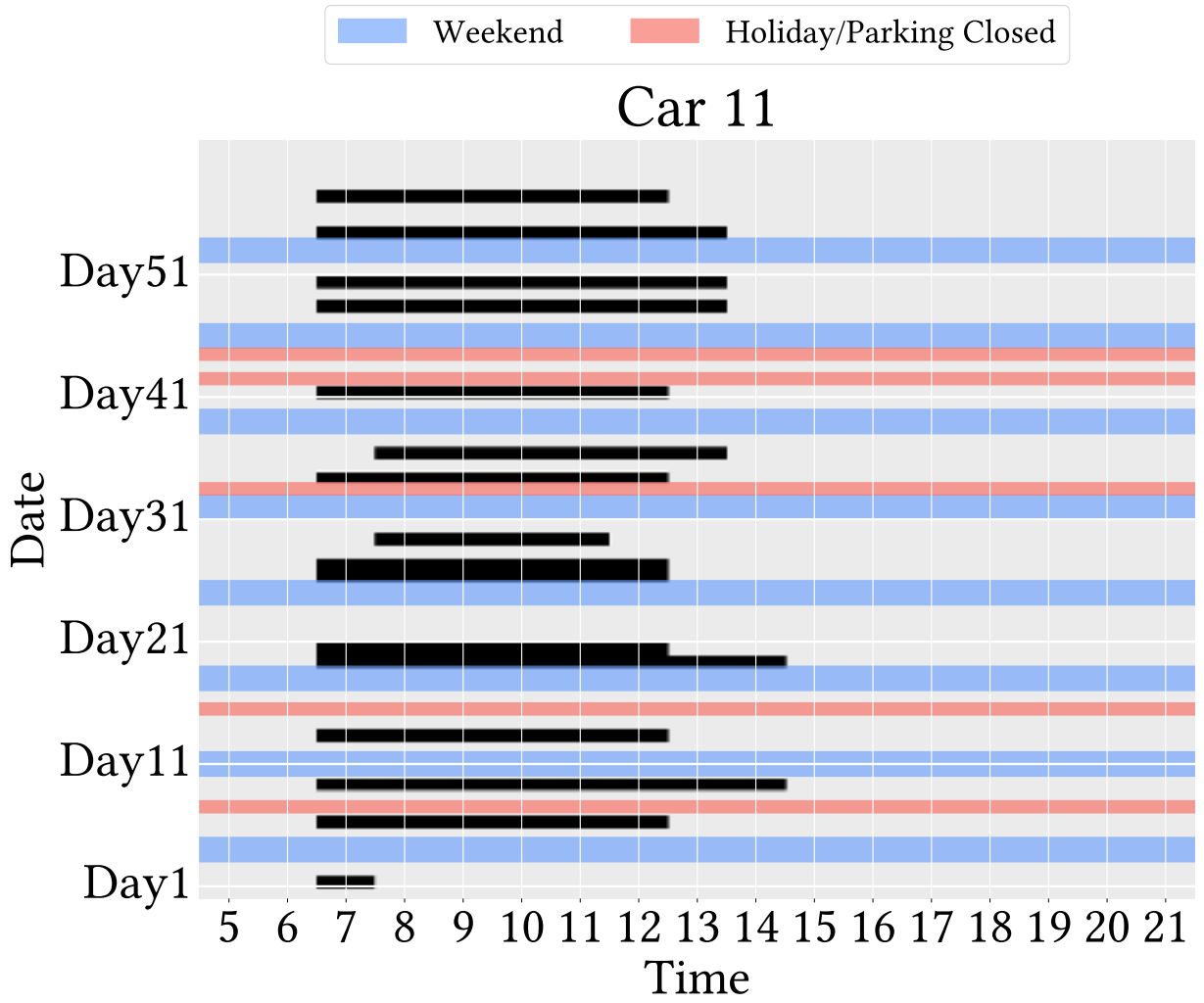
Long Term Patterns (II)





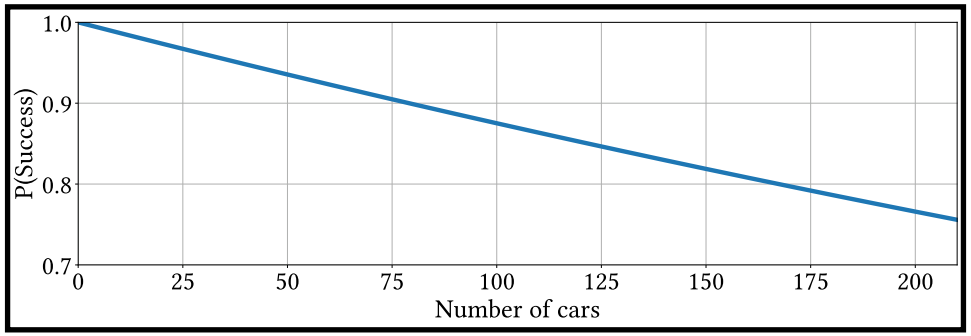
Long-Term Patterns (III)

- Some brands are chattier than others:
  - Some sensors only transmit when the car starts moving
  - Others transmit from time to time even when stopped
  - The last type transmits at all times in regular time periods
- In our research:
  - All Toyotas that we looked into transmit at least every 15 min even when stopped
  - High-Transmit power as well

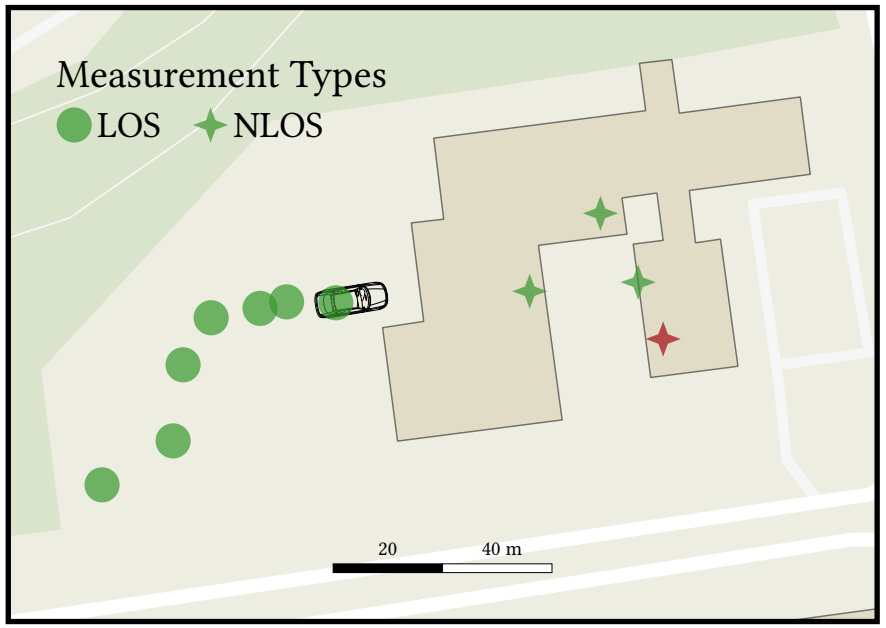


What happens with more/moving/faraway cars

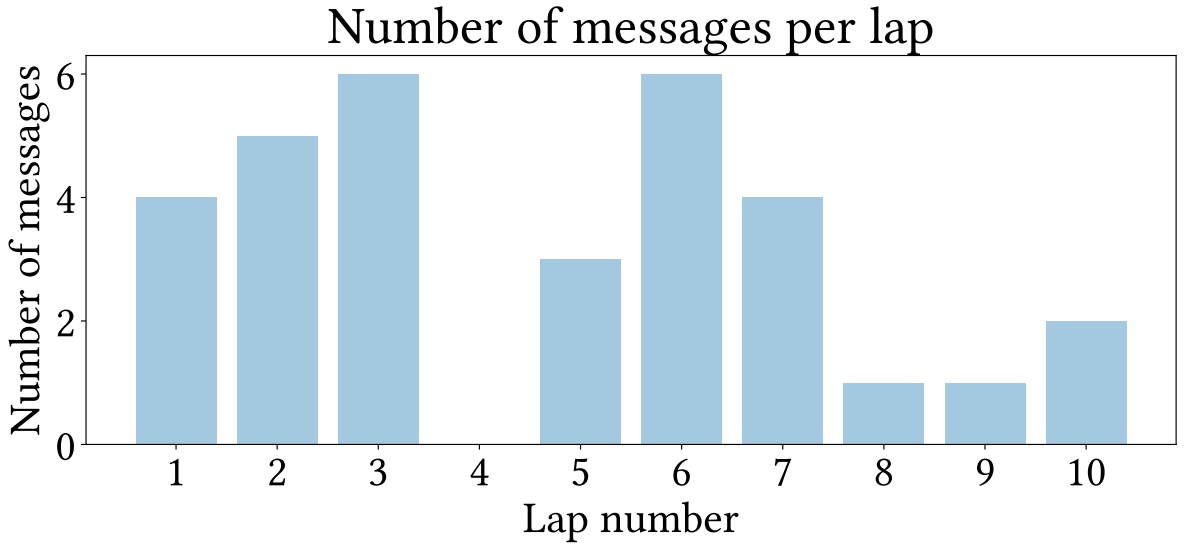
- We estimate that 1 sensor can track:
  - Around 200 cars can be tracked in 30 second windows



- We estimate that 1 sensor can track:
  - Much more than 60 m even in NLOS



- Up to 50 kph:
  - We can capture messages ‘easily’



…To active attacks

Study: Renault ZOE (2021)



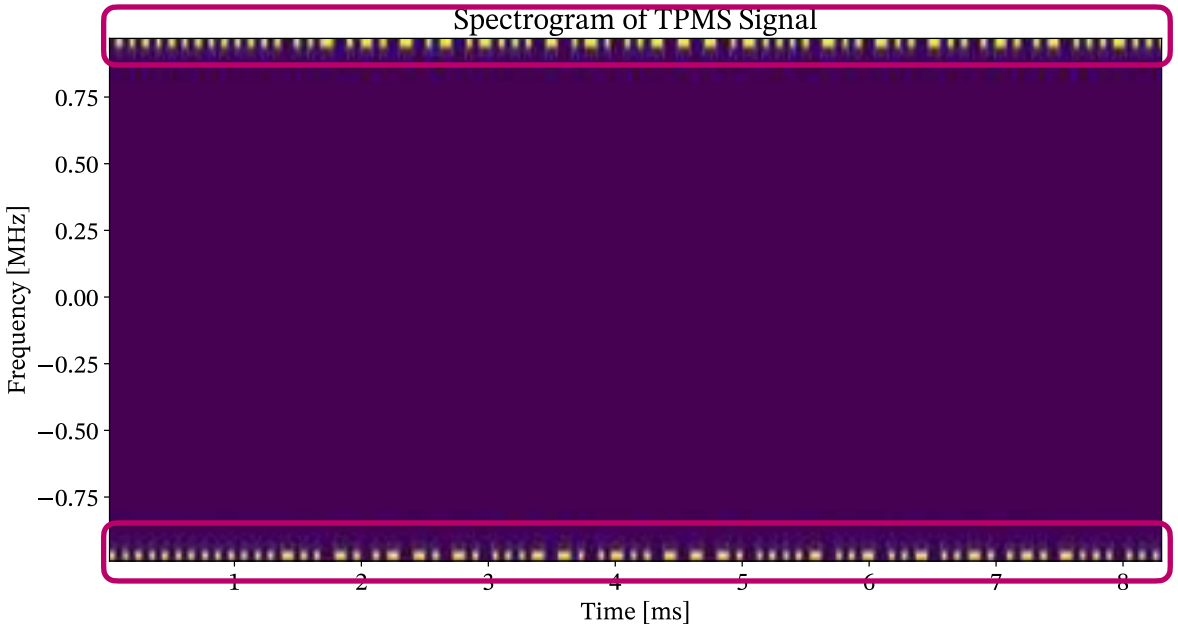
- **Renault** uses **dTPMS** technology:
  - Modulation is widely known
  - We build a signal spoofer to test how the car responds to different messages
- Some of the characteristics:
  - Frequency: 433 MHz
  - Modulation: 2-FSK + PWM
  - Manchester Encoding
  - Bit duration: 52 µs
  - Main fields:
    - Flags (1 byte)
    - ID (3 bytes)
    - Pressure (2 bytes)
    - Temperature (1 byte)
    - Unknown (2 byte)

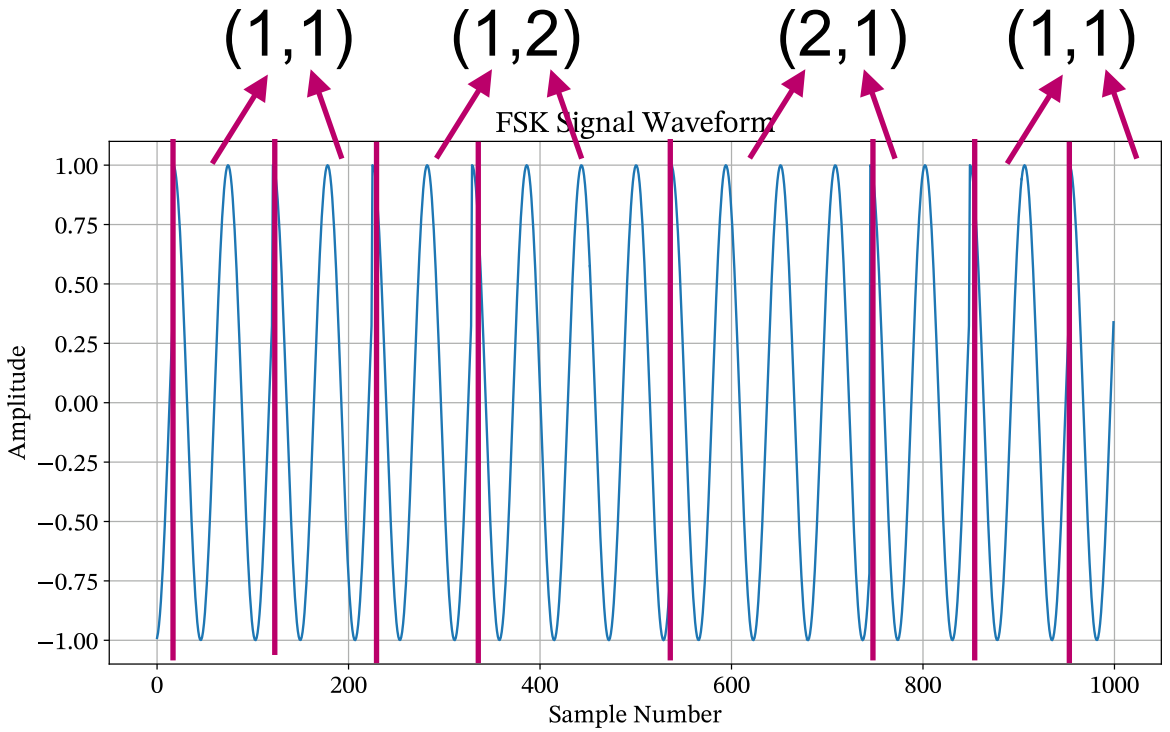
Toolset: SDR with RX/TX capabilities



From PHY to Pulses

- 2-FSK generates a sequence of pulse-gaps:
  - We decode FSK and generate tuples





From Pulses to the message

From a sequence of tuples:
[(1,1),(1,2),(2,1),(1,1),…]

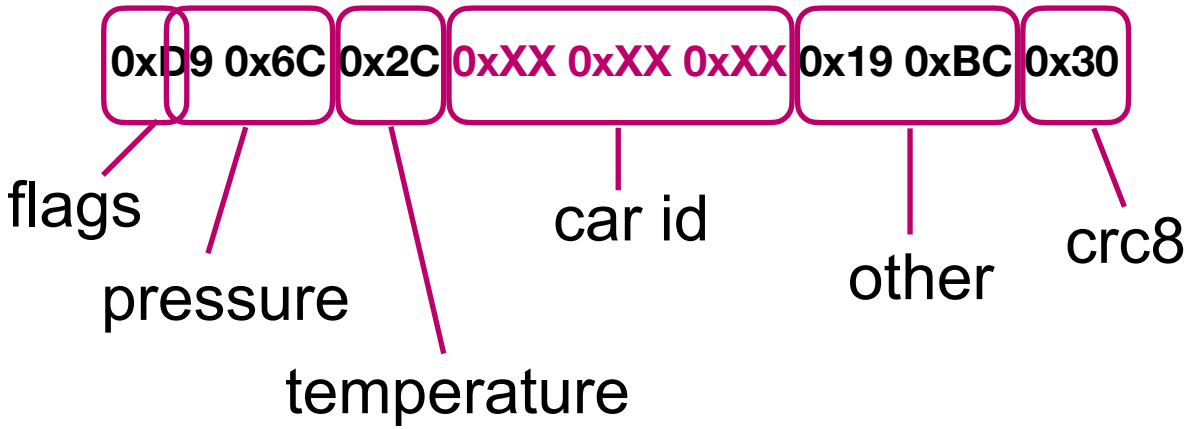
We generate a sequence of bits:
1010011010…

We invert the sequence:
0101100101…

Manchester Decoding:
11011…

We find the preamble:
For Renault cars, it is **0xaa, 0xa9**

Final Message



How to Transmit?

We reverse the flow 😊

Producing Errors



Wrapping up…

What are the conclusions?

- dTPMS systems are widely vulnerable to all sorts of attacks:
  - Given the current status of SDR hardware attacks that combine passive monitoring and active spoofing are quite feasible
- Passive Monitoring can affect some brands (Toyota) more than others
- What solutions exist:
  - Ditch dTPMS (not feasible for all cars in the streets)
  - Add rolling IDs (same as car key fobs)
  - Add encryption (research has shown it is possible)
- We provide 2 repositories to replicate this research

tpms-analysis



tpms-tools



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