MobiDeke: Fuzzing the GSM Protocol Stack

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Who we are

Sébastien Dudek

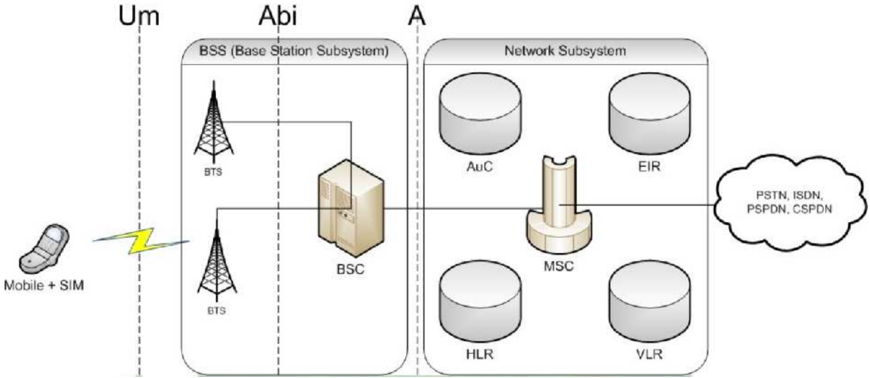
- Has joined the ESEC R&D lab this year (2012) after his internship
- Subject: Attacking the GSM Protocol Stack
- Developer of a GSM fuzzing framework ('MobiDeke')

Guillaume Delugré

- Researcher working at Sogeti ESEC R&D lab
- Working on embedded devices / reverse engineering
- Developer of 'qcombbdbg' (Qualcomm 3G key Icon255 debugger) and 'Origami'

Summary

The GSM (2G) network



User Equipments (mobile phones)

Radio control functions are highly timing dependant, so most of the phones use two separated CPUs nowadays

The application processor

- Runs the user OS: Android, iOS, Windows Mobile, and so on
- Documented (often)

The baseband processor

- Responsible for handling telecommunications
- Includes stacks for telephony protocols
- Closed binary blob running RTOS

See the talk of Guillaume at 28c3 (Chaos Computer Congress) for more information.

Existing attacks

Many papers have been published:

- Harald Welte: Fuzzing your GSM phone using OpenBSC (2009);
- Collin Mulliner: Fuzzing the Phone in your Phone (2009);
- Collin Mulliner, Nico Golde and Jean-Pierre Seifert : SMS of Death: from analyzing to attacking mobile phones on a large scale (2011);
- Nico Golde: SMS Vulnerability Analysis on Feature Phones (2011);
- Ralf-Philipp Weinmann: Baseband Attacks, WOOT 2012
- ...

What we are looking for

- The baseband: new angle of attack
- Setup a network is easy today thanks to SDR contributions (OpenBTS, OpenBSC, and so on)

  ⇒ Attacking a cellphone 'over-the-air' could be fun! (+ not completely explored)

Typical scenario

- The attacker controls a rogue base station
- The victim joins the cell and gets remotely exploited

*SDR: Software-Defined Radio

To reach our goal

- Baseband code is proprietary

How to find bugs?

- Reverse-engineering: Hard because the code is very complex
- Fuzzing: The easier way, but need some knowledge and a radio device like the USRP (we've won one at hack.lu;) or a nanoBTS, UmTRX, Phi card...

For more information: Harald Welte's presentation at SSTIC 2010 gives also a good overview of the GSM industry and security

Fuzzing

4 very important points

- Choose your target
  - Targeting the baseband GSM stack (2G), not 3G, HSDPA, LTE...
  - SMS are usually not parsed by the baseband (passed as raw PDUs to the APP)
  - Smartphones: HTC Desire S, Desire Z, iPhone 4S. . .
- Inject malformed data
- Monitor target activity
- Classify bugs, behaviours

Fuzzing

4 very important points

- Choose your target
- Inject malformed data
  - Smart generation of GSM packets (specs, existing librairies. . .)
  - Mutate each field of the generated message (describe a structure with Sulley)
- Monitor target activity
- Classify bugs, behaviours

Fuzzing

4 very important points

- Choose your target
- Inject malformed data
- Monitor target activity
  - Quite difficult because we don't have a debugger
  - Check if the phone is responding
  - Look for strange behaviors / side-effects
  - ...
- Classify bugs, behaviours

Fuzzing

4 very important points

- Choose your target
- Inject malformed data
- Monitor target activity
- Classify bugs, behaviours
  - Crash reporting: report with indicators
  - Replay the recorded payload and see what happens

Summary

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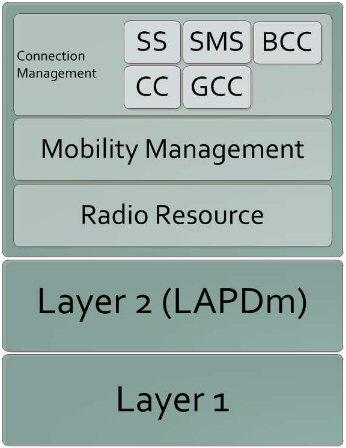
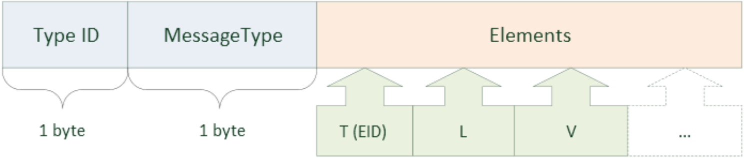
GSM layers



Layers

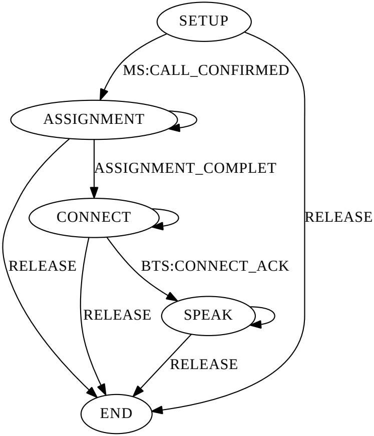
- Layer 3
  - Radio Ressource: Channel set up and tear-down
  - Mobility Management: User location...
  - Connection Management: Call (CC), SMS and other services
- Layer 2
  - Fragmentation
  - Integrity check
- Layer 1
  - Transfers data over the air interface
  - Uses GMSK modulation
  - F/TDMA for multiple accesses

L3 Messages structure



There are 5 standards defining information elements (described in `11.1.14` in the `TS 04.07`)

State Machines: Originating a Call example (simplified)



Observations

- There is often a way to exit from a state machine (e.g.: The `RELEASE` message)
- Sometimes a state requires user interaction
- There are 'obscure' elements: present in specs, but never seen in real life...

Message exchanges

Some message exchanges can be considered as stateless, but there are also finite state machines

Stateless exchanges

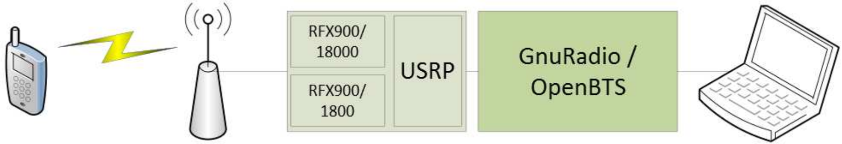
- Simple to fuzz

Finite state machines

- Complex and harder to fuzz
- Also harder to program correctly: potential surprises

Let's fuzz it!

We have set up our network with OpenBTS as follows



But how to send a payload to a targeted cellphone? ⇒ Use the '`testcall`' feature

The ‘testcall’ feature

The ‘testcall’ feature

- Included in OpenBTS (since 2.5 version) and OpenBSC
- Opens a channel for each targeted IMSI*
- The channel ties to an UDP socket on local computer
- Takes packets as Layer 3 messages and forwards them to the mobile

*IMSI: International Mobile Subscriber Identity

Fuzzing problems...

`Testcall` exists for fuzzing handsets, but it's not enough because

- It works for a limited time
- OpenBTS crashes a lot
- The reserved channel is not very stable
  - You're stuck to your chair while trying to send all your testcases...
- What about the monitoring?

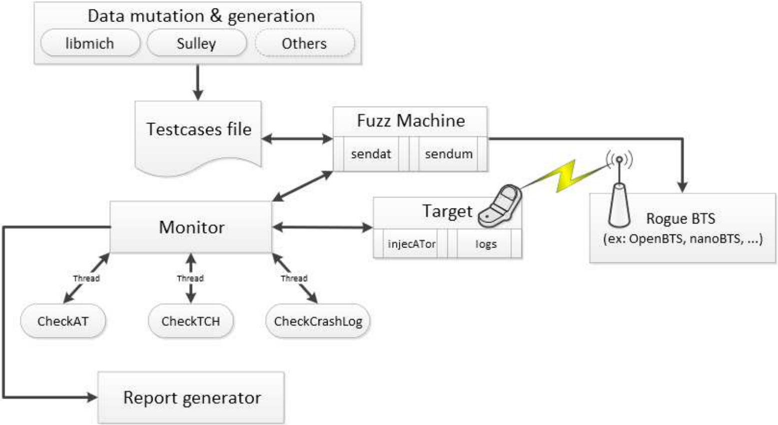
Summary

MobiDeke?

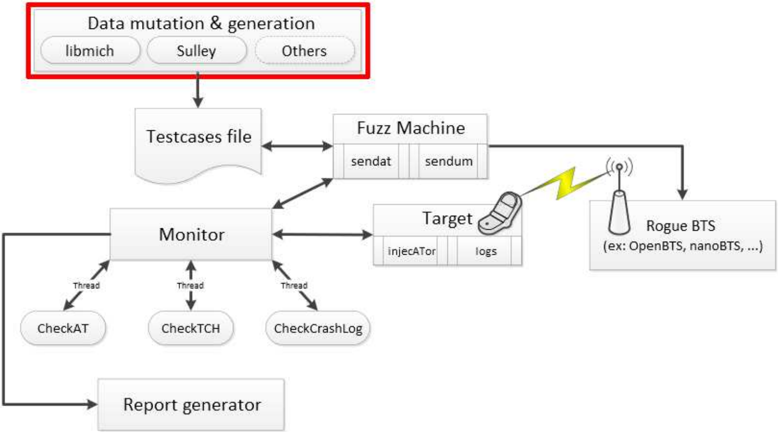
To perform our fuzzing tests, we created a framework that:

- Generates and mutates L3 messages
- Sends payload ‘over-the-air’
- Checks if a handset is ready to receive our payload
- Monitors states (Phone and BTS)
- Records a final report

MobiDeke Architecture Diagram



MobiDeke: Data generation and mutation



Methods for data generation and mutation

Creating crafted L3 messages

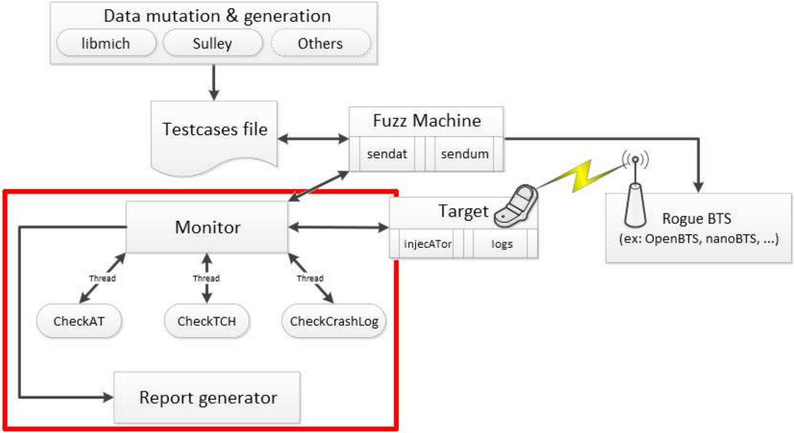
- Dumb: using captures (MBUS Nokia, OsmocomBB...) and bit-flipping
- Smarter: knowing the structure of the messages
  - `gsm_um` for scapy: interesting but not complete
  - `libmich` developed by Benoît Michau: we have chosen this solution for the most part

Mutations

- 'libmich' Mutor
- Sulley mutation engine

It is better to combine multiple generation methods to cover as much testcases as possible.

MobiDeke: Monitoring



Methods used to monitor crashes

Problems

- Blackbox monitoring
  - Did the baseband crash?

Solutions

- Check if the baseband still responds correctly to ‘AT’ commands
- Look for bugs on the application processor by checking crashlogs
- Check the radio channel state reserved by OpenBTS

Check the reserved channel: 'over-the-air'

Motivations

- OpenBTS crashes a lot! During that time your fuzzer continues to send payloads...
- Is the reserved channel stable enough?
- Is the baseband ready to receive the next payload?
- Did the baseband crash?

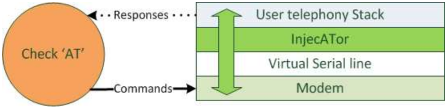
Solutions

- Check the radio channel state regularly ⇒ Transaction entries, paging states in OpenBTS.
- Send 'ping' requests to the baseband 'over-the-air'
  - Send a `IDENTITY REQUEST`, the mobile will respond with an `IDENTITY RESPONSE`

Check 'AT' responses with the 'injecATor' locally

- We checked for phone responsiveness on the radio side
- What about on the local interface?

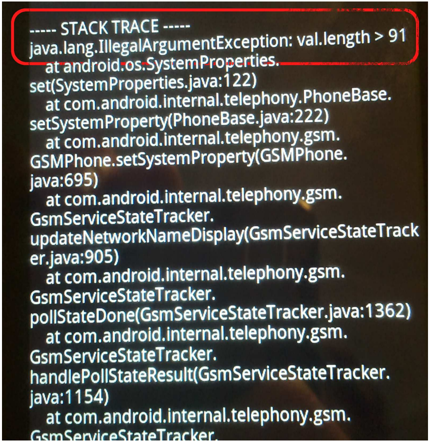
We modified Collin Mulliner's 'injector' to forward 'AT' responses over the opened socket.



- Lack of AT response can indicate a baseband crash/reboot
- Can also be used to simulate user interactions (e.g. accept a phone call)

Application OS bug report

- Even though we are targeting the baseband, some messages still get parsed by the application OS
- Can be the case for SMSs, Information Messages. . . .



Logfiles: Android logcats

Some useful data...

- When something crashes, it is likely to be reported in the *logcat* (Android syslogs)

Extract the information

- Fetch the logs using `adb` and filter this information
- Check for any known vocabulary in the log that could be related to a crash: '***', 'uncaught exception', 'Error Process'...

Logfiles: iOS CrashReporter

- iOS CrashReporter records application bugs
- Path: `/var/wireless/Library/Logs/CrashReporter`

Note: On Infineon X-Gold (iPhone 1 to iPhone 3) it's possible to save baseband core dumps in '`CrashReporter`' if the `CORE` option is enabled.

The final report

Indicators

- 0: The state changed, but everything is fine
- 1: The baseband takes a little bit longer to respond
- 2: Maybe something happened (takes to long to respond, applicative crash...)
- 3: It is probably a crash (can't talk with the baseband at all...)
- ...

You can define new indicators depending on your analysis.

Sample of a crash in the report


```
<?xml version="1.0" ?>
<report>
  <informations>
    <started>
      Fri, 07 Sep 2012 16:18:47
    </started>
    <finished>
      Fri, 07 Sep 2012 16:21:07
    </finished>
  </informations>
  <events>
    <event time="16:18:49" id="0" lastpayload="1658" level="0">
      Fuzzing (re)started
    </event>
    <event time="16:19:52" id="1" lastpayload="1665" level="2">
      AT answer: Timeout!
    </event>
    <event time="16:19:54" id="2" level="0">
      AT is working once again
    </event>
    <event time="16:20:00" id="3" lastpayload="1666" level="3">
      AT Error
    </event>
    <event time="16:20:04" id="4" level="0">
      AT is working once again
    </event>
    <event time="16:20:57" id="5" lastpayload="1674" level="4">
      AT answer: Strange Oo!
    </event>
  </events>
</report>
```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Monitoring enhancement

- Hard without a debugger: a lot of states to check
- We lately managed to get a `qcombbdbg` running on some phones: HTC Desire S/Z
- It's also possible to debug using the JTAG interface and additional hardware (e.g.: RIFFBOX)
- With a debugger: we don't need heuristics to detect crashes

Demo!

The fuzzing platform (injecATor, OpenBTS and MobiDeke)

Summary

Problems

- Mostly the unstability of OpenBTS for fuzzing tests
- Deadlocked phones can require human intervention to reboot
- Did not have time to test all layers yet:
  - A lot of fixes required on the monitoring part
- Checking the phone state slows down fuzzing
- We don't have debuggers for every phone models
- A debugger is always needed to decide about exploitability

Our results

- MobiDeke is a handy way to automate fuzzing tests on GSMs
- Not a lot of bugs have been found with stateless messages
    - `MM_INFORMATION`: few DoS and applicative crashes
    - `TMSI_RELOCATION_COMMAND`: few DoS
    - 1 state of `Call Origin`: 1 crash and a lot of DoS
    - `LOCATION UPDATING`: not tested completely, few DoS
- A fuzzing test takes time: days, weeks or months (depends on the number of testcases and complexity)

*DoS: The phone was not responding

Todo

- There are still plenty of vectors to fuzz
- Integration with a debugger (e.g. JTAG)
- Implement state machines
- Source code not to be released at the moment

Thank you! ;)

Any questions?