Security and Privacy Vulnerabilities of In-Car Wireless Networks: A Tire Pressure Monitoring System Case Study

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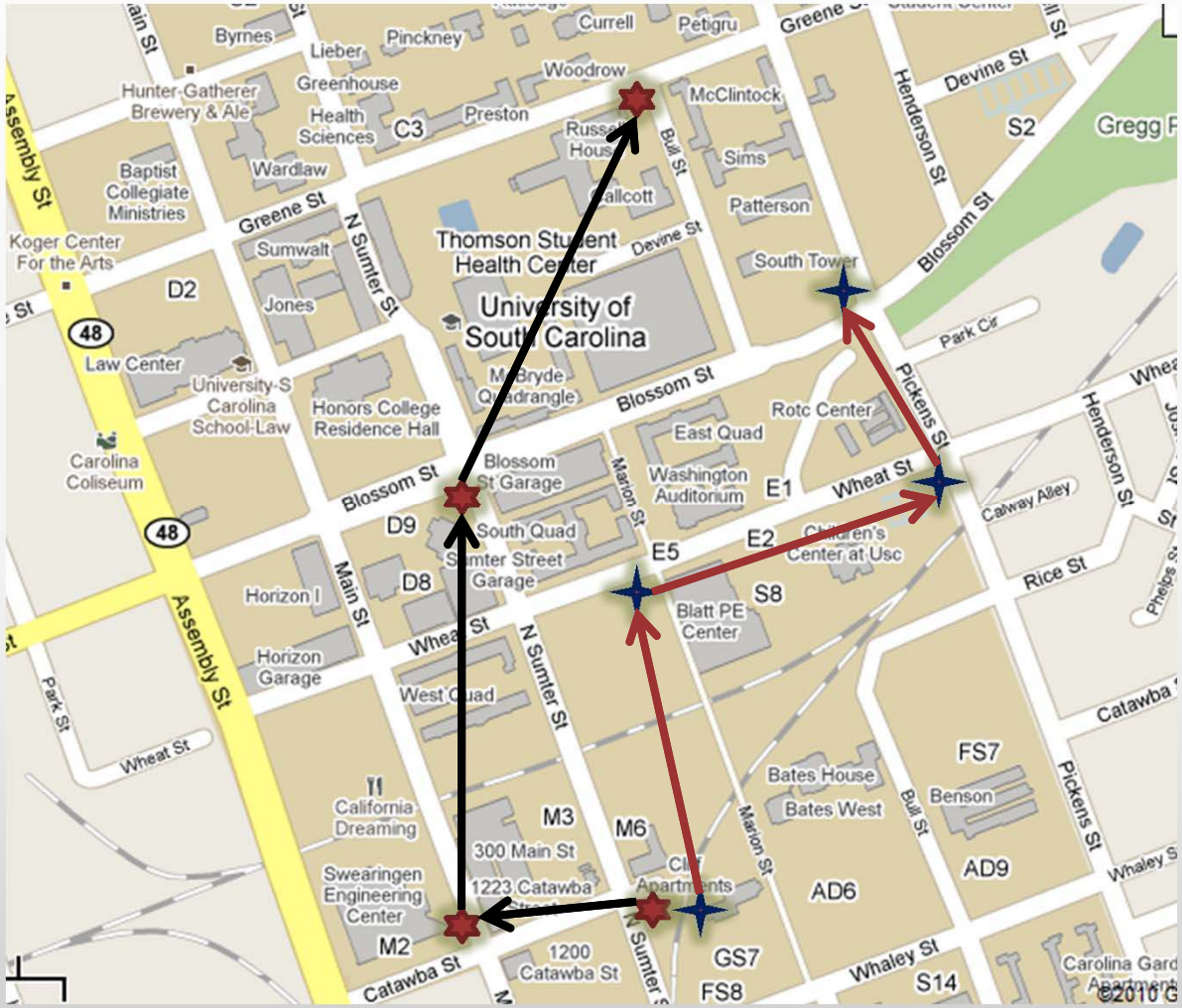
Wireless in Automobiles

- Wireless increasingly connected to CAN bus in automobiles
  - Web-based vehicle-immobilization system
  - MyRate from insurance companies to collect data
  - "iChange" controls the car via an iPhone
  - More in-car wireless sensor networks

Tire Pressure Monitoring System (TPMS)

- What is TPMS?
  - Monitors tire-pressure in real time
  - Alerts drivers if underinflated
  - To increase safety and fuel economy
  - Indirect TPMS vs. direct TPMS
- National Highway Transportation Safety Administration (NHTSA) ***mandates*** TPMS. Virtually, all new cars sold or manufactured after ***2007*** in US are equipped with wireless TPMS.

Misuse 1: Car Tracking



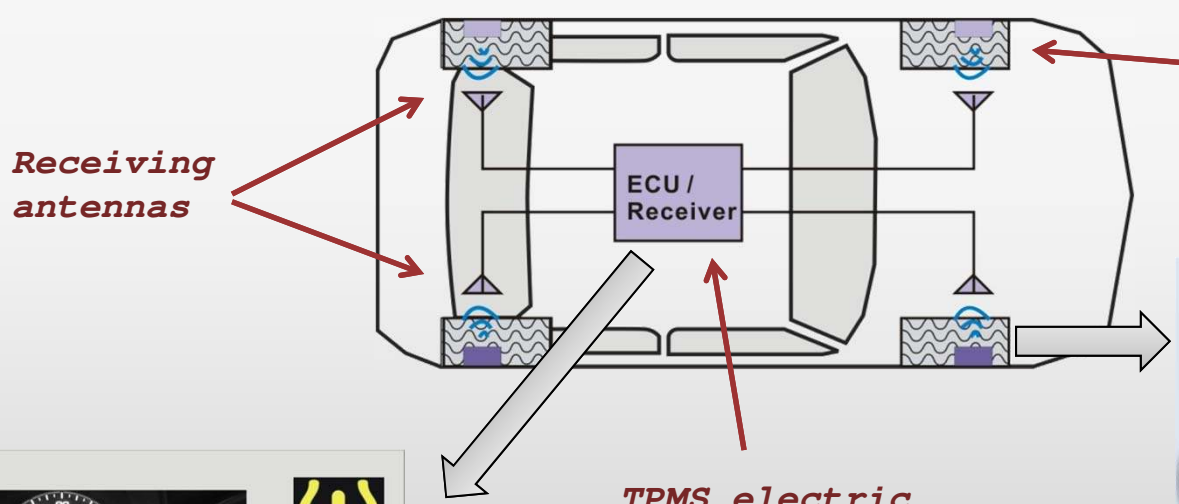
Misuse 2: Trick The Driver To Stop

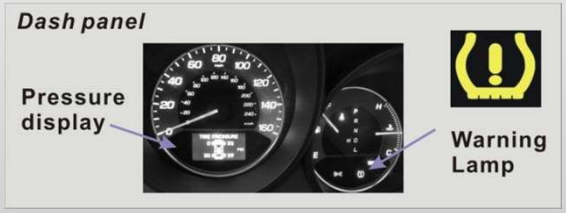
TPMS – To Be Discovered

- What are the communication protocol details?
  - How difficult to reverse engineer?
  - Messages encrypted? Authenticated?
- How easy to eavesdrop TPMS communication?
  - What is the *range*?
  - Travel speeds, car's metal body, message rate, transmission power
- How easy to spoof TPMS communication?
  - What is the *range*?
  - ECU filters/rejects suspicious packets?
  - How much damage can spoofing accomplish?
- What can be done to protect TPMS communication?

TPMS – From the Public Domain

- Communication protocols
  - Link Sensor IDs with TPMS ECU
  - Sensors → ECU **315/433Mhz**
    - ECU filters packets based on IDs
  - Sensors can be waken up by
    - ECU → sensors **125kHz**
    - Travel at high speeds (>40 km/h)





Security and Privacy Analysis
Step 1: Reverse-engineering

- Proprietary protocols
  - Security through obscurity?
- Equipment
- Goal
  - Modulation schemes
  - Encoding schemes
  - Message formats (encrypted?)

ATEQ VT55

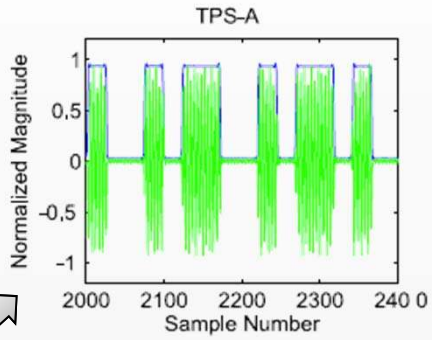
Sensors: TPS-A and TPS-B

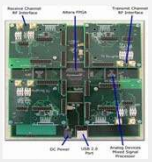
Universal Software Radio Peripheral (USRP)

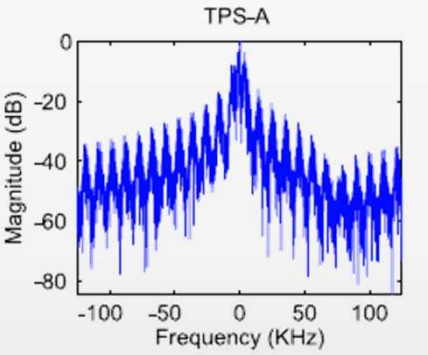
Agilent Vector Signal Analyzer (VSA)

Reverse-Engineering Walk-Through

- Reverse engineering steps
  - Capture packet transmission
  - Demodulate and decode data
  - Determine packet format
- Observations
  - Reverse engineering possible
  - No encryption



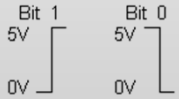




Triggered sensors at 125 kHz → **Responded at 315 MHz** → **Captured RF transmission at 315 MHz** → **Determined Modulation ASK** → **Encoding Scheme Manchester** → **Determined Message Format**

32-bit or 28-bit

preamble	Sensor ID	Pressure	Temperature	Flags	Checksum



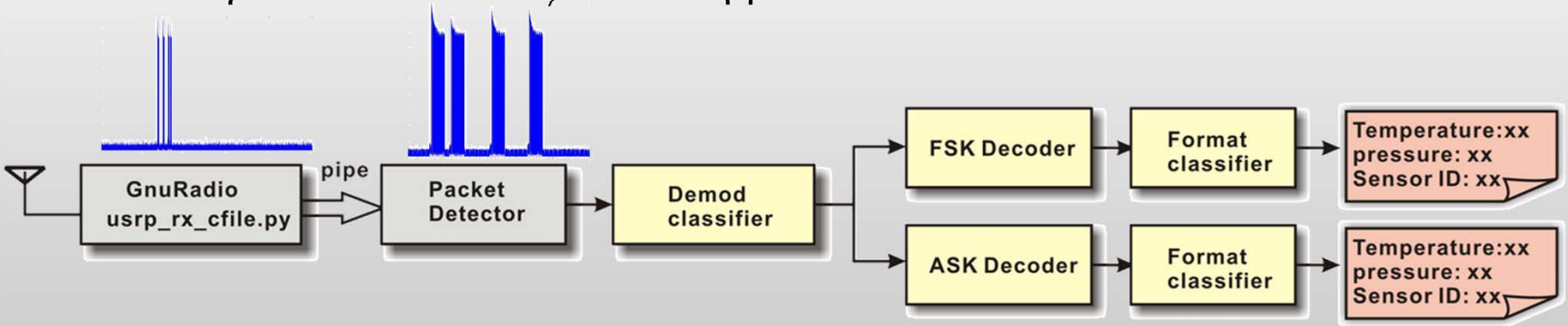
How likely that two cars have the same ID?

→ 10^{15} cars with P_c = 1%.

Security and Privacy Analysis
Step 2: Eavesdrop capability

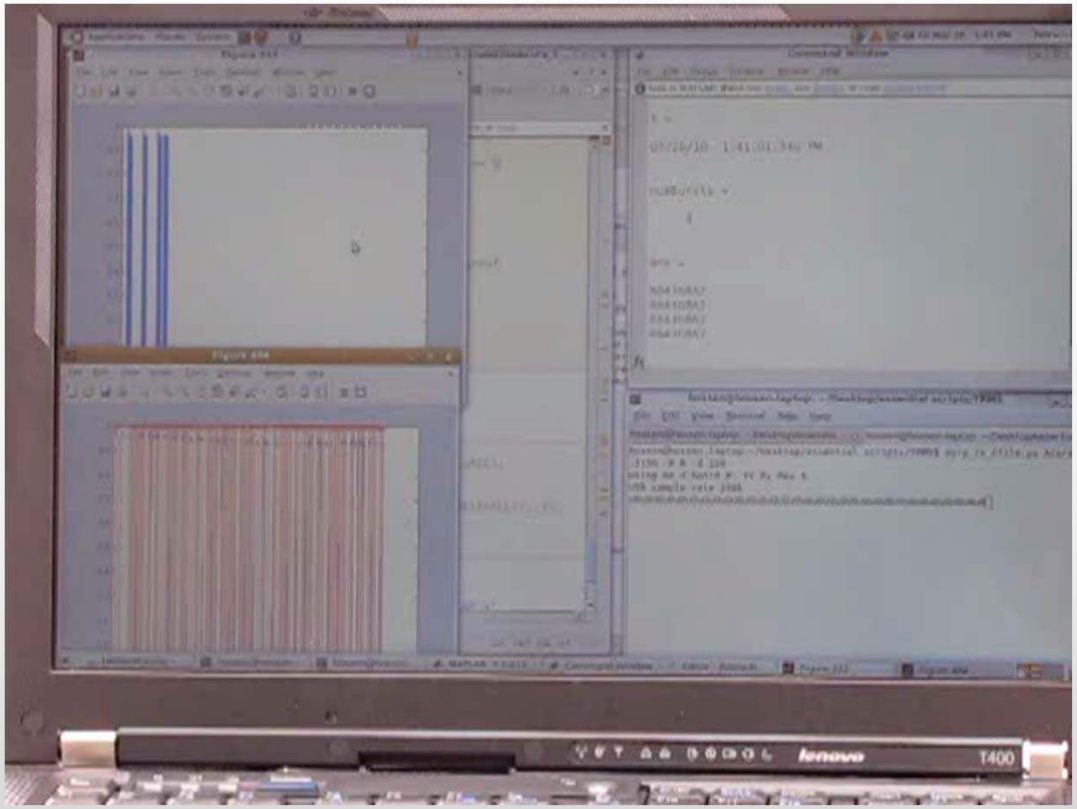
- How likely to eavesdrop?
  - Cars travel at high speeds
  - Cars' metal bodies shield RF
  - TPMS message rate (1 per 60s-90s)
  - Low transmission power (battery)
- Eavesdropping System
  - Used USRP only, no VSA
  - Used low noise amplifier (LNA)
  - Reused decoders from RE
  - Developed a live decoder/eavesdropper

Low noise amplifier (LNA)



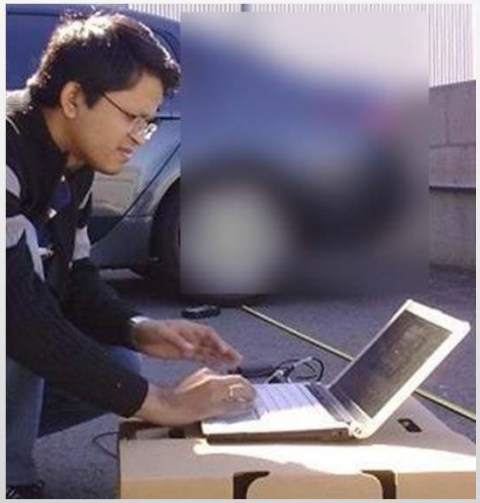
Demonstration of Live Eavesdropping

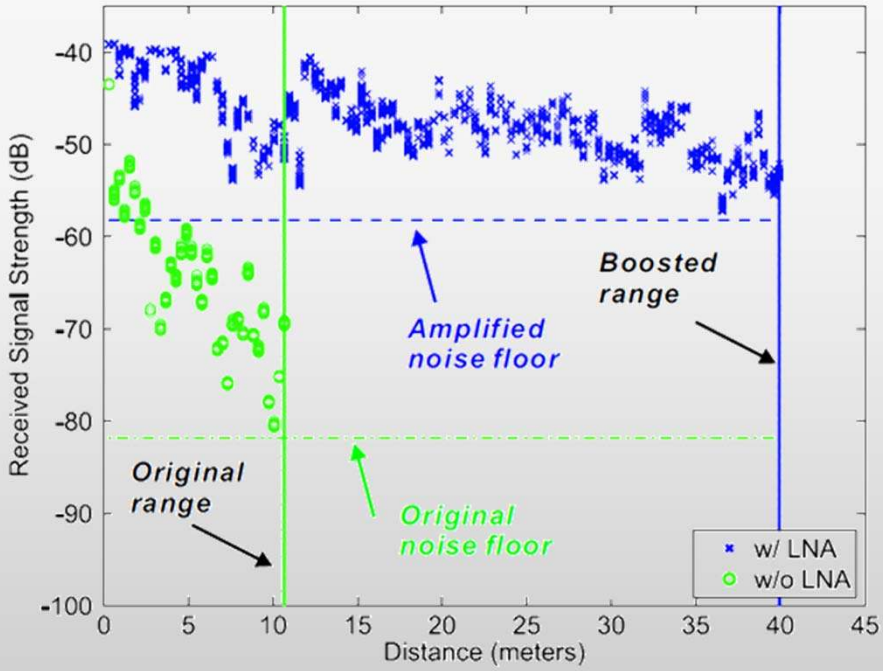
Sensor ID 884368A2



Exp. 1: Eavesdropping Distance

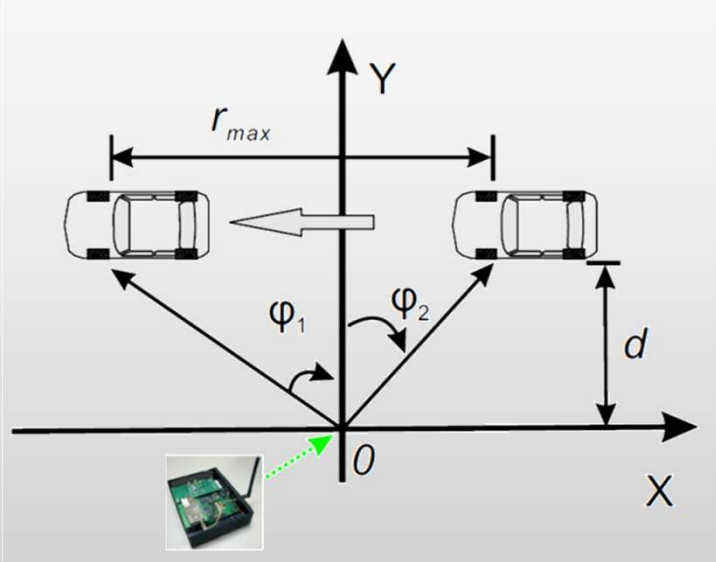
- Scenarios
  - USRP + cheap antenna
  - USRP + LNA ($75) + cheap antenna
- Observations
  - Able to decode packets, if RSS (received signal strength) > Ambient noise floor
  - LNA boosts the decoding range from 10.7m to **40m**

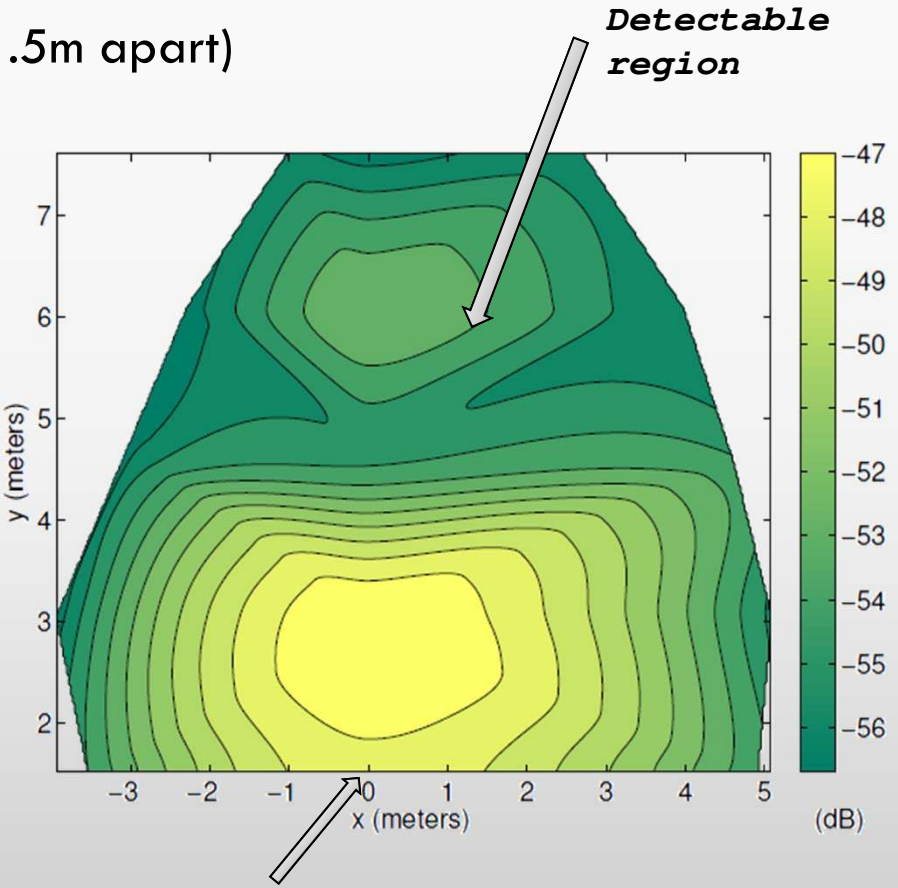




Exp. 2: Eavesdropping Distance and Angle

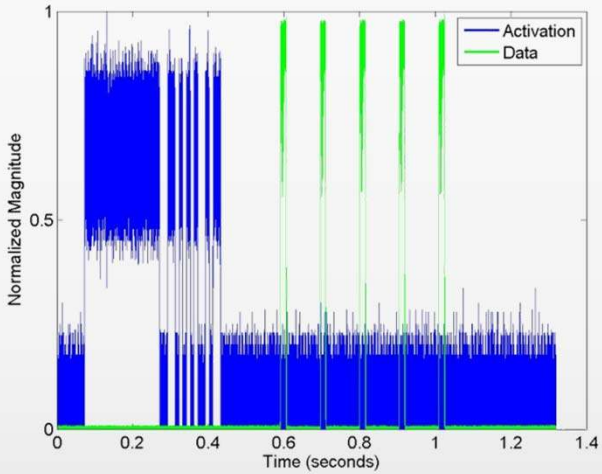
- Setup
  - USRP at origin
  - Car moved parallel to the x-axis (1.5m apart)
- Observations
  - The widest range is 9.1 meters
  - Sniffed at over 70mph speed





Feasibility of Tracking

- Passive tracking
  - Complete location tracking is difficult
  - Given: 1 packet per 60 seconds, eavesdropping range 9 meters
  - A car at 60km/h → 110 sniffers
- Active tracking
  - Activation signal makes the tracking easier
  - Send the activation signal at 125kHz
  - The sniffer places down the road
  - Experiments
    - Obtained timing data: USRP + TVRX (315MHz) + LFRX (125kHz)
    - Validation: ATEQ VT55 (activator) + USRP (sniffer);



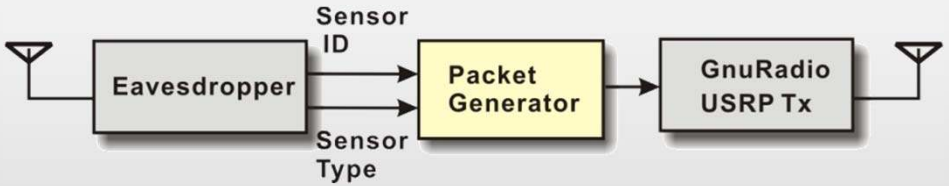
Tracking via TPMS
- Independent of LOS → hidden
- Higher technical requirement to deactivate TPMS

Tracking via License Plate Capture Cameras (LPCC)
- Requires LOS → visible camera mounting location
- Affected by weather
- Less technical sophistication to hide license plates

Security and Privacy Analysis Step 3: Packet Spoofing

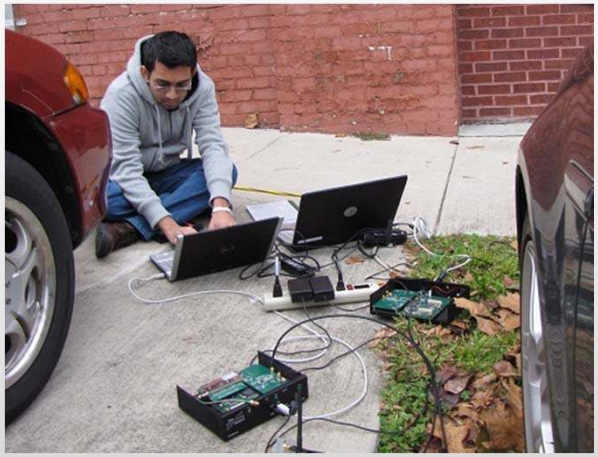
- How likely to spoof TPMS communication?
  - Is the in-car radio able to pick up spoofing packets from outside the vehicle or a neighboring vehicle?
  - Security mechanisms in ECU?
    - Will ECU filter/reject suspicious packets?
    - How long will ECU recover from the spoofing?
- Spoofing System
  - Frequency mixer
  - Reused eavesdropper from step 2
  - Developed a packet generator
    - Include a proper checksum
    - Contain the alarm flag

Frequency mixer



Spoofing Validation

- Tested on two equipment:
  - ATEQ VT55 validates packet structure
  - A car (TPS-A) validates ECU's logic
    - 40 packets per minute



Spoofing Validation

- Tested on two equipment:
  - ATEQ VT55 validates packet structure
  - A car (TPS-A) validates ECU's logic
    - 40 packets per minute

- Observations
  - No authentication
  - **No input validation**
  - Warning lights only depend on the alarm flag, not the real pressure
  - Large range: 38 meters with a cheap antenna without any amplifier
  - Inter-vehicle Spoofing is feasible; travel speed 55 km/h and 110 km/h

TPMS-LPW light

Vehicle's warning light

Disabled TPMS ECU

- Timer and window-based filtering opens vulnerabilities
- *Broke TPMS ECU purely by spoofing! Replaced the ECU at the dealership.*

Recommendations

- Reliable software design
  - Cross-check pressure reading with flag
  - Detect conflict messages
  - Set packet delivery rate limit

??

- Cryptographic solutions:
  - Use encryption and key-establishment protocols
  - Include sequence number in packets
  - Use cryptographic checksum (e.g., MAC)

- Preventing spoofed activation

Conclusions

- Tracking risks
  - (i) The TPMS messages contain fixed sensor IDs in plaintext
  - (ii) TPMS packets can be intercepted up to **40 meters** using USRP with an LNA
  - (ii) Active tracking is possible while cars are travelling
- Spoofing risks
  - (i) Spoofing attacks are possible to a car traveling at high speeds from a nearby car
  - (ii) **No input validation and weak filtering**
  - (iii) **Permanently disabled the TPMS ECU** by spoofing attacks only
- Raise awareness before more serious security and privacy vulnerabilities emerge
- Many of these issues can be addressed by reliable software design and cryptographic algorithms

Thank you & Questions?

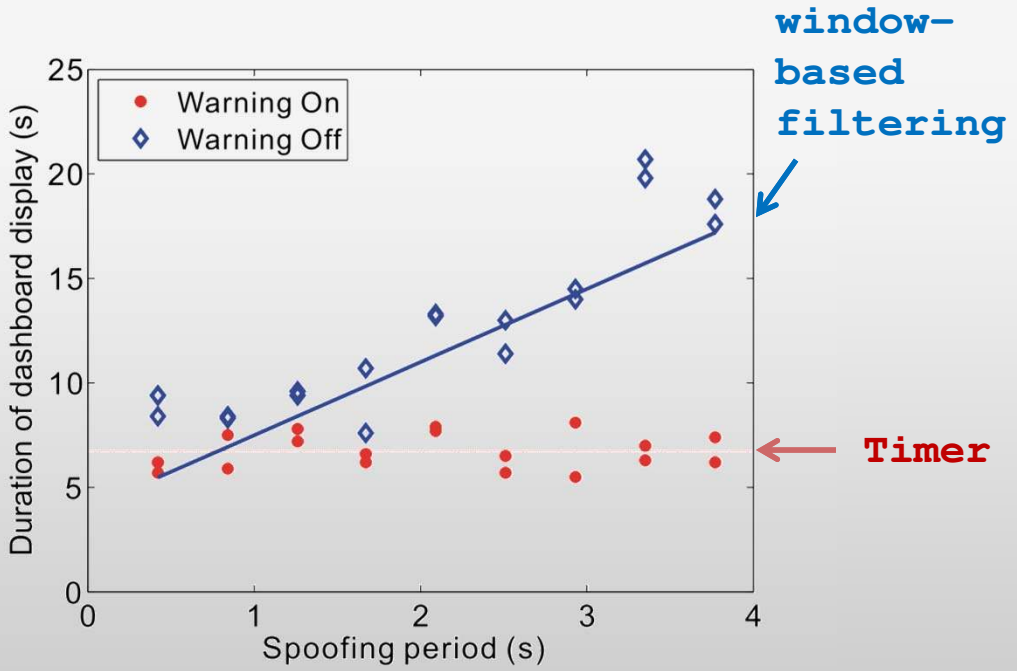
Exploring the Logic of ECU Filtering

- Sustainability of the spoofing attacks
  - Q: Minimum number of packets to trigger the TPMS warning light once

    A: Trigger requirement: 4 pkts (240ms apart)
  - Q: Minimum spoofing rate to keep the TPMS warning light on

    A: Sustain requirement: 1 pkt per 4 seconds
  - Q: Can we permanently illuminate warning lights even after stopping the spoofing attack?

- Explored TPMS-LPW Light
  - Change the number of packets
  - Change the rate of packets



Related Work

- Security and privacy analysis of other wireless systems
  - RFID systems [Koscher2009], [Molnar2004], [Weis2004]
  - UbiComp devices [Saponas2007]
  - Implantable medical devices [Halperin2008]
  - House robots [denning2009]
- Location privacy
  - Monitoring radiometric signatures [Brik2008]
  - Leveraging link- and application-layer information [Grutesers2003]
  - Pseudonym-based defense [Jiang2007]
  - Identifier-free-based defense [Greenstein2008]
- Security and privacy in sensor networks
  - SPIN and random key predistribution [Perrig2001] [Chen2003]
- Security analysis of a modern car [Koscher2010]
  - Directly mounting into a car's internal network via the On Broad Diagnostics (OBD) port