Formal analysis of the EMV protocol suite

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What is EMV?

Standard for communication between chip based payment cards and terminals

What is EMV?

Maintained by

Owned by

What is EMV?

- Initiated in 1993
- Over 1 billion cards in circulation
- Compliance required for Single Euro Payments Area

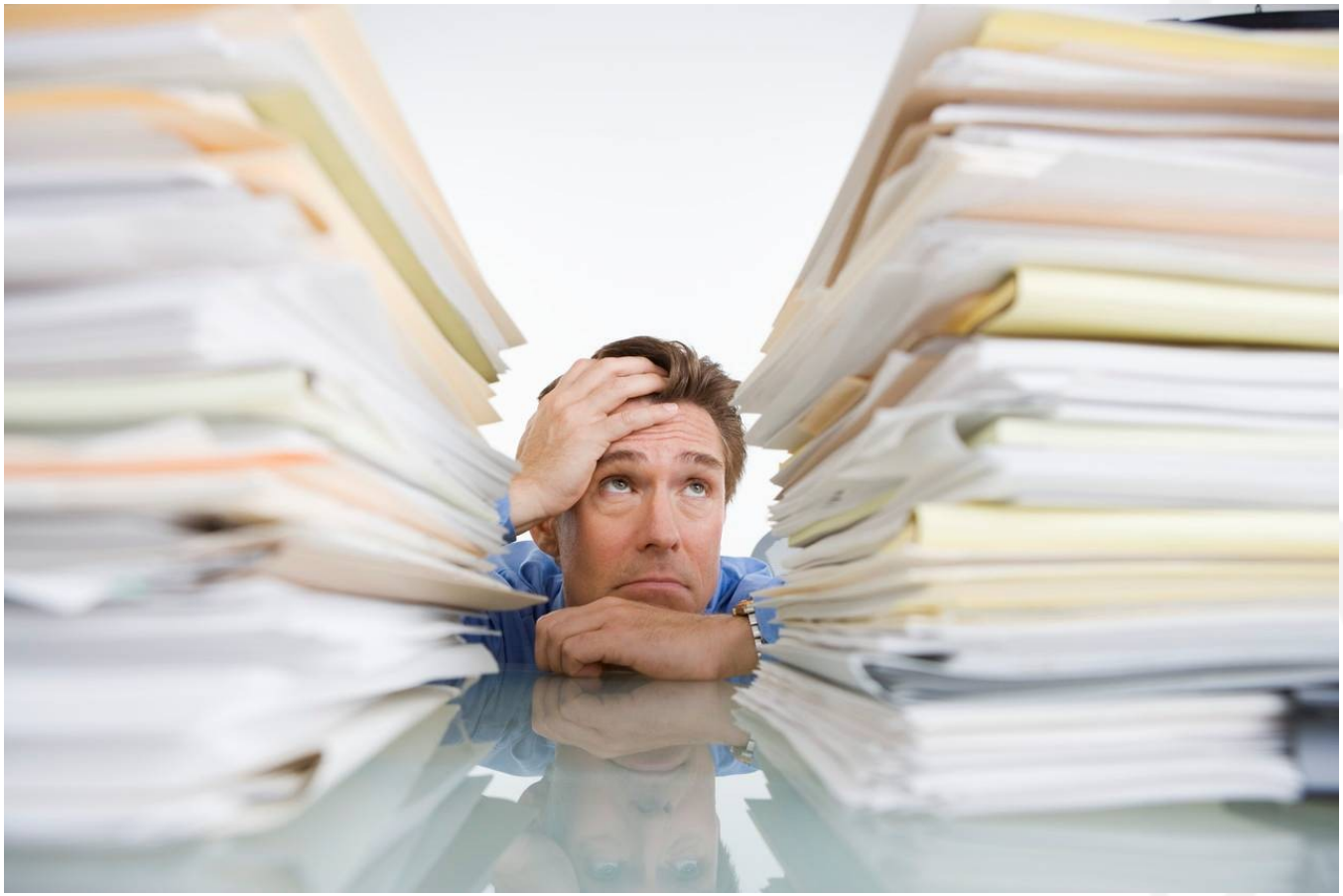
Why EMV?

- Reducing fraud
  - Skimming
  - Usage of stolen credit cards with forged signatures
  - Card-not-present fraud (EMV-CAP)

- Liability shift
  - Merchant: if no EMV is used
  - Customer: if PIN is used

Complexity

- Over 700 pages



Complexity

- Many options and parameterisations
  - 3 card authentication methods
    - SDA / DDA / CDA
  - 5 cardholder verification methods
    - PIN / Handwritten signature / None
  - 2 types of transactions
    - Online / offline
  - Parameterisation using Data Object Lists

Key set-up

- Card and issuer: symmetric key
  - For authentication of transactions
- Issuer: private/public keypair
  - For authentication of cards
- Cards (optional): private/public keypair
  - For authentications of cards/transactions

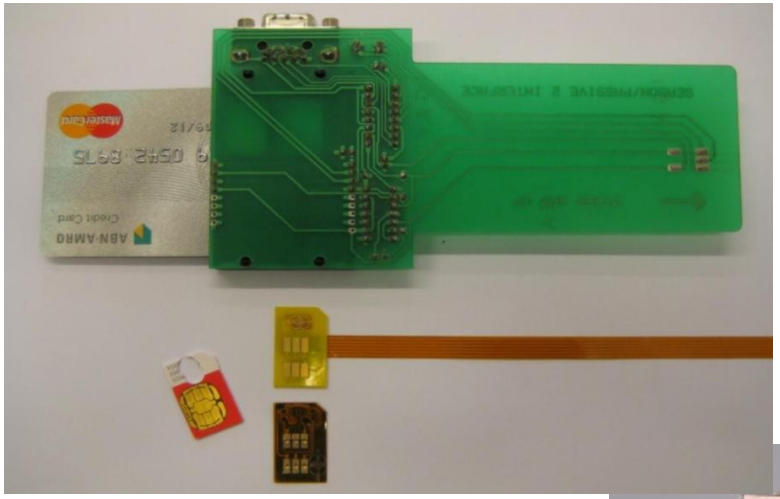
Card authentication

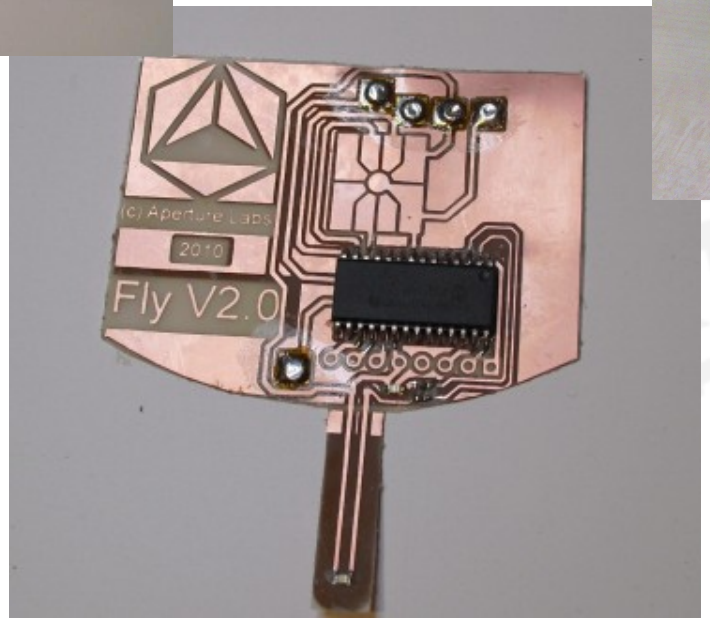
- Static Data Authentication (SDA)
  - Static data on card signed by issuer
- Dynamic Data Authentication (DDA)
  - Using asymmetric crypto
  - Challenge/response mechanism
- Combined Data Authentication (CDA)
  - Transaction data signed

Attacking smartcards

- No direct copying possible
- Eavesdropping on communication
  - Existing hardware used for pay TV and SIM cards
- Active / wedge attacks
  - Modifying traffic between card and terminal
  - Developed our own hardware

Attacking smartcards





Known weaknesses

- Cloning SDA card
  - Possible to perform offline transactions
- DDA wedge attack
  - Possible to perform offline transactions
- “Chip & PIN is broken” [Murdoch et al. 2010]
  - Possible with both online and offline transactions
    - If card is not reported stolen
    - If PIN-less transactions are allowed

Formal verification - ProVerif

- Automated cryptographic protocol verifier
- Active / passive attacker
- Cryptography considered to be perfect
- Unbounded number of sessions
  - Due to some approximations
  - False attacks possible
  - Claimed properties always hold

Formal verification - ProVerif

- Input in applied pi-calculus
- Queries
  - Secrecy

```
query attacker:M.
```

  - Authenticity

```
query ev:End ==> ev:Begin.
query evinj:End ==> evinj:Begin.
```

- Attack reconstruction

F#

- Formalisation in F#
  - Functional programming language
  - Developed by Microsoft Research
  - Executable code
  - Translated to applied pi-calculus using FS2PV
    - Subset of F# language
    - More flexibility

Formalisation

- Card and terminal formalised
- Options can be either unspecified or fixed
- DOLs fixed for Dutch banking cards
- 370 lines of F# code
  - Over 2500 lines of applied pi-calculus

Formalisation

Formalisation

```
// Card initialisation
let sIC = rsa_keygen () in
let pIC = rsa_pub sIC in
let pan = mkNonce () in
let mkAC = create_mkAC pan in

let (sda_enabled, dda_enabled, cda_enabled) = Net.recv c in

card_process (sIC, pIC, mkAC, pan) c (sda_enabled, dda_enabled,
    cda_enabled))
```

Formalisation

```
// Perform DDA Authentication if requested, otherwise do nothing
let card_dda (c, atc, (sIC,pIC), nonceC) dda_enabled =
  let data = Net.recv c in
  if Data.INTERNAL_AUTHENTICATE = APDU.get_command data then
    if dda_enabled then
    begin
      let nonceT = APDU.parse_internal_authenticate data in
      let signature = rsa_sign sIC (nonceC, nonceT) in
      Net.send c (APDU.internal_authenticate_response nonceC signature);
      Net.recv c
    end
    else  failwith "DDA not supported by card"
  else  data
```

Security properties

- Sanity checks
- Secrecy of private keys
- Highest supported authentication method used
- Transaction authentication

Security properties

- Card and terminal agree whether PIN is entered correctly

  evinj:TerminalVerifyPIN(True)
  ==>
  evinj:CardVerifyPIN(True)

- Transaction are authentic

  evinj:TerminalTransactionFinish(sda,dda,cda,pan,atc,True)
  ==>
  evinj:CardTransactionFinish(sda,dda,cda,pan,atc,True)

Results

- Reduction from 700 pages to 370 lines
  - Resulting in over 2500 lines of applied pi-calculus
- ProVerif was still able to verify our queries
- All known weaknesses found
- Existing tools mature enough to be used on industry standards

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Thanks for your attention!