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Hardware Security

5. Smartcards (tutorial)

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Today

2 parallel activities

- Breaking and reverse-engineering MIFARE Classic (group activity)
  - PN532 NFC reader + CP2102 USB-to-UART converter
  - Identify card types
  - Attack and get the keys
  - Reverse-engineer the format
- Analyzing smartcards you brought (me & you)
  - Proxmark 3
  - Identify card types & properties
- **Demo:** NFC passport/eID sniffing
  - Proxmark 3

Hardware

- PN532
  - Low-cost NFC reader (5£)
  - Supports ISO/IEC 14443 Type A & B, FeliCa, RFID
  - Can emulate cards (but UID emullation has limits)
  - Communication interfaces: UART, SPI, I2C
  - 5€
- CP2102
  - USB-to-UART converter
  - Converts USB to TTL serial (TX, RX, GND, VCC)
  - 3.3V logic level (safe for PN532)
  - 3€
- Proxmark 3
  - Much more capable (HF & LF)
  - Many, many protocols & tools
  - Can emulate cards & sniff
  - From 40€ to 400€

https://anagolife.com/gioi-thieu-ve-module-nfc-pn532-voi-arduino/

https://dangerousthings.com/product/proxmark3-easy/

Group activity

- I have 11 readers
- Work in groups of 3-4
  - Identify
  - Exploit
  - Reverse-engineer

Group activity

Tasks

3 phases

- Identification
  - Get a card
  - Use the `id.py` script to obtain ATQA and SAK
  - Identify the card, using the docs
- Exploitation (Mifare Classic only)
  - Run `mfoc`
  - Run `mfoc-staticnested` (only if necessary)
  - Save dump
  - Pass the card to the next group
- Reverse-engineering
  - Explore the dumps
  - There will be clues
  - The cards are related
  - Public-transport-like (fictional)

After each phase we will discuss what you learned.

MIFARE

A family of smartcards by NXP

- All kinds of broken, some more than others
  - Reader vs EM-tracing setup
- Classic, Plus, DESFire, Ultralight
- Multiple sizes and variants

MIFARE

ISO 14443

- Type A and Type B
- MIFARE is Type A
- Only some MIFARE products support ISO 14443-4 (T=CL)
  - DESFire and Plus
  - See the docs or this guide
- Lingo
  - PCD - Reader
  - PICC - Card

MIFARE

ISO 14443-3

- REQA
  - Request Type A
  - Wakes up cards, reply with ATQA
- ATQA
  - Answer To Request Type A
  - 2 bytes: UID size, anti-collision support, some proprietary info
- Anti-collision loop
- SAK
  - Select Acknowledge
  - After the reader selected the card
  - ISO 14443-4 compatibility, some proprietary info

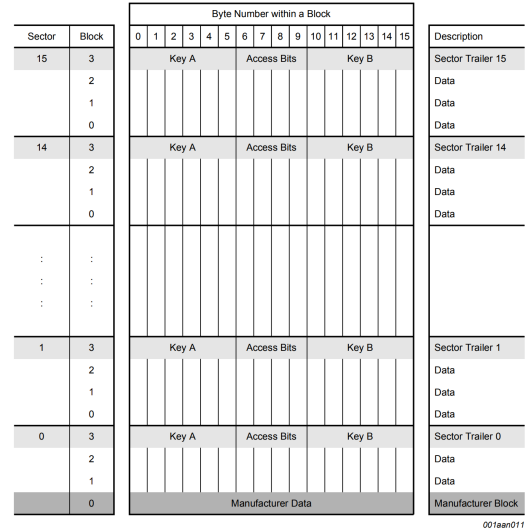
MIFARE

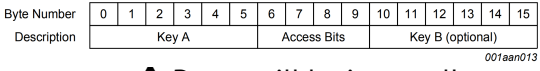
Classic

Specification

- Proprietary cryptography
  - Crypto-1 (Crapto-1) stream cipher
  - LFSR (Linear Feedback Shift Register)
  - 48-bit keys and state
  - 16-bit LFSR for nonces (PRNG)
- 1k, 2k, 4k memory
- Data layout
  - Block: 16 bytes
  - Sector: 3 data blocks + sector trailer
  - Sector trailer
    - Key A (6 bytes)
    - Access bits: Which key can do what?
    - Key B (6 bytes)
- Operations
  - Read, Write
  - Increment, Decrement (Value blocks)

End of memory





⚠ Dump will be inverted!

Overview

1. Reader: Picks sector and key (A/B), sends this info
2. Card: Generates N_{card} nonce (32-bit) and sends N_{card}
3. Reader: Generates N_{reader} nonce (32-bit) and sends $E_k(N_{card}, N_{reader})$
4. Card: Decrypts and verifies that N_{card} matches and sends $E_k(N_{reader})$

- Authenticated: Both parties know k
- Encrypted: Keystream synced and used for encryption (XOR)
- Nonces prevent replay attacks

MIFARE

Classic attacks

Card-only

- Darkside: `mfcuk`
  - **Exploit:** Keystream leakage through errors
  - Card encrypts known error value -> You get the keystream
- Nested: `mfoc`
  - Requires 1 known key
  - **Exploit:** Keystream leakage through predictable nonces
- Hardnested: `mfoc-hardnested`
  - Requires 1 known key
  - **Exploit:** Keystream leakage through parity bits
- Staticnested: `mfoc-staticnested`
  - Requires 1 known key
  - **Exploit:** Keystream leakage through static nonces
- Backdoor: `mfoc-backdoor`
  - **Exploit:** Known backdoor keys

You do not need to understand the attacks to mount them!

Reader-only ... **Card-reader sniff** ...

Group activity

Setup

- Follow the setup instructions
- Linux (Docker) setup preferred
- Linux (native) also works, but takes longer
- Windows (WSL) is complicated
- Mac is unsupported, sorry

Start the setup now.

Group activity

Cards

- A (4 copies)
- B (4 copies)
- C (4 copies)
- D (4 copies)
- EC1
- VS
- MC

Group activity

Identification

- Use the `id.py` script
- Evaluate the ATQA and SAK
- Also the `GetVersion` response
- Also the PPSE response
  - Hint: emvlab TLV decode
- Once card is identified
  - Mifare Classic: Continue with exploitation
  - Other: Pass it on
- Make notes for each card
  - What information can you get from the card?

Group activity

Identification (solution)

- A (4 copies)
  - MIFARE Classic 1k
- B (4 copies)
  - MIFARE Classic 1k
- C (4 copies)
  - MIFARE Classic 1k
- D (4 copies)
  - MIFARE Classic 1k
- EC1
  - MIFARE Classic EV1 1k
  - Taiwanese EasyCard
- VS
  - Visa debit card
- MC
  - Mastercard debit card

Group activity

Exploitation

- Run `mfoc` (Nested attack)
  - If it works, you are done
  - If it shows you logs with the `distance` not changing, **abort** and try the attack below
  - Which keys were the default?
- Run `mfoc-staticnested` (Staticnested attack)
  - Explore the options (you may need `--force-detect-distance`)
  - If it works, you are done
  - Which keys were the default?
- Save the dump!
- Pass on the card

Group activity

Exploitation (solution)

- A (4 copies)
  - Dump
- B (4 copies)
  - Dump
- C (4 copies)
  - Dump
- D (4 copies)
  - Dump
- A, B, C, D
  - Same set of keys
  - Always the default one for sector 0
- EC1
  - mfoc and mfoc-staticnested do not work for this one
  - Yet I got the dump on a Proxmark3
    - It has some reverse-engineered ways of computing the keys
  - Dump

Group activity

Reverse-engineering

Tips

- Look at the hexdump `hexdump -Cv <dump.bin>`
- Find strings `strings <dump.bin>`
- Find timestamps (e.g., unix epoch)
- Find and examine value blocks
  - value, negated value, value, then `00ff00ff`
- Values may be little-endian
- Diff the dumps
  - Examine the changes and the static values
  - What actions could one do with a public transport card?
- A -> B -> C -> D
  - What actions were performed in between the dumps?
- Consider the **HardwareLand**

Group activity

Reverse-engineering

HardwareLand

2026-05

Public transport

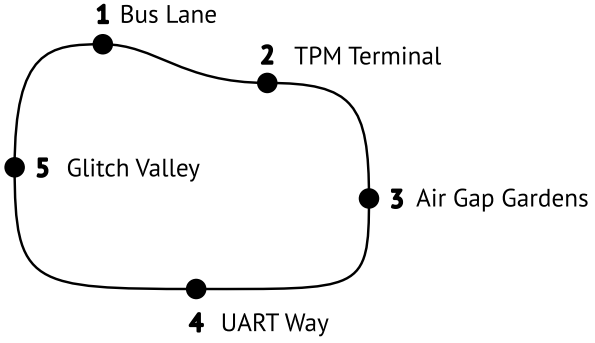
Ticket prices

Short-trip	10ℍ
Long-trip	20ℍ

Tariffs

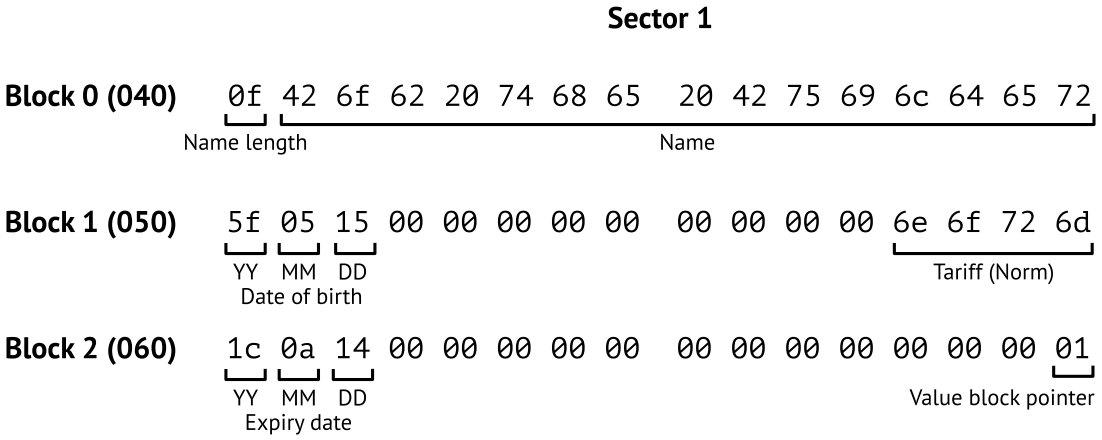
Normal

Half



Group activity

Reverse-engineering (solution)



Group activity

Reverse-engineering (solution)

Sector 2

Block 0 (080)	`aa 00 00 00` (Value)	`55 ff ff ff` ($\overline{\text{Value}}$)	`aa 00 00 00` (Value) `00 ff 00 ff`
Block 1 (090)	`96 00 00 00` (Value)	`69 ff ff ff` ($\overline{\text{Value}}$)	`96 00 00 00` (Value) `00 ff 00 ff`
Block 2 (0a0)	`00 00 00 00`	`ff ff ff ff`	`00 00 00 00 00 ff 00 ff`

Group activity

Reverse-engineering (solution)

Sectors 3,4,5,6

Ride

11	02	35 92 fc 69	14 00	aa 00 00	05	1e 96 fc 69
Type	From	Entry time	Cost	Balance before	To	Exit time

Recharge

22	64 00 00	96 00 00	fa 00 00	62 9a fd 69	00 00
Type	Value	Balance before	Balance after	Time	

Ride

11	05	af a8 fd 69	14 00	fa 00 00	02	b4 ac fd 69
Type	From	Entry time	Cost	Balance	To	Exit time

Group activity

Reverse-engineering (solution)

(Sector 1)

- Bob the Builder, born 1995-05-21
- Card valid until 2028-10-20
- Normal tariff
- Pointer to current value block (0, 1, 2)

(Sector 2)

- Value blocks track last 3 changes in card value

(Sectors 3, 4, 5, 6)

- Ride (Tag 0x11)
  - Stop entry (1 byte)
  - Entry time (Unix epoch 4 bytes, LE)
  - Cost (2 bytes, LE)
  - Balance before (3 bytes, LE)
  - Stop exit (1 byte)
  - Exit time (Unix epoch 4 bytes, LE)
- Recharge (Tag 0x22)
  - Value (3 bytes, LE)
  - Balance before (3 bytes, LE)
  - Balance after (3 bytes, LE)
  - Timestamp (Unix epoch 4 bytes, LE)

Group activity

Reverse-engineering (solution)

A

- Ride from stop 2 to stop 5, cost 20, before 170, after 150
- Entry 2026-05-07 15:23:01: 1778160181
- Exit 2026-05-07 15:39:42: 1778161182

B

- Recharge 100, before 150, after 250
- Time 2026-05-08 10:10:10: 1778227810

C

- Ride from stop 5 to stop 2, cost 20, before 250, after 230
- Entry 2026-05-08 11:11:11: 1778231471
- Exit 2026-05-08 11:28:20: 1778232500

D

- Ride from stop 2 to stop 1, cost 10, before 230, after 220
- Entry 2026-05-08 15:15:15: 1778332515
- Exit 2026-05-08 15:17:10: 1778332630

NFC passport/eID sniffing demo

- Can sniff a BAC exchange between card and phone (reader)
- MRZ entropy is low, could brute-force the key and get the data

Tools

- nfc-tools GitHub org
  - mfoc
  - mfcuk
- Proxmark3 & Iceman fork
- Farebot

Takeaways

- What are **you** taking away from this tutorial?
- What surprised you?

References

- CCC'07: MIFARE Security
- A Practical Attack on the MIFARE Classic
- Dismantling MIFARE Classic
- Algebraic Attacks on the Crypto-1 Stream Cipher in MiFare Classic and Oyster Cards
- Darkside
- Nested and an Overview
- Hardnested
- Staticnested
- Backdoor

Workshops

- Cracking Mifare Classic on the cheap (workshop)
- Hacking Mifare Classic Cards

EasyCard

- CCC'10: Reverse Engineering a real-world RFID payment system
- slides
- easytool