Osmocom SIMtrace

SIM card protocol tracing - why and how

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Terminology

SIM	Subscriber Identity Module
USIM	Universal Subscriber Identity Mdoule
UICC	Universal Integrated Chip Card
MS	GSM Mobile Station (phone, modem)
UE	UMTS User Equipment
ME	GSM Mobile Equipment (MS + SIM)
OTA	Over The Air
SAT	SIM Application Toolkit
CAT	Card (UICC) Application Toolkit
USAT	USIM Application Toolkit
TAR	Toolkit Application Reference

Relevant Specification Bodies

- ISO (ISO 7816) smart cards
- ETSI (Eurpoean Telecomms Standardisation Institute)
    - Classic GSM SIM
    - UICC card as basis for various telecom ID purposes
    - Card Application Toolkit (CAT)
- 3GPP (3rd Generation Partnership Project)
    - USIM Application
    - USIM Application Toolkit (USAT)
    - API based applet interworking
- Global Platform
    - Overall spec for SIM/USIM with Java
- Sun Microsystems (now Oracle)
    - Java Card Virtual Machine
    - Java Card Runtime Environment

The Subscriber Identity Module (SIM)

- Basic idea was to store cryptographic identity of subscriber inside smart card
- User can thus migrate identity from one device to another
- User can furthermore use different SIM in same device (e.g. local prepaid SIM while travelling)
- Original SIM card design mostly ISO 7816-4 filesystem and single command to execute A3/A8 algorithm inside card
  - This could even be done in logic, no processor required

The modern SIM

The modern SIM is an entirely different beast

- Cryptographic processor smart card
  - Symmetric cryptography such as DES, 3DES, AES
  - Public key cryptography such as RSA, ECC
- Java Card including a small Java VM and Java RE
- Multiple application support
- Ability to download applications (Applets) into card

Smart Card Basics

- microprocessor with RAM, Flash and Operating System
- Interface: Electrical + Logical Protocol (ISO7816-3, ISO7816-4)
- File System based representation of information
- Protocol describes remote operations on the file system
- Few non-filesystem related commands for e.g. authentication

Smart Card Filesystem

- Hierarchical file system like on PC

  MF (master file): root directory

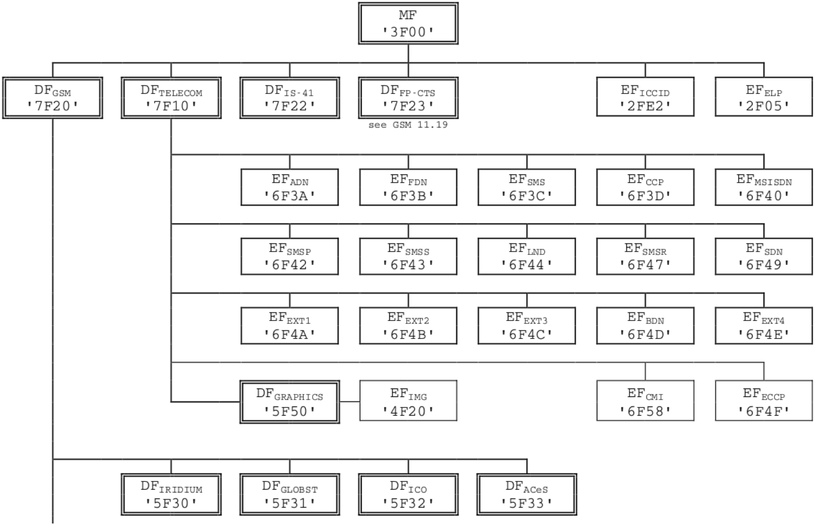
  DF (dedicated file): subdirectory

  EF (entry file): actual file

  - transparent or record oriented
  - record linear fixed/variable or record cyclic

- File names don't exist on card. 16bit FID (File ID) or 8bit SFID used instead

Smart Card Filesystem Hierarchy



MF '3F00'

DF_{GSM} '7F20'

$\text{DF}_{\text{TELECOM}}$ '7F10'

$\text{DF}_{\text{IS-41}}$ '7F22'

$\text{DF}_{\text{FP-CTS}}$ '7F23'

see GSM 11.19

EF_{ICCID} '2FE2'

EF_{ELP} '2F05'

EF_{ADN} '6F3A'

EF_{FDN} '6F3B'

EF_{SMS} '6F3C'

EF_{CCP} '6F3D'

$\text{EF}_{\text{MSISDN}}$ '6F40'

EF_{SMSP} '6F42'

EF_{SMSS} '6F43'

EF_{LND} '6F44'

EF_{SMSR} '6F47'

EF_{SDN} '6F49'

EF_{EXT1} '6F4A'

EF_{EXT2} '6F4B'

EF_{EXT3} '6F4C'

EF_{BDN} '6F4D'

EF_{EXT4} '6F4E'

$\text{DF}_{\text{GRAPHICS}}$ '5F50'

EF_{IMG} '4F20'

EF_{CMI} '6F58'

EF_{ECCP} '6F4F'

$\text{DF}_{\text{IRIDIUM}}$ '5F30'

$\text{DF}_{\text{GLOBST}}$ '5F31'

DF_{ICO} '5F32'

DF_{ACeS} '5F33'

SIM Card APDU Commands

Classic SIM card commands include the following

- SELECT (change directory / open file)
- READ BINARY, UPDATE BINARY (read/write transparent EF)
- READ RECORD, UPDATE RECORD (read/write record EF)
- ENABLE CHV, DISABLE CHV, CHANGE CHV (enable, disable or change PIN)
- VERIFY CHV, UNBLOCK CHV (verify or unblock PIN)
- RUN GSM ALGORITHM (A3/A8 authentication)

Smart Card Filesystem

Typical operations of the phone include

- navigating inside filesystem by SELECT on DF/EF
- authenticating the user PIN
- reading/updating files
  - reading IMSI
  - old-school SMS and contact storage
  - storing session keys (Kc/KcGPRS, ...)
  - storing last cell on power-off

Smart Card PINs

The level of access to the filesystem and other card features is determined by authentication using a shared secret, called ’PIN’.

- Regular PIN for normal use of the card by the end user
- PUK for resetting the pin after too many retries
- ADM1..n PIN for access by the operator only

SIM Application Toolkit (SAT)

- Ability for card to run applications that have UI on the phone
  - Display menu items on-screen
  - Get user input from keypad/touch-screen
- Original Version Described in TS 11.14 and 11.11

SAT – Proactive SIM

The *Proactive SIM* features

- Sending a short message
- Setting up a voice call
- Playback of a tone in earpiece
- Providing location information from ME to SIM
- Have ME execute timers on behalf of SIM
- Sending DTMF to network
- Running an AT command received from SIM, sending result back to SIM
- Ask ME to launch browser to SIM-provided URL

SAT – Call and SMS Control

- ME passes MO call setup attempts to SIM for approval
- SIM can then
  - approve or decline the MO call
  - modify the call details such as phone number
  - replace the call with USSD message
- ME passes USSD requests similar to Call Control
- Similar mechanism exists for all MO SMS

SAT – Provide local information

The SIM can inquire the ME about

- MCC / MNC / LAC / Cell ID
- IMEI of ME
- Network Measurement Results
- BCCH channel list
- Date, Time, Timezone
- ME language setting
- Timing Advance

SAT – Event download

The SIM is notified by ME about certain events such as

- Call Connected / Disconnected
- Location Status (Location Area change)
- User activity (keyboard input)
- Idle screen available
- Browser termination

SAT - Data download

- Enables Operator to exchange arbitrary data with the SIM
- Could be RFM (Remote File Management)
  - Read or modify phone book entries
  - Even change the IMSI of the SIM (!)
- In case of Java Card, can be download of card applets
  - Applets are stored permanently on SIM
  - Can later use SAT procedures to interact with ME
  - TS 03.19 specifies Java API to access SAT from Java RE

SAT - Data download

SAT Data Download can happen via

- via SMS or Cell Broadcast
  - Uses TS 03.40 TP-PID *SIM DATA Download*
  - ME forwards such SMS to the SIM in `ENVELOPE` APDU
  - Response from SIM is sent back as MO-SMS or DELIVERY REPORT
- via BIP (Bearer Independent Protocol)
  - Dedicated CSD call between network and SIM
  - GPRS session between network and SIM

SAT - Data download

Data download security

- GSM TS 03.48 specifies secure messaging for data download
- Includes replay protection
- Supports DES and 3DES
- SMS chaining for long commands / large data

SIM card abuse by hostile operator

- Even if the phone might be considered trusted, the SIM card is owned and controlled by the operator
- Using SAT features, the operator can control many aspects of the phone
- Examples
  - Remotely reading address book / stored SMS
  - Monitor user behavior (browser termination, idle screen, ...)
  - Ask phone to establish packet data session

SIM card re-programming by attacker

- If the SIM is not properly secured (auth + encryption keys, ...) a third party attacker can send SAT envelope SMS to the card and install resident Java applets
- The attacker can then
  - Obtain detailed location information and send it via SMS
  - Intercept/log outgoing calls
  - Sending copies of incoming + outgoing SMS elsewhere
- Even using SIM card channel to exploit baseband stack is feasible

SIM card proxy / MITM by attacker

As soon as an attacker has temporary physical access to a phone, he can

- Insert a proxy-SIM between real SIM and phone
- Do everything a Java applet could do, but even with a securely configured SIM as he does not modify the existing SIM
- Sniff current Kc and send it out e.g. via SMS or even UDP/TCP packets over GPRS
- ... by only using standard interfaces that are common among all phones (as opposed to baseband software hacking which is very model-specific)

Most users would never notice this as they rarely check their SIM slot

Defending against SIM based attacks

- SIM cards are Operator issued, Ki is on the SIM
  - SIM card can thus not be replaced, but original SIM must be used
- Configure telephone to not store contacts or SMS on SIM
- Communication between SIM and ME is not encrypted/authenticated
- Solution: Proxy SIM between SIM and ME to break STK / OTA
  - Filter all STK/OTA/Proactive commands like ENVELOPE
  - Indicate lack of STK support to ME (EF.Phase)

Proxy SIM with firewall

- There are no known commercial products that implement STK/OTA filtering
- But there are a number of shim SIM cards that are plugged between SIM and SIM slot
- Most of them are used for SIM unlocking modern phones
- Some vendors produce freely (re)programmable proxy SIMs:

Figure: Bladox TurboSIM (AVR) and RebelSIM II (8051)

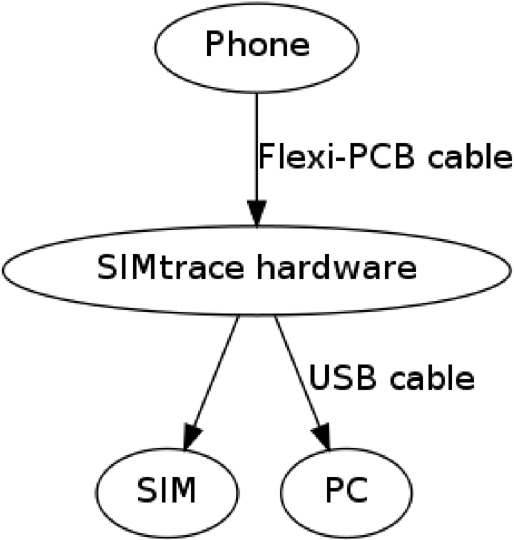
Analyzing SIM toolkit applications is hard

- Regular end-user phone does not give much debugging
- SIM card itself has no debug interface for printing error messages, warnings, etc.
- However, as SIM-ME interface is unencrypted, sniffing / tracing is possible
- Commercial / proprietary solutions exist, but are expensive (USD 5,000 and up)
- Technically, sniffing smard card interfaces is actually very simple

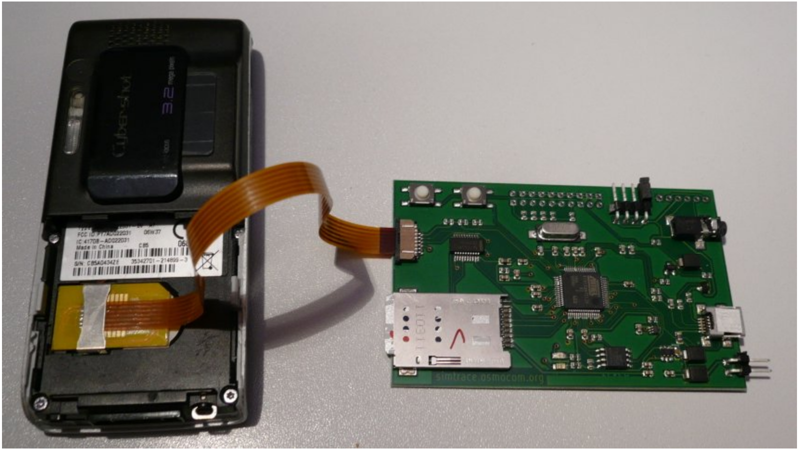
Introducing Osmocom SIMtrace

- Osmocom SIMtrace is a passive (U)SIM-ME communication sniffer
- Insert SIM adapter cable into actual phone
- Insert (U)SIM into SIMtrace hardware
- SIMtrace hardware provides USB interface to host PC
- `simtrace` host PC program encapsulates APDU in GSMTAP
- GSMTAP is sent via UDP to localhost
- wireshark dissector for GSM TS 11.11 decodes APDUs

Osmocom SIMtrace Principle



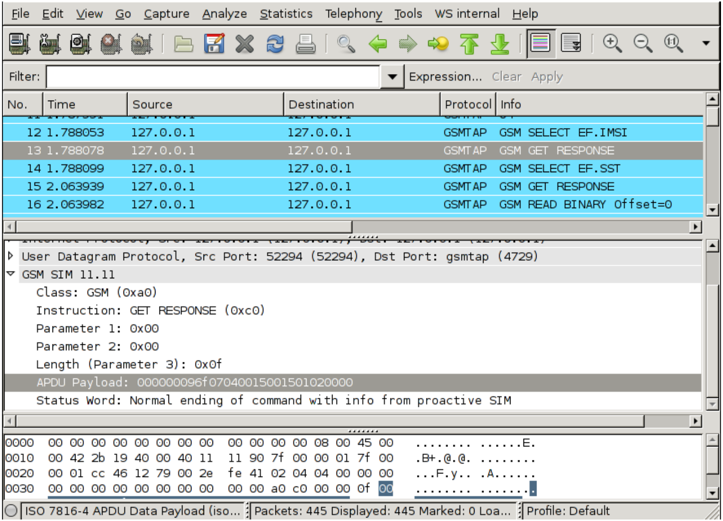
Osmocom SIMtrace Hardware



Osmocom SIMtrace Hardware

- Hardware is based around AT91SAM7S controller
- SAM7S Offers two ISO 7816-3 compatible USARTs
- USARTs can be clock master (SIM reader) or slave (SIM card)
- Open Source Firmware on SAM7S implementing APDU sniffing
- Auto-bauding depending CLK signal, PPS supported
- Schematics / layout is open source (CC-BY-SA)
- Assembled + tested kits can be bought from http://shop.sysmocom.de/

wireshark decoding


File Edit View Go Capture Analyze Statistics Telephony Tools WS internal Help
Filter:
Expression... Clear Apply

```
No.  Time       Source      Destination   Protocol  Info
  12 1.788053   127.0.0.1   127.0.0.1     GSMTAP    GSM SELECT EF.IMSI
  13 1.788078   127.0.0.1   127.0.0.1     GSMTAP    GSM GET RESPONSE
  14 1.788099   127.0.0.1   127.0.0.1     GSMTAP    GSM SELECT EF.SST
  15 2.063939   127.0.0.1   127.0.0.1     GSMTAP    GSM GET RESPONSE
  16 2.063982   127.0.0.1   127.0.0.1     GSMTAP    GSM READ BINARY Offset=0
```

```
▷ User Datagram Protocol, Src Port: 52294 (52294), Dst Port: gsmtap (4729)
▽ GSM SIM 11.11
    Class: GSM (0xa0)
    Instruction: GET RESPONSE (0xc0)
    Parameter 1: 0x00
    Parameter 2: 0x00
    Length (Parameter 3): 0x0f
    APDU Payload: 000000096f07040015001501020000
    Status Word: Normal ending of command with info from proactive SIM
```

```
0000  00 00 00 00 00 00 00 00  00 00 00 00 08 00 45 00   ........ ......E.
0010  00 42 2b 19 40 00 40 11  11 90 7f 00 00 01 7f 00   .B+.@.@. ........
0020  00 01 cc 46 12 79 00 2e  fe 41 02 04 04 00 00 00   ...F.y.. .A......
0030  00 00 00 00 00 00 00 00  00 00 a0 c0 00 00 0f 00   ........ ........
```

○ ISO 7816-4 APDU Data Payload (iso... | Packets: 445 Displayed: 445 Marked: 0 Loa... | Profile: Default

SIMtrace TODO

SIMtrace hardware is capable, but no software yet for:

- perform MITM (APDU filtering)
- full software SIM card emulation
- PC/SC compatible smart card reader
- autonomous tracing operation (No PC / USB), store APDU logs *in the field* on integrated SPI flash

Firmware and host software all FOSS, anyone can extend and innovate!