Contactless Payment Cards: Vulnerabilities, Attacks, and Solutions

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© All wrongs reversed

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CyberCamp 2015
Madrid (Spain)
$whoami

- Ph.D. on Comp. Sci. (Univ. of Zaragoza, Spain) (2013)
- **Assistant Professor** at University of Zaragoza
  - Performance analysis on critical, complex systems
  - Secure Software Engineering
  - Advance malware analysis
  - RFID/NFC Security
- Not prosecuted 😊
- Speaker at NcN, HackLU, RootedCON, STIC CCN-CERT, HIP, MalCON, HITB...
Agenda

PART 1: Theory on RFID and NFC
PART 2: EMV
PART 3: EMV Contactless cards
PART 4: Solutions, Conclusions, and References

(some slides borrowed from Joeri de Ruiter, University of Birmingham – thanks mate! 😊)
Part I – Theory on RFID and NFC

1 RFID
   • What is it?
   • Where is it used?

2 Near Field Communication (NFC)
   • What is it?
   • Where is it used?
   • NFC vs. RFID
   • NFC vs. Other Wireless Technologies
   • NFC (in)Security

3 ISO/IEC 14443
RFID: What is it? (I)

- Stands for Radio-Frequency IDentification
- Wireless use of electromagnetic fields to transfer data
- Main purposes:
  - Automatically identify objects
  - Automatically track objects
RFID: What is it? (I)

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- Its market is $\geq US$20 billion (estimation by 2014)
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- Its market is $\geq US$20 billion (estimation by 2014)
- Different types of powered tags:
  - Electromagnetic induction
  - Passive transponder
  - Local power source

Main advantages to barcodes

- No need to be aligned with the reader
- Can be embedded in the tracked object
RFID: What is it? (II)

A bit of history . . .

- 1945: Soviet Union espionage tool that retransmitted incident radio waves with audio information (Léon Theremin, the Great Seal bug)
  - Sound waves vibrated a diaphragm which slightly altered the shape of the resonator, which modulated the reflected radio frequency
RFID: What is it? (II)

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Devices

- Tags: Attached/embedded in the objects
  - Passive, active or battery-assisted passive
  - Read-only, read/write (write-once/read-multiple...)
  - Two components: Integrated Circuit (for storing, processing, de/modulating, collecting DC power), and an antenna (for receiving and transmitting the signal)
  - Information stored in non-volatile memory

- Readers
  - Passive: Needs an active tag. Reception range 0.30 to 609.60m
  - Active
<table>
<thead>
<tr>
<th>Band</th>
<th>Regulations</th>
<th>Range</th>
<th>Data speed</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>120–150 kHz (LF)</td>
<td>Unregulated</td>
<td>10 cm</td>
<td>Low</td>
<td>Animal identification, factory data collection</td>
</tr>
<tr>
<td>13.56 MHz (HF)</td>
<td>ISM band worldwide</td>
<td>10 cm - 1 m</td>
<td>Low to moderate</td>
<td>Smart cards (MIFARE, ISO/IEC 14443)</td>
</tr>
<tr>
<td>433 MHz (UHF)</td>
<td>Short Range Devices</td>
<td>1–100 m</td>
<td>Moderate</td>
<td>Defence applications, with active tags</td>
</tr>
<tr>
<td>865-868 MHz (Europe),</td>
<td>ISM band</td>
<td>1–12 m</td>
<td>Moderate to high</td>
<td>EAN, various standards</td>
</tr>
<tr>
<td>902-928 MHz (North America)</td>
<td>UHF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2450-5800 MHz (microwave)</td>
<td>ISM band</td>
<td>1–20 m</td>
<td>High</td>
<td>802.11 WLAN, Bluetooth standards</td>
</tr>
<tr>
<td>3.1–10 GHz (microwave)</td>
<td>Ultra wide band</td>
<td>200 m</td>
<td>High</td>
<td>Requires semi-active or active tags</td>
</tr>
</tbody>
</table>
RFID: Where is it used? (IV)

- Access management
- Tracking of goods
- Tracking of persons and animals
- Toll collection and contactless payment
- Machine readable travel documents
- Smartdust (for massively distributed sensor networks)
- Tracking sports memorabilia to verify authenticity
- Airport baggage tracking logistics
- Timing sporting events
Near Field Communication: What is it? (I)

Near Field Communication (NFC)

- Standard to establish radio communication between devices
  - By touching or bringing them into close proximity
- Builds upon RFID
  - Radio-Frequency ID: identify and track (things/animals/people) using radio waves
  - Works at 13.56MHz band on ISO/IEC 18000-3 (no license needed)
- Distance needed: \( \leq 10\text{cm} \) (theoretically \( \leq 20 \))
- Rates: 106 – 424 kbit/s
- Two main actors
  - Initiator: generates a RF field
  - Target
- Two working modes
  - Passive: initiator device provides a carrier field. Target is a transponder
  - Active: initiator + target generate their own fields
Near Field Communication: What is it? (II)

“Big” actors

NFC Forum

- Non-profit industry association
- Formed on March 18, 2004
- Founders: NXP Semiconductors (formerly Philips Semiconductors), Sony and Nokia
- Promotes implementation and standardisation of NFC
- 190 member companies (June 2013).
  Some located at Spain:
  - Applus
  - AT4 Wireless
Near Field Communication: What is it? (III)
Real actors (1)

**PICC**
- Proximity Integrated Circuit Card
- Commonly named as *tag*
- Passive or active (depends on power supply)
  - Widely used (cheaper): passive ones
- It contains:
  - Internal capacitor
    - Stores the energy coming from the reader
  - Resistor
Near Field Communication: What is it? (III)
Real actors (2)

PCD
- Proximity Coupling Device
- Commonly named as *reader/writer*
- Active (forced)
- Contains the *antenna*
  - Communication at the 13.56MHz (±7kHz) frequency
  - Electronic field
Near Field Communication: What is it? (IV)

An interesting reading on this topic...

(Taken from 13.56 MHz RFID Proximity Antennas, http://www.nxp.com/documents/application_note/AN78010.pdf)
Near Field Communication: Where is it used? (V)
NFC vs. RFID

Remember: **NFC operates at 13.56MHz → extension of High Frequency RFID standards**

<table>
<thead>
<tr>
<th></th>
<th>HF RFID</th>
<th>NFC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating Frequency</strong></td>
<td>13.56 MHz</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>One way</td>
<td>Two way</td>
</tr>
<tr>
<td><strong>Standards</strong></td>
<td>ISO 14443, 15693, 18000</td>
<td>ISO 14443</td>
</tr>
<tr>
<td><strong>Scan Distance</strong></td>
<td>Up to 1 m</td>
<td>Up to 10 cm</td>
</tr>
<tr>
<td><strong>Scan Tags Simultaneously</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
NFC vs. Other Wireless Technologies

(taken from http://www.cnx-software.com/2010/12/28/near-field-communication-nfc/)
Why NFC? Why??

- NFC brings “cards” to mobile devices
- Payment sector is quite interested in this new way for making payments
  - 500M NFC payment users expected by 2019
- Almost 300 smart phones available at the moment with NFC capabilities
  - www.nfcworld.com/nfc-phones-list/
- Most of them runs Android OS

We will recall this issue later on...
NFC security threats

- **Eavesdropping**
  - Secure communication as solution

- **Data modification** (i.e., alteration, insertion, or destruction)
  - Feasible in theory (but requires quite advanced RF knowledge)
NFC security threats

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- Relays
  - Forwarding of wireless communication
NFC security threats

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  - Forwarding of wireless communication
  - Types: *passive* (just forwards); and active (forwards and alters the data)
Herein, we focus on **eavesdropping and relay threats**

- **Eavesdropping**
  - Secure communication as solution
- **Data modification** (i.e., alteration, insertion, or destruction)
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ISO/IEC 14443 (I)
Identification cards – Contactless integrated circuit cards – Proximity cards

ISO/IEC 14443 standard
- Four-part international standard for contactless smartcards
  1. Size, physical characteristics, etc.
  2. RF power and signalling schemes (Type A & B)
     - Half-duplex, 106 kbps rate
  3. Initialization + anticollision protocol
  4. Data transmission protocol
- IsoDep cards: compliant with the four parts
- Example: contactless payment cards

NOT SURE IF TROLLING
OR ACTUALLY BEING SERIOUS

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ISO/IEC 14443 (II)

ISO/IEC 7816

- Fifteen-part international standard related to contacted integrated circuit cards, especially smartcards
- Application Protocol Data Units (APDUs)
ISO/IEC 14443 (II)

Fifteen-part international standard related to contacted integrated circuit cards, especially smartcards

Application Protocol Data Units (APDUs)
- SELECT command: AID (App. ID, printed in the card)
  - RID (Registered Application Provider Identifier): 5B
  - PIX (Proprietary Identifier Extension): To distinguish apps
ISO/IEC 14443 (III)
Selection and anti-collision protocol (ISO 14443-3A)

1: REQA
1.1: ATQA

2: SELECT
2.1: SAK

[UID not complete]
[UID complete, PICC compliant to ISO/IEC 14443-4]

opt

loop

ref

ISO/IEC 14443-4
ISO/IEC 14443 (IV)
Transmission protocol – preamble (ISO 14443-4)
• IsoDep cards: Compliant with 4 parts of the ISO/IEC 14443
• But this is not a requirement... 
  • MIFARE Classic: Fulfills ISO/IEC 14443-1, ISO/IEC 14443-2 
    • Some parts of ISO/IEC 14443-3 
    • Own ISO/IEC 14443-4 protocol
**ISO/IEC 14443 (V)**

- **IsoDep cards**: Compliant with 4 parts of the ISO/IEC 14443
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**A note on MIFARE Classic**...

- Nice example for **security by obscurity** problem
- Well known vulnerabilities (and documented)
- Most critical: low entropy of random number generation
  - Replay attacks
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  - “Darkside” attack
  - Nested attack
ISO/IEC 14443 (V)

- **IsoDep cards**: Compliant with 4 parts of the ISO/IEC 14443
- But **this is not a requirement**.
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Recall: show video demo
ISO/IEC 14443 (V)

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Recall: show video demo

MFCAB tool: [http://www.bitbucket.org/rjrodriguez/mfcab](http://www.bitbucket.org/rjrodriguez/mfcab)
ISO/IEC 14443 (VI)
Optional selection of AID (ISO 14443-4)

PICC

PCD

ISO/IEC 14443-4

1. SELECT AID

1.1: success

2: ISO/IEC 14443-4 DESELECTION

[Explicit Select]

[Error]
ISO/IEC 14443 (VIII)

Examples

- MIFARE cards
- Calypso (electronic ticketing system)
- Biometric passports
- EMV payment cards (PayPass, payWave, ExpressPay)
- Spanish & German identity cards
- ...
Part II – EMV

4. EMV Protocol
   - What is it?
   - EMV Protocol Details
   - Known Weaknesses
EMV: What is it? (I)
Europay, Mastercard, and VISA standard for inter-operation of IC cards, Point-of-Sale terminals, and automated teller machines
EMV: What is it? (I)

Europay, Mastercard, and VISA standard for inter-operation of IC cards, Point-of-Sale terminals, and automated teller machines

Owners (with joining dates)

- American Express (Sept 2013)
- Discover (Feb 2009)
- MasterCard Worldwide (May 13)
- China UnionPay
- VISA
Standard initially written in 1993-1994
Different deployment dates (e.g., 2003 at UK)
Required for Single Euro Payment Area (SEPA)
Why?
- Tying to reduce fraud:
  - Skimming
  - Stolen credit cards with forged signatures
  - Card-Not-Present (CNP) fraud
- Liability shift
  - Merchant: when no EMV card is used
  - Customer: when PIN is used
EMV: What is it? (III)

(taken from “Chip and PIN is broken”, S.J. Murdoch et al.; IEEE S&P 2010)
EMV Protocol Details (I)

Since version 4.0... (June 2004)

- Standard specification distributed over 4 books (~ 700 pp.)

Book 1. Application Independent ICC to Terminal Interface Requirements
Book 2. Security and Key Management
Book 3. Application Specification
Book 4. Cardholder, Attendant, and Acquirer Interface Requirements

We haven't finished yet!

- Four card authentication methods
- Six cardholder verification methods
- Two types of transactions
  - Everything customised using Data Object Lists (DOL)
  - Madness complexity!
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EMV Protocol Details (II)

EMV actors

- Card
- Card bank issuer
- Point-of-Sale terminals
## EMV Protocol Details (III)

### Cryptography used

- **Symmetric key (3DES)**
  - Between the card (derived key) and issuer/bank (master key)
  - Authenticate transactions to bank
EMV Protocol Details (III)

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  - Payment scheme: authenticate issuers
  - Card Issuer: authenticate cards
  - Cards: authenticate cards/transactions to terminal (optional)
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Cryptography setup

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  - Payment scheme’s public keys
EMV Protocol Details (III)

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Cryptography setup

- **Terminal**
  - Payment scheme’s public keys

- **Card**
  - Card issuer’s public key certificate, signed by payment scheme
  - Card’s public key certificate, signed by card issuer
EMV Protocol Details (IV)

- Based on ISO/IEC 7816
- Application Protocol Data Units (APDUs)
- Command-response / master-slave protocol
  - Command packets
  - Response packets
EMV Protocol Details (V)
ISO/IEC 7816: command APDU

<table>
<thead>
<tr>
<th>CLA</th>
<th>INS</th>
<th>P1</th>
<th>P2</th>
<th>Lc</th>
<th>Data</th>
<th>Le</th>
</tr>
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</table>

- **CLA**: 1B. Instruction class; type of command (e.g., interindustry or proprietary)
- **INS**: 1B. Instruction code; specific command (e.g., “write data”)
- **P1-P2**: 2B. Instruction command parameters (e.g., offset into file at which to write the data)
- **Lc**: 0, 1 or 3B. Number ($N_c$) of bytes of command data
- **Data**: $N_c$B. Data
- **Le**: 0, 1 or 3B. Maximum number ($N_e$) of response bytes
EMV Protocol Details (VI)
ISO/IEC 7816: response APDU

<table>
<thead>
<tr>
<th>Data</th>
<th>SW1</th>
<th>SW2</th>
</tr>
</thead>
</table>

**Data**: $N_r \leq N_e$ Response data

**SW1-SW2**: 2B. Response trailer. Command processing status (e.g., 0x9000 indicates successful operation)
EMV Protocol Details (VII)
ISO/IEC 7816: verifying PIN

> 00 20 00 80 08 24 12 34 FF FF FF FF FF FF

Command detailed description

00 20 : VERIFY command
00 80 : Plaintext Personal Identification Number (PIN)
08 : Length data
24 12 34 FF FF FF FF FF FF : Data (yes, your PIN is there in plain text 😕)
EMV Protocol Details (VII)
ISO/IEC 7816: verifying PIN

> 00 20 00 80 08 24 12 34 FF FF FF FF FF FF

Command detailed description

00 20 : VERIFY command
00 80 : Plaintext Personal Identification Number (PIN)
08 : Length data
24 12 34 FF FF FF FF FF : Data (yes, your PIN is there in plain text 😞)

< 90 00

Response detailed description

90 00 : Command executed without error

NOTE: card may reply with 69 85 to prevent brute force attacks
EMV Protocol Details (VIII)

Establishing a session to communicate

<table>
<thead>
<tr>
<th>Steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Initialization</td>
</tr>
</tbody>
</table>

Do you see that something is missing?
EMV Protocol Details (VIII)
Establishing a session to communicate

### Steps

1. Initialization
2. Card authentication

Do you see that something is missing?
EMV Protocol Details (VIII)

Establishing a session to communicate

<table>
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<tr>
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</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Do you see that something is missing?
EMV Protocol Details (VIII)

Establishing a session to communicate

Steps

1. Initialization
2. Card authentication
3. Cardholder verification
4. Transaction

Do you see that something is missing?
EMV Protocol Details (VIII)

Establishing a session to communicate

<table>
<thead>
<tr>
<th>Steps</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Initialization</td>
</tr>
<tr>
<td>2</td>
<td>Card authentication</td>
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<td>3</td>
<td>Cardholder verification</td>
</tr>
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<td>4</td>
<td>Transaction</td>
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Do you see that something is missing?
**EMV Protocol Details (VIII)**

Establishing a session to communicate

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<td>3 Cardholder verification</td>
</tr>
<tr>
<td>4 Transaction</td>
</tr>
</tbody>
</table>

Do you see that something is missing?
EMV Protocol Details (IX)

File structure

- Master File (MF): top-most file
  - One (or more) Application Definition Files (ADF)
  - May be distributed in directories
- ADF selected using Application Identifier (AID)
  - Registered application provider IDentifier (RID): 5B (issued by ISO/IEC 7816-5 RA)
  - Proprietary application Identifier eXtension (PIX): differentiate among applications from the same RID
  - AID is printed in receipts
EMV Protocol Details (IX)

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- **ADF divided in Application Elementary Files (EF):**
  - EF contains data
  - Selection of EF thr. Short File Identifier (SFI)
## Example of AIDs

<table>
<thead>
<tr>
<th>Card issuer</th>
<th>RID</th>
<th>Specific card</th>
<th>PIX</th>
<th>AID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visa</td>
<td>A0000000003</td>
<td>Visa credit or debit</td>
<td>1010</td>
<td>A00000000031010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visa Electron</td>
<td>2010</td>
<td>A00000000032010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V PAY</td>
<td>2020</td>
<td>A00000000032020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plus</td>
<td>8010</td>
<td>A00000000038010</td>
</tr>
<tr>
<td>MasterCard</td>
<td>A0000000004</td>
<td>MasterCard credit or debit</td>
<td>1010</td>
<td>A00000000041010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MasterCard</td>
<td>9999</td>
<td>A00000000049999</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maestro (debit card)</td>
<td>3060</td>
<td>A00000000043060</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cirrus (interbank network)</td>
<td>6000</td>
<td>A00000000046000</td>
</tr>
</tbody>
</table>
EMV Protocol Details (XI)

Initialization (1)

- **Processing Option Data Object List (PDOL):** data to provide
  - Terminal language, capabilities, country code, etc.
- **Application Interchange Profile (AIP):** data authentication methods
- **Application File Locator (AFL):** lists available files

![EMV Protocol Sequence Diagram]

1: SELECT 1PAY.SYS.DDF01

1.1: success

2: SELECT EMV applet

2.1: PDOL

3: GET PROCESSING OPTIONS + PDOL data

3.1: AIP + AFL

00 A4 04 00 0E 31 50 41 59 2E 53 59 53 2E 44 44 46 30 31 00
OK, let’s proceed with the transaction!
OK, let’s proceed with the transaction!

Online or offline transaction? → Card Authentication and Cardholder Verification Methods
Online CAM

- Needs Internet (or phone) connection (obviously)
- Authentications done in issuer’s network
Online CAM

- Needs Internet (or phone) connection (obviously)
- Authentications done in issuer’s network

Offline CAM – based on RSA

- Terminal performs all authentication processes
- Two types
  - Offline Static CAM: Static Authentication Data (SDA)
  - Offline Dynamic CAM: Dynamic Authentication Data (DDA)
    - Standard DDA
    - Combined DDA/generate AC (also termed as CDA)
## EMV Protocol Details (XIV)

### Cardholder Verification Method

<table>
<thead>
<tr>
<th>Method</th>
<th>$b_7$</th>
<th>$b_6$</th>
<th>$b_5$</th>
<th>$b_4$</th>
<th>$b_3$</th>
<th>$b_2$</th>
<th>$b_1$</th>
<th>$b_0$</th>
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</thead>
<tbody>
<tr>
<td>Fail CVM processing</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Plaintext PIN verification</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Enciphered online PIN verification</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Plaintext PIN verification and Signature verification</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
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<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Encipher PIN verification and Signature verification</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Signature verification</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No CVM needed</td>
<td>X</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
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**CVM list of rules**
EMV Protocol Details (XV)

**Transaction**

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<tr>
<td><strong>Transaction Certificate</strong> (TC)</td>
</tr>
<tr>
<td>- Transaction approved</td>
</tr>
<tr>
<td><strong>Authorization Request Cryptogram</strong> (ARQC)</td>
</tr>
<tr>
<td>- Online authorization requested</td>
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<tr>
<td><strong>Application Authentication Cryptogram</strong> (AAC)</td>
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<td>- Transaction declined</td>
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EMV Protocol Details (XV)

Transaction

Application cryptograms

- **Transaction Certificate** (TC)
  - Transaction approved

- **Authorization Request Cryptogram** (ARQC)
  - Online authorization requested

- **Application Authentication Cryptogram** (AAC)
  - Transaction declined

**Offline mode:** GENERATE AC + TC (or AAC)

**Online mode:**
- Terminal initiated: ARQC + ARQC (or AAC)
- Card initiated: TC + ARQC
- ARQC forwarded to bank issuer → ATC
- EXTERNAL AUTH (or second GENERATE AC) + TC (or AAC)
EMV Known Weaknesses (I)

- Skimming
  - Magnetic stripe data also present on chip data
Skimming
- Magnetic stripe data also present on chip data

Cloning SDA cards
- Possible for offline transactions
- Only static data authenticated
- YES-card (accepts any PIN code)
EMV Known Weaknesses (I)

- **Skimming**
  - Magnetic stripe data also present on chip data

- **Cloning SDA cards**
  - Possible for offline transactions
  - Only static data authenticated
  - YES-card (accepts any PIN code)
  - SDA no longer allowed for offline-enabled cards
EMV Known Weaknesses (II)

DDA Man-in-the-middle attack

For offline transactions
- Authenticity of a transaction undetermined
- Transaction not connected to card authentication
EMV Known Weaknesses (III)

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<td><strong>For offline and online transactions</strong></td>
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<tr>
<td>- When card is not blocked</td>
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<tr>
<td>- When transaction without PIN are accepted</td>
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<tr>
<td><strong>MITM attack</strong></td>
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<td><strong>YES-card</strong></td>
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- Barisani et al., 2011
  - Rollback attack
  - Force CVM to plaintext PIN
  - Online transaction in case of failed data authentication

- Bond et al., 2015
  - Preplay attack
  - No POS terminal verification
  - Nonce generated by a non-relying party
  - And besides, with low entropy
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Part III – EMV Contactless cards

5 What?

6 EMV Contactless Protocol Details

7 Eavesdropping

8 Relay Attack
   ● Attack Description
   ● Android and NFC: A Tale of Love
   ● Demo Experiment
   ● Threat Scenarios
EMV contactless cards (I)

- Authenticating credit and debit card transactions
- Commands defined in ISO/IEC 7816-3 and ISO/IEC 7816-4
  (http://en.wikipedia.org/wiki/EMV)
- Application ID (AID) command
EMV contactless cards (II)
MasterCard PayPass, VISA payWave, and AmericanExpress ExpressPay

Are they secure?
EMV contactless cards (II)
MasterCard PayPass, VISA payWave, and AmericanExpress ExpressPay

Are they secure?

- Amount limit on a single transaction
  - Up to £20 GBP, 20€, US$50, 50CHF, CAD$100, or AUD$100
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    (http://www.bankinfosecurity.com/android-attack-exploits-visa-emv-flaw-a-7516/op-1)

- Sequential contactless payments limited – it asks for the PIN

- Protected by the same fraud guarantee as standard transactions (hopefully)
EMV Contactless Protocol Details (I)

- Standard specification distributed over 4 books
  - Book A. *Architecture and General Requirements*
  - Book B. *Entry Point*
  - Book C. *Kernel Specification*
  - Book D. *Contactless Communication Protocol*

- Different variants for book C (seven!)
- Based on ISO/IEC 14443
  - Recall the introduction 😊
- All EMV applications listed in “2PAY.SYS.DDF01” file
EMV Contactless Protocol Details (II)

MasterCard PayPass (1)

- Kernel 2
- Two modes
  - EMV mode
  - Magnetic stripe mode
EMV mode

- No DDA
- One application cryptogram for online transactions
- **RECOVER AC command** (to restore torn transactions)
- Data may be temporally stored on card ("scratch pad")
EMV Contactless Protocol Details (IV)
MasterCard PayPass (3)

Mag-stripe mode

- Backward compatibility (❤❤)
- COMPUTE CRYPTOGRAPHIC CHECKSUM command: generate Card Verification Code (CVC3)
  - Unpredictable number (UN)
  - Application Transaction Number (ATC)
  - Secret Key
- CVC3 + UN used to construct valid mag-stripe data
EMV Contactless Protocol Details (IV)
MasterCard PayPass (3)

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  - Unpredictable number (UN)
  - Application Transaction Number (ATC)
  - Secret Key
- CVC3 + UN used to construct valid mag-stripe data

Pre-play + rollback attack (Roland and Langer, 2013)
- UN length: 1 to 3 digits
- Fallback possible
  - To mag-stripe mode
  - To shorter UN
EMV Contactless Protocol Details (V)

VISA payWave (1)

- Kernel 1 and 3
- Two modes
  - EMV modes
    - VSDC: original EMV + minor changes
    - qVSDC: different from original EMV
- No offline plaintext PIN allowed
EMV Contactless Protocol Details (VI)

VISA payWave (2)

1. SELECT 26#SYS.DDF01
   1.1: success

2. SELECT VISA payWave AID
   2.1: PDOL

3. GET PROCESSING OPTIONS + PDOL data
   3.1: AIP + AFL

4. GPO (amount, currency, UN, ...)
   4.1: ATC, AC, SDAD, PAN

Generate nonce $N_c$
Session key based on ATC:

$K_s = Enc_{K_{des}}(ATC)$

$AC = MAC_{K_s}(\text{amount, ATC, currency, UN, ...})$

$SDAD = \text{sign}(AC, amount, ATC, currency, UN, N_c, ...)$
NFC Eavesdropping

What data are being transmitted from my card?
(without any reader verification, it rocks!)
NFC Eavesdropping

What data are being transmitted from my card?
(without any reader verification, it rocks!)

- Primary Account Number (PAN)

Recall: demo here

Hw used: Proxmark3 + Google Nexus + NFC-capable MasterCard
NFC Eavesdropping

What data are being transmitted from my card? (without any reader verification, it rocks!)

- Primary Account Number (PAN)
- Name

Recall: demo here

Hw used: Proxmark3 + Google Nexus + NFC-capable MasterCard
NFC Eavesdropping

What data are being transmitted from my card?
(without any reader verification, it rocks!)

- Primary Account Number (PAN)
- Name
- Expiration date

Recall: demo here

*Hw used:* Proxmark3 + Google Nexus + NFC-capable MasterCard
NFC Eavesdropping

What data are being transmitted from my card?
(without any reader verification, it rocks!)

- Primary Account Number (PAN)
- Name
- Expiration date
- Transaction history

Recall: demo here

Hw used: Proxmark3 + Google Nexus + NFC-capable MasterCard
NFC Eavesdropping

What data are being transmitted from my card?
(without any reader verification, it rocks!)

- Primary Account Number (PAN)
- Name
- Expiration date
- Transaction history
  - Data from NFC plus chip payments...

Recall: demo here

Hw used: Proxmark3 + Google Nexus + NFC-capable MasterCard
NFC Relay Attack Description (I)

Relay attacks

Mafia frauds – Y. Desmedt (SecuriCom’88)

\[ P \rightarrow \overline{V} \leftarrow \text{communication link} \rightarrow \overline{P} \rightarrow V \]

- Real-time fraud where a fraudulent prover \( \overline{P} \) and verifier \( \overline{V} \) cooperate
NFC Relay Attack Description (I)

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- Real-time fraud where a fraudulent prover \( \text{\overline{P}} \) and verifier \( \text{\overline{V}} \) cooperate
- Honest prover and verifier: contactless card and Point-of-Sale terminal
- Dishonest prover and verifier: two NFC-enabled Android devices
NFC Relay Attack Description (II)

Using Android!

[reader/writer mode]

[card-emulation mode]

P2P communication (WiFiDirect, TCP/IP, Bluetooth...)

\[ P \rightarrow V \]

\[ V \rightarrow P \]

Bank Card

Bank Name

P

V

R. J. Rodríguez (UZ)
Android and NFC: A Tale of Love (I)

Recap on evolution of Android NFC support

Android 2.3.3 Gingerbread (API level 10)
- NfcA (ISO/IEC 14443-3A)
- Ndef
- NfcV (ISO/IEC 15693)
- NdefFormattable
- MifareClassic
- MifareUltraLight

Android 4.2 Jelly Bean (API level 17)
- NfcBarcode
- NfcB (ISO/IEC 14443-3B)
- IsoDep (ISO/IEC 14443-4)
- NfcF (JIS 6319-4)

Android CyanogenMod OS 9.1
- IsoPcdA (ISO/IEC 14443-4A)
- IsoPcdB (ISO/IEC 14443-4B)

Android 4.4 KitKat (API level 19)
- NfcAdapter.ReaderCallback added

NFC operation modes supported
- Reader/Writer
- Peer-to-peer
- Card-emulation

CyberCamp 2015 60 / 78
Android and NFC: A Tale of Love (II)

Digging into Android NFC stack – just a bit!

- Event-driven framework, nice API support
- Two native implementations (depending on built-in NFC chip)
  - libnfc-nxp
  - libnfc-nci
Android and NFC: A Tale of Love (II)

Digging into Android NFC stack – just a bit!

- Event-driven framework, nice API support
- Two native implementations (depending on built-in NFC chip)
  - libnfc-nxp
  - libnfc-nci
- NXP dropped in favour of NCI:
  - Open architecture, not focused on a single family chip
  - Open interface between the NFC Controller and the DH
  - Standard proposed by NFC Forum
Android and NFC: A Tale of Love (III)

Digging into Android NFC stack – Reader/Writer mode

- Not allowed to be set directly → Android activity
- Android NFC service selects apps according to tag definition of Manifest file
- In low-level, libnfc-nci uses reliable mechanism of queues and message passing – General Kernel Interface (GKI)
  - Makes communication between layers and modules easier
A service must be implemented to process commands and replies. HostApduService abstract class, and processCommandApdu method. AID-based routing service table. This means you need to declare in advance what AID you handle!
### Android and NFC: A Tale of Love (V)

Digging into Android NFC stack – summary & limitations

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- Only valid communication with IsoDep cards
- `libnfc-nci` do not allow sending raw ISO/IEC 14443-3 commands
  
  
  Solution: modify NFCC

- Device in HCE mode
  
  - AID must be known in advance

  **Solution:** `sudo make me a sandwich`

- Maximum delay allowed in the relay channel:
  
  - `FWT = 256 · (16 / fc) · 2`  
  - `FWI, 0 ≤ FWI ≤ 14`, where `fc = 13.56 MHz`

  - `FWT ∈ [500 µs, 5 s]` → relay possible if delay is ≤ 5 s
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Relay Attack Implementation (I)

Experiment configuration

- **PoS device**: Ingenico IWL280 with GRPS + NFC support
- **Android app developed**: (±2000 LOC)
- **Two OTS Android NFC-capable devices**
  - One constraint only: dishonest prover must run an Android ≥ 4.4
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### Experiment Details

| $V \rightarrow P$ | 00A4 0400 0E32 5041 592E 5359 532E 4444 4630 3100 |
| $P \rightarrow V$ | 6F30 840E 3259 4159 2E53 5953 2E44 4446 3031 A51E BF0C 1B61 194F 08A0 0000 0004 1010 0250 0A4D 4153 5445 5243 4152 4487 0101 9000 |
| $V \rightarrow P$ | 00A4 0400 08A0 0000 0004 1010 0200 |
| $P \rightarrow V$ | 6F20 8408 A000 0000 0410 1002 A514 8701 0150 0A4D 4153 5445 5243 4152 445F 2D02 6361 9000 |
| $V \rightarrow P$ | 80A8 0000 0283 0000 |
| $P \rightarrow V$ | 7716 8202 1880 9410 0801 0100 1001 0100 1801 0200 2001 0200 9000 |
| $V \rightarrow P$ | 00B2 0114 00 |
| $P \rightarrow V$ | 7081 9357 13X0 XXXX XXXX XXXX XXXX XXXX XXXX XXXX XXXX XXXX XXXX 5A08 XXXX XXXX XXXX 5F24 03XX XXXX 5F28 0207 245F 3401 018C 219F 0206 9F03 069F 1A02 9505 5F2A 029A 039C 019F 3704 9F35 019F 4502 9F4C 089F 3403 8D0C 910A 8A02 9505 9F37 049F 4C08 8E0C 0000 0000 0000 0000 4203 1F03 9F07 023D 009F 0802 0002 9F0D 05B0 50AC 8000 9F0E 0500 0000 0000 9F0F 05B0 70AC 0800 9F4A 0182 9000 |
| $V \rightarrow P$ | 00B2 011C 00 |
| $P \rightarrow V$ | 7081 C28F 0105 9F32 0301 0001 9204 3DD0 2519 9081 0304 45XX ...XX62 9000 |
| $V \rightarrow P$ | 00B2 021C 00 |
| $P \rightarrow V$ | 7081 B393 81B0 3445 XXXX XXXX XXXX ...XXX XXXX XX62 9000 |
| $V \rightarrow P$ | 00B2 0124 00 |
| $P \rightarrow V$ | 7033 9F47 0301 0001 9F48 2A3E XXXX ...XXX XXXX XX6D 9000 |
| $V \rightarrow P$ | 00B2 0224 00 |
| $P \rightarrow V$ | 7081 949F 4681 9018 XXXX XXXX XXXX ...XXX XXXX XXF5 9000 |
| $V \rightarrow P$ | 80AE 8000 2B00 0000 0000 0100 0000 0000 0007 2480 0000 8000 0978 1502 2400 37FB 88BD 2200 0000 0000 0000 001F 03 |
| $P \rightarrow V$ | 7729 9F27 01XX 9F36 02XX 9X9F 2608 XXXX XXXX XXXX XXXX 9F10 12XX ...XX90 00 |
Relay Attack Implementation (II)

Threat Scenarios – Scenario 1

DISTRIBUTED MAFIA FRAUD

BOTMASTER

BOT

BOT

BOT

BOT

BOT
Relay Attack Implementation (III)
Threat Scenarios – Scenario 2

HIDING FRAUD LOCATIONS
Part IV – Solutions, Conclusions, and References

9. Mechanisms Against NFC Security Threats

10. Related Work

11. Conclusions
Mechanisms Against NFC Security Threats

### Against eavesdropping
- RFID blocking covers
- Physical button/switch activation
- **Secondary authentication methods** (e.g., on-card fingerprint scanners)
Mechanisms Against NFC Security Threats

Against eavesdropping

- RFID blocking covers
- Physical button/switch activation
- Secondary authentication methods (e.g., on-card fingerprint scanners)

Against relay attacks

- Distance-bounding protocols
  - Upper bounding the physical distance using Round-Trip-Time of cryptographic challenge-response messages
- Timing constraints
  - Not enforced in current NFC-capable systems
  - The own protocol allows timing extension commands (WTX)
- Physical countermeasures
  - Whitelisting/Blacklisting random UID in HCE mode → unfeasible
Related Work (I)

On EMV cards attacks

- Singleton, T.; *Credit Card Crimewave: What to Do?*. Journal of Corporate Accounting & Finance, 2014, 25, 7–11
- Bond, M. et al.; *Chip and Skim: Cloning EMV Cards with the Pre-play Attack*. In IEEE Symposium on Security and Privacy, 2014, 49–64
Related Work (II)

On Point-of-Sales


Sanders, R.; From EMV to NFC: the contactless trail?. Card Technology Today, 2008, 20, 12-13
Related Work (IV): on relay attacks

- **2005-2009** Built on specific hardware (Hancke et al., Kfir & Wool)
- **2010** NFC-enabled Nokia mobile phones plus a Java MIDlet app (Francis et al., Verdult & Kooman)
- **2012-2013** Relay attacks on Android Secure Elements (Roland et al.)
  - Secure storage for credit/debit cards data
  - Needs a non-OTS Android device
- **2013** Delay upon relay channel: (Oren et al., Sportiello & Ciardulli)
  - Latency of the relay channel isn’t a hard constraint at all
- **2014** Active relay attacks with custom hardware and custom Android firmware (Korak & Hutter)
- **2015** Passive relay with Android OTS devices (Vila & Rodríguez)

Android apps available (SF and Google Play)

- **2012** nfcproxy (Cyanogen Mod, card-emulation support)
- **2014** nfcspy (catch-all AID module from XPosed framework)
Conclusions (I)

Security of NFC is based on the physical proximity concern
Conclusions (I)

Security of NFC is based on the physical proximity concern

Definitely, physical proximity is not a reliable constraint

- NFC threats: eavesdropping, data modification, relay attacks
- Android NFC-capable devices are rising
  - Abuse to interact with cards in its proximity
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EMV contactless payments threats

- EMV threats

Virtual pickpocketing attack may appear before long!
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EMV contactless payments threats

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- NFC threats

Virtual pickpocketing attack may appear before long!

Take-home message: watch your wallet and any NFC-capable cards on your own
Conclusions (II)

What can I do?
Conclusions (II)
Bonus Track: DNI v3.0 (I)

ARE MY ID DATA

FLYING OVER MY POCKET?
Bonus Track: DNI v3.0 (I)

Yep, it is!*
Bonus Track: DNI v3.0 (I)

Basic Access Control: $f(MRZ)$

MRZ (Machine Readable Zone) code:
- Document number: 3 chars + 6 numbers
- Date of birth: 6 numbers
- Expiration date: 6 numbers

Yep’s, it is!*
Bonus Track: DNI v3.0 (I)

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Yep, it is!*

- Basic Access Control: $f(MRZ)$
- MRZ (MachineReadableZone) code:
  - Document number: 3 chars + 6 numbers
  - Date of birth: 6 numbers
  - Expiration date: 6 numbers
Potential problems ahead...

- Attacks on identity (important for the Government)
  - Forgery
  - Impersonation
  - ...

- Attacks on confidentiality (important for the people)
  - Privacy
  - Anonymity
  - ...

R. J. Rodríguez (UZ)
Contactless Payment Cards: Vulnerabilities, Attacks, and Solutions

Dr. Ricardo J. Rodríguez

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