Berlin Institute of Technology
FG Security in Telecommunications

# “SMS-o-Death: from analyzing to attacking mobile phones on a large scale”

CanSecWest 2011

Nico Golde & Collin Mulliner, Vancouver, March 9-11 2011
{nico,collin}@sec.t-labs.tu-berlin.de

# About us

- Collin Mulliner
  - coder, hacker, security researcher, PhD student
  - Past:
    - p0wnd iPhone, Android, Windows Mobile with SMS
    - Bluetooth and NFC phone security
    - p0wnd Windows Mobile with MMS
- Nico Golde
  - (almost not anymore) student

# Agenda

- Introduction
- SMS
- Fuzzing Setup
- Fuzzing Results
- Fun with the Network Operators
- Attacks
- Conclusions

# Introduction

- Mobile phone security research is a really HOT topic right now

- Research areas
  - Protocol level attacks
  - Crypto (A5/1)
  - Application level attacks on smart phones
  - SMS-based attacks against smart phones

- > 4 billion mobile phone users
  - High attack surface

# Introduction

- Mobile phone security research is a really HOT topic right now

- Research areas
  - Protocol level attacks
  - Crypto (A5/1)
  - Application level attacks on smart phones
  - SMS-based attacks against smart phones

- > 4 billion mobile phone users
  - High attack surface

- **In this talk we will focus on <u>feature phones</u>**
  - We will look at the (in)security of SMS implementations

# So what is a Feature Phone?

- Mobile phone with “additional features” → feature phone
  - Web browser, MP3 player, ....

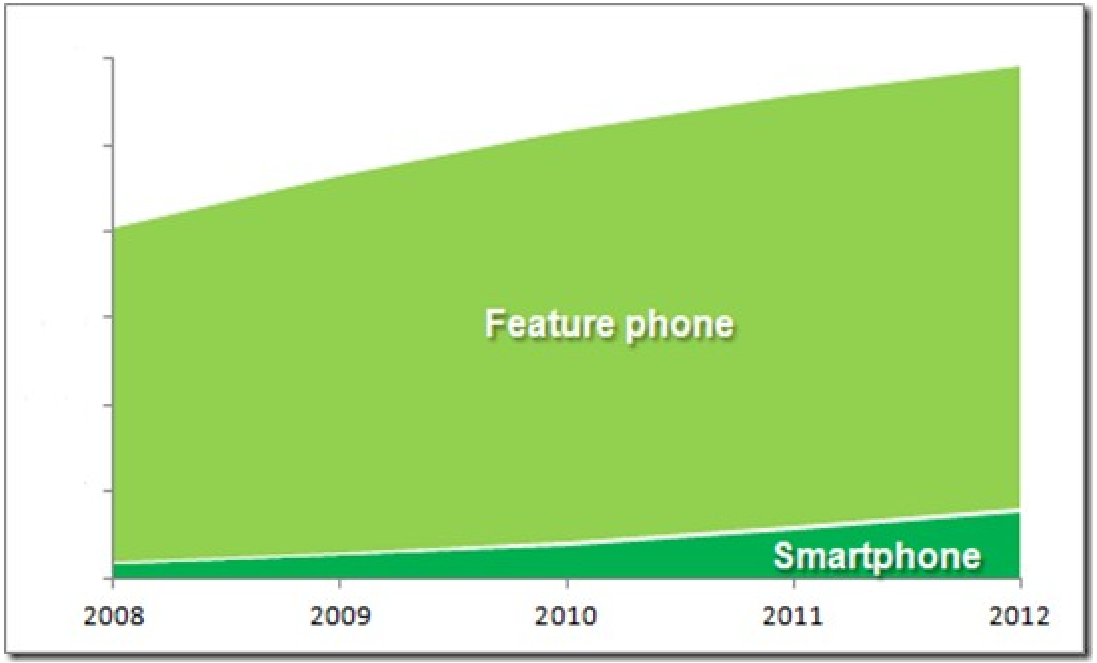
- Single CPU device (smart phones normally have 2 CPUs)
  - Baseband and applications run on same processor

- 3rd party applications just J2ME, BREW, …
  - No native code!

- Reasons why feature phones are still very popular
  - Price, battery run time, rugged case, …

# Why Feature Phones?

- World wide ~4.6 billion mobile phone users
- Only 16% of mobile phones in the world are smart phones!
  - A little more in the western world
- Therefore: Feature phones → large impact!
- Further: feature phones haven been ignored by previous work!



# Feature Phone Platforms...

- Manufacturer has one OS for their entire line of feature phones
  - Nokia **S40**, Sony Ericsson **OSE**, ...
- Theory 1: since all phones are based on same platform
  - A bug found on phone *A* works on phones *B, C,* and *D*
- Theory 2: single CPU architecture
  - Application crash → phone crash → reboot

# Manufacturer Selection

- Way too many mobile phone manufacturers
  - We can't go after all of them

- Select the few ones that have a good market share
  - This makes sure that we have a global effect, remember our aim is “large scale”!

# Manufacturer Selection

- Way too many mobile phone manufacturers
  - We can't go after all of them

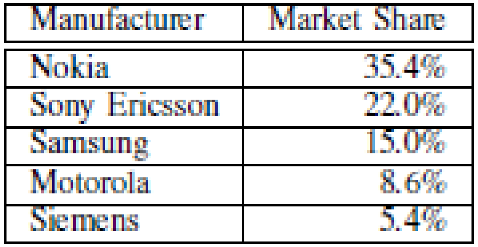
- Select the few ones that have a good market share
  - This makes sure that we have a global effect, remember our aim is “**large scale**”!

# Selected Manufacturers

- **Nokia, Samsung, Sony Ericsson, LG, Motorola,** and **Micromax**
  - Micromax is a very popular brand in India

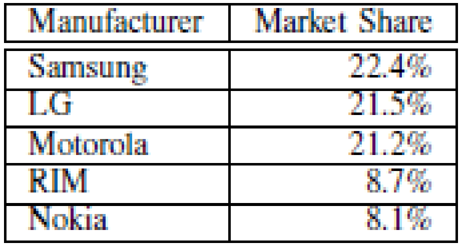
- Market shares are a good basis for targeted attacks
  - Say you want to attack mobile users in *Germany* you just look at the market shares for your target country and know what to attack ;-)

(a) Germany, November 2009



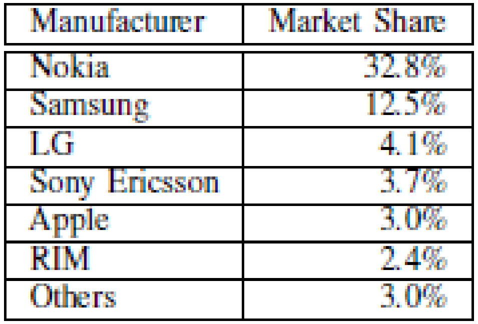
| Manufacturer | Market Share |
|---|---|
| Nokia | 35.4% |
| Sony Ericsson | 22.0% |
| Samsung | 15.0% |
| Motorola | 8.6% |
| Siemens | 5.4% |

(b) U.S.A., May 2010



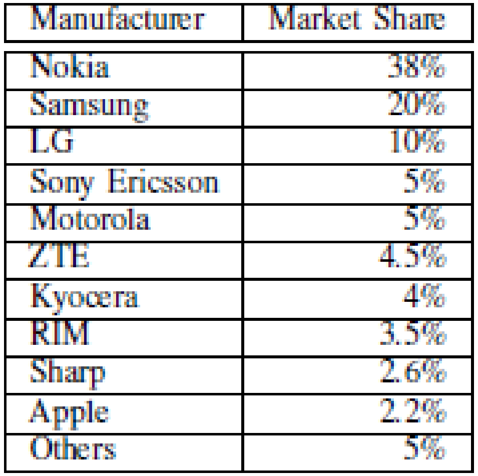
| Manufacturer | Market Share |
|---|---|
| Samsung | 22.4% |
| LG | 21.5% |
| Motorola | 21.2% |
| RIM | 8.7% |
| Nokia | 8.1% |

(c) Europe, June 2010



| Manufacturer | Market Share |
|---|---|
| Nokia | 32.8% |
| Samsung | 12.5% |
| LG | 4.1% |
| Sony Ericsson | 3.7% |
| Apple | 3.0% |
| RIM | 2.4% |
| Others | 3.0% |

(d) World, for the year 2009



| Manufacturer | Market Share |
|---|---|
| Nokia | 38% |
| Samsung | 20% |
| LG | 10% |
| Sony Ericsson | 5% |
| Motorola | 5% |
| ZTE | 4.5% |
| Kyocera | 4% |
| RIM | 3.5% |
| Sharp | 2.6% |
| Apple | 2.2% |
| Others | 5% |

`Data: ComScore (see references...)`

# Acquiring Phones

- We need a phones from all our selected manufacturers
  - We selected 6 manufacturers...
- Buying them new is no option, since this becomes expensive
  - About 150 Euro per phone
- eBay is our friend ;)
  - Decent feature phones are still expensive
  - We bought many “half broken” phones (5...30 Euro)

- Phones from eBay are always fun...
  - Many phones don't really allow a “hard reset” Phones still have: SMS, appointments, and pictures...

# Why SMS (Short Message Service)?

Text message
abc
91 (1)
To Schumi
Dear Schumi, please answer my calls. It's only a game. love, Ralf
Options
Send

- Supported by every mobile phone
  - ...and of course by every mobile operator

- Works everywhere in the world
  - Attacker can be everywhere
  - No proximity required

- A ton of features
  - Flash SMS, VCard, MMS notification, multipart, Port addressing, SIM toolkit, ...
  - Many implemented but rarely used (untested code!)

- Mostly no user interaction required
  - True remote bugs!

# Analyzing Feature Phones ... the Problem

- Completely closed system
  - Too many platforms

- No native 3rd party applications
  - No SDK and no debugger

- JTAG is no solution
  - Need detailed platform knowledge to use JTAG for serious work
  - Don't want to hook up JTAG +10 different phones

- Reverse Engineering is a lot of work
  - Multiple platforms make it even worse

# The Solution...

- **Use own GSM network for analysis**
  - SMS messages for free!
  - Don't interfere with operator's network
  - Speed improvement over real operator network
  - Full control over everything
  - Use phone ↔ BTS communication for analysis

- Fuzzing-based testing
  - No source code no reverse engineering required
  - Make test cases once … use them for all phones

- But fuzzing requires monitoring!
  - Without monitoring fuzzing is useless!

# GSM Network Equipment

- Industry traditionally very closed
  - Protocol specs exist (>1k PDFs)
  - No public documentation of GSM equipment

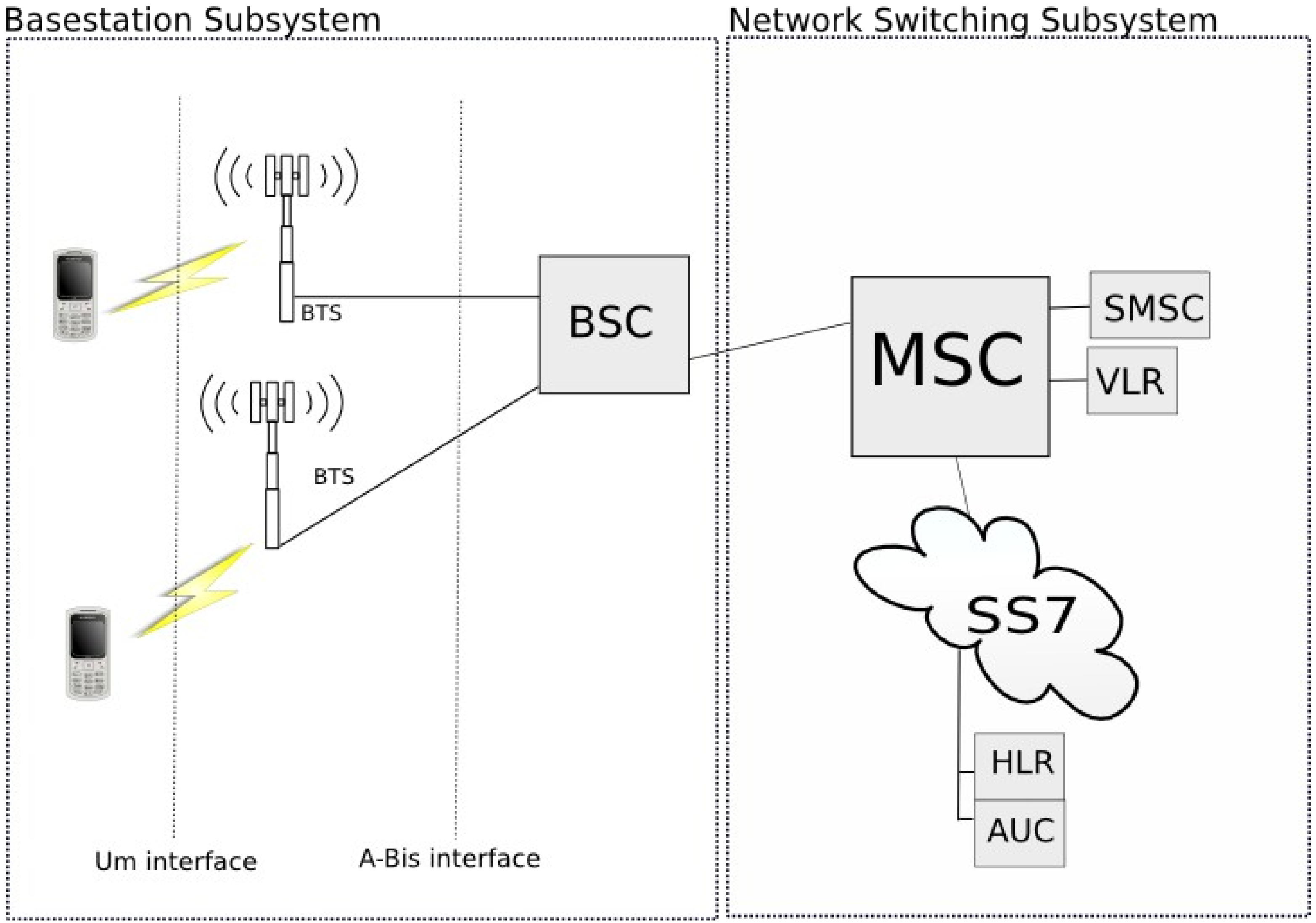
→ OpenBSC, OpenBTS, OsmocomBB are game changers

- OpenBSC:
  - Free Software implementing A-bis over IP
  - Minimal subset of HLR ,MSC, SMSC, BSC, AUC
  - Supports nanoBTS and BS11

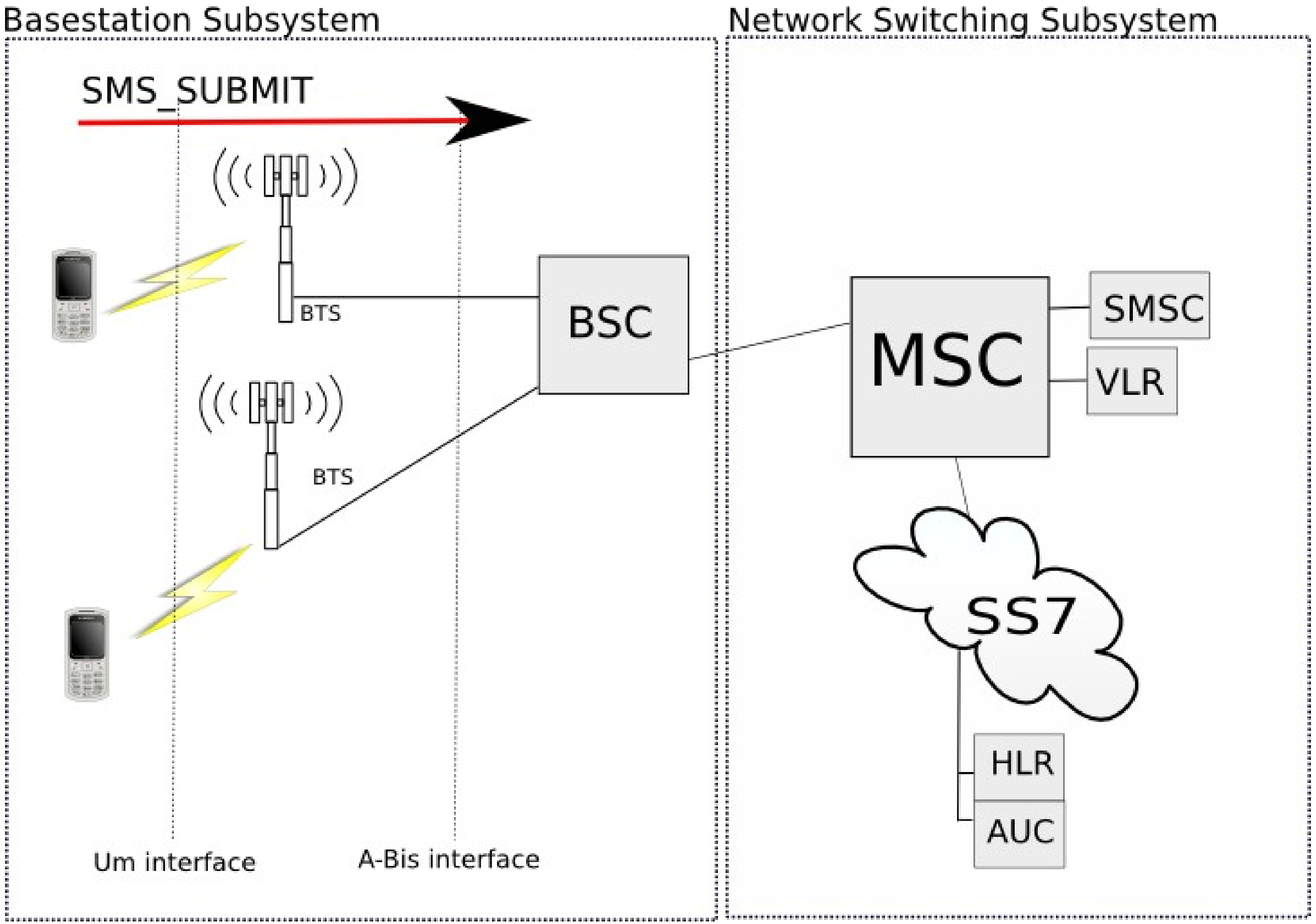
# The Setup

- Laptop (running OpenBSC), nanoBTS, and some phones

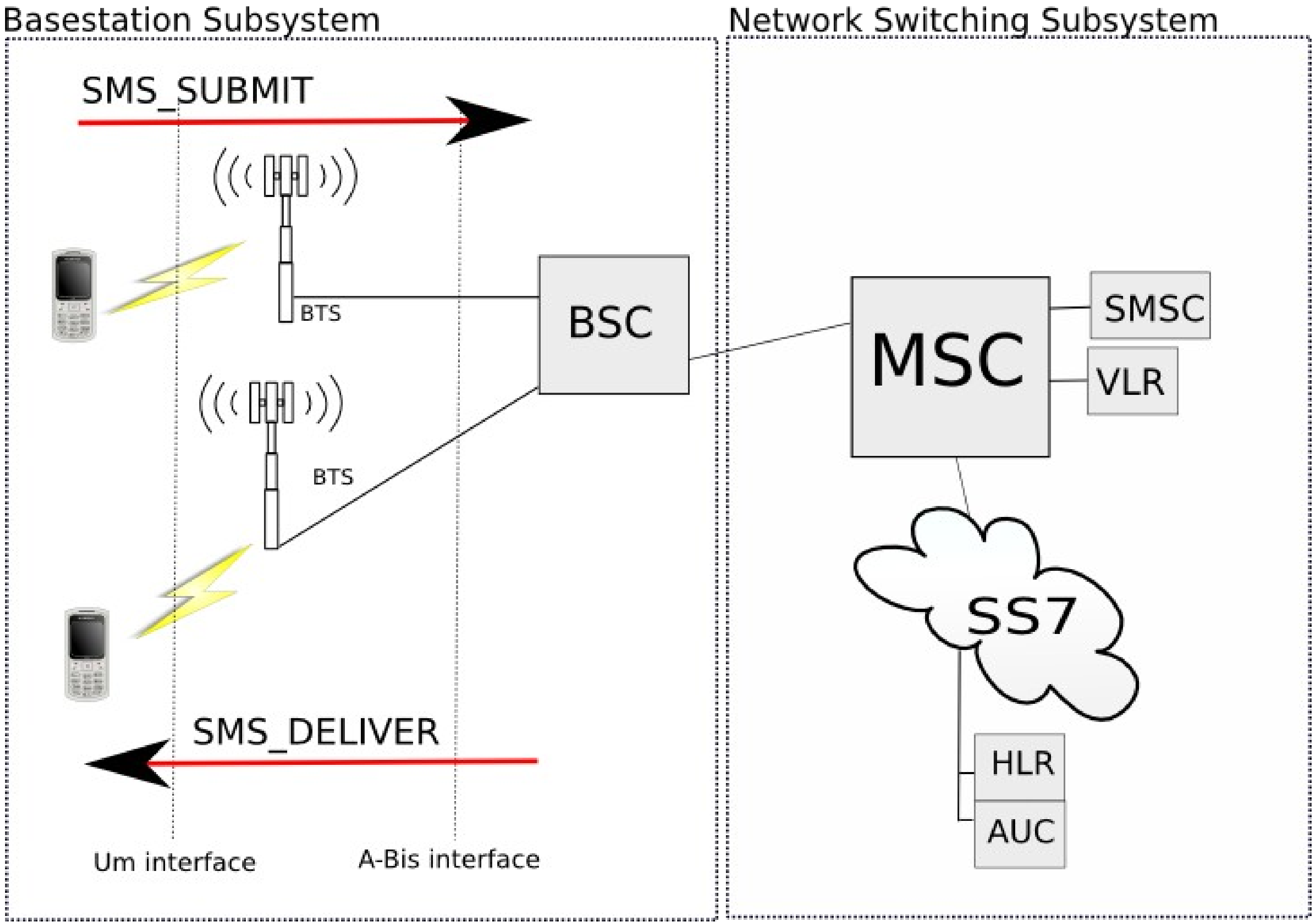
# A typical GSM network (simplified)



# SMS submission



# SMS delivery



# OpenBSC and SMS

- Supports SMS from phone → phone

- Provides telnet interface for text messages
  → by default not fuzzing friendly
  - Only text
  - Very slow/for attached subscribers
  - Stored message sent to all subscribers

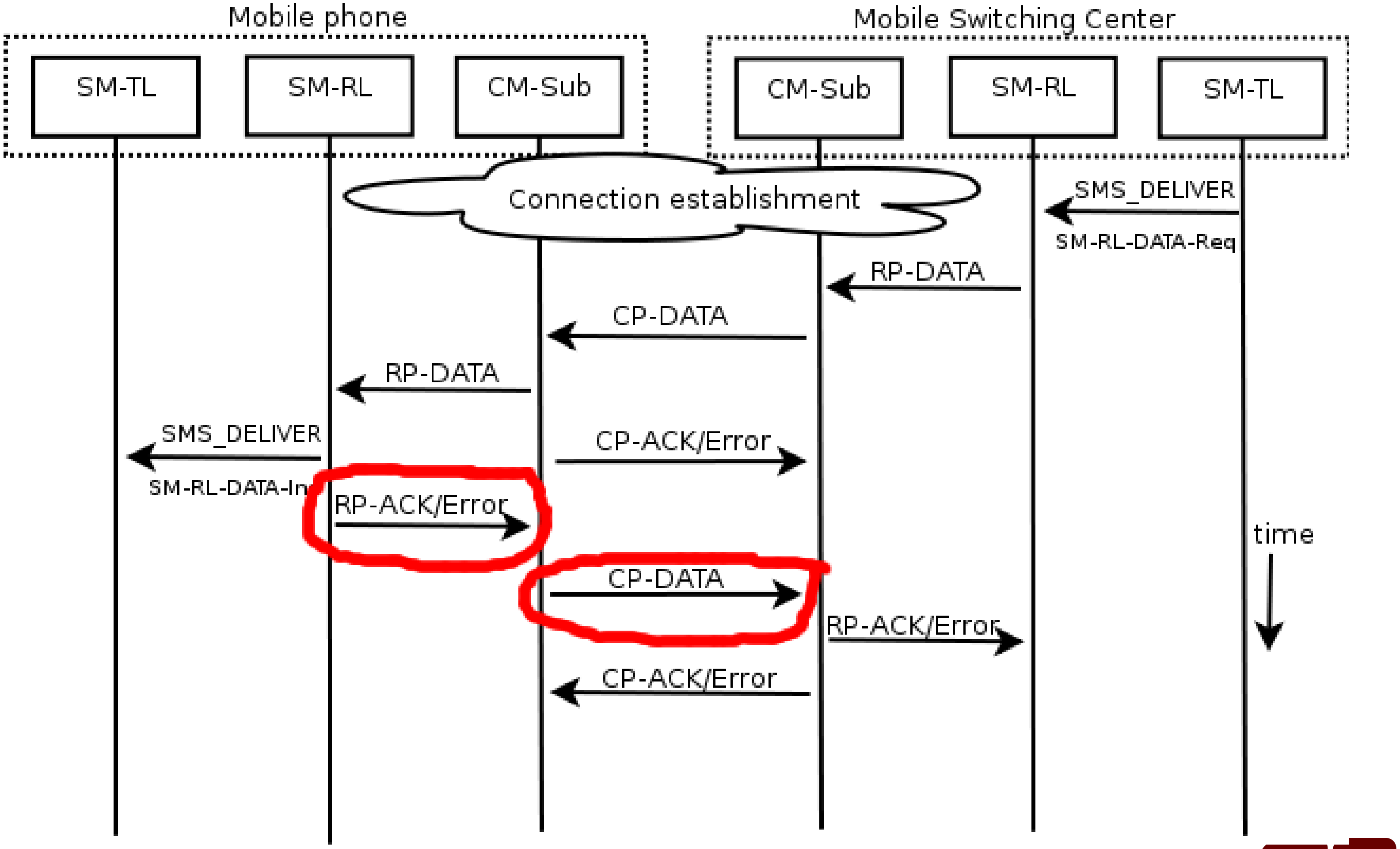
# OpenBSC Modifications

- Injection of pre-encoded SMS in PDU format (SMS_SUBMIT)
- Relaxed message checking
  - Allow fuzzed/unsupported message types
- Logging
  - Phone feedback: Memory full, Protocol errors, ...
  - Channel release states (break downs)
- Event → message mapping

```
phone (1331) went offline at 2010-10-29 14:28:37,
checking last sms...
the error was very likely caused by the following sms:
41000491311300f1880500034affdb4040404040404....
```

# Monitoring the Phones

- Messages sent over SDCCH/SACCH
  - Monitor feedback and channel tear down



# Additional monitoring

- Finding more than crashes
  - State fuckups → swallowed messages

- Health monitoring with “echo server” on the phone
  - Binds to SMS port
  - Receives incoming message
  - Replies with message to “special” number
  - Implemented in J2ME

- Inject “echo” SMS every *N* messages
  - Check message counter in SMSC database (OpenBSC)

# SMS_SUBMIT

- “Hello World” SMS to 1234 in PDU format

  **01000491214300000BE8329BFD06DDDF723619**

| Field | Size | Bytes (Hex) |
|---|---|---|
| SUBMIT | 1 | 01 |
| TP-MR | 1 | 00 |
| Destination | 5 | 04 91 2143 |
| TP-PID | 1 | 00 |
| TP-DCS | 1 | 00 |
| TP-VP | variable | 00 |
| TP-UDL | 1 | 0B |
| TP-UD | variable | E8329BFD06DDDF723619 |

# More...

- ← simple text message
- Messages can carry binary payload
- Additional features added by UDH chunks
  - Part of TP-UD

05040b8423f0

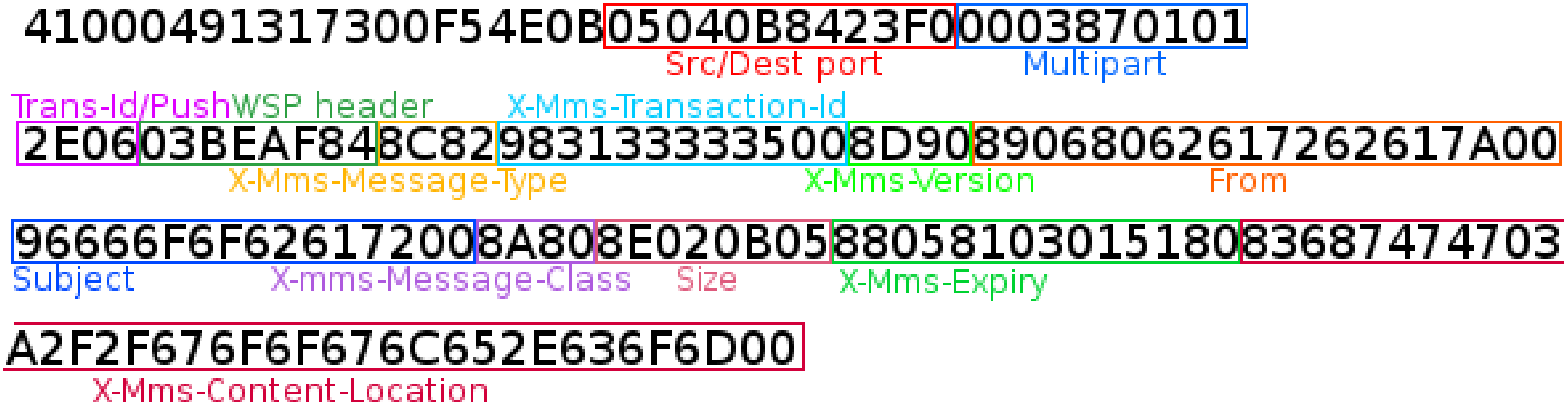
| Field | Size | Bytes (HEX) |
|---|---|---|
| IET | 1 | 05 |
| IEDL | 1 | 04 |
| IED | 4 | 0B8423F0 |

16 bit port addressing, dst: 2948 src: 9200

# UDH features

- Concatenated messages
- Port addressing (8 and 16 bit)
  - WAP-push
  - MMS notification
  - iPhone visual voicemail
- Rich text formatting (EMS)
- RFC 822 Email header
- (U)SIM Toolkit
- Sound
- Lots of others...
- Can be combined

# SMS/UDH example (MMS notification)l



```
41000491317300F54E0B05040B8423F00003870101
2E0603BEAF848C82983133333500 8D908906806261726 2617A00
```

41000491317300F54E0B05040B8423F00003870101

Src/Dest port

Multipart

Trans-Id/Push

WSP header

X-Mms-Transaction-Id

2E0603BEAF848C829831333335008D908906806261726 2617A00

X-Mms-Message-Type

X-Mms-Version

From

96666F6F626172008A808E020B058805810301518083687474703

Subject

X-mms-Message-Class

Size

X-Mms-Expiry

A2F2F676F6F676C652E636F6D00

X-Mms-Content-Location

# Test cases

- Multipart
  - UDH (reference, parts, current part)
- MMS notification
  - Various variable length strings
- Simple text
  - Invalid alphabet encoding (array out of bounds)
- Flash SMS
  - Separated code paths
  - Multipart
- TP-PID/TP-DCS combinations
  - In combination with UD payload

- ~120k messages

# Fuzzing trial

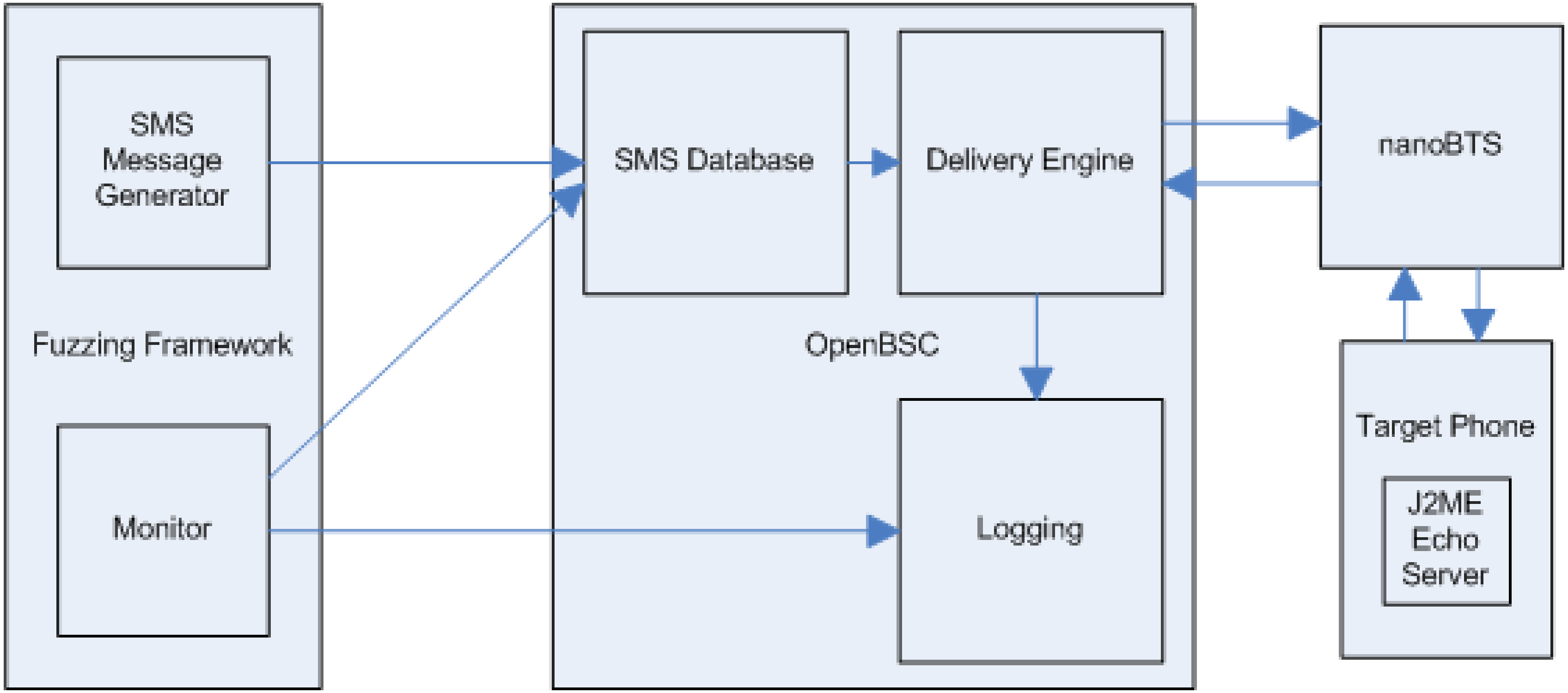
- Python library for SMS generation

- Submit tons of messages to OpenBSC
  - Stored in SMSC database

- Send message to fuzz-phone(s)
  - Open channel
  - Send message 1...n
  - Close channel

- Script evaluating added logging
  - Flag invalid messages
  - Monitor channel breakdown → SMS

# The Complete (logical) Setup



# Our Faraday Cage ... so we can do what ever...

- Don't need a GSM license if you have one of these :)

# Results

- Fuzzed for quite some time
  - Took a lot of work

- A lot of automation but you still have to...
  - delete messages by hand
  - get phones out of the “totally stuck” mode → “hard reset”

- We were mostly looking for crashes that...
  - Disconnect phone from network
  - Reboot the phone

- Here are some interesting bugs we found!

# Nokia S40

- The world wide market leader!
- S40 → Nokia's feature phone platform
  - Our test phones: 3110c, 6300, 6233, 6131 NFC,...

- BUG
  - 8 bit class 0 (Flash SMS) with certain TP-UD payload
- Impact
  - “Nokia White Screen of Death”
  - Interface reboot
  - Disconnect phone from network (interrupting call)
  - Message ACK never reaches network (more on that later...)
  - Message not visible on the phone
  - Watchdog shuts down phone after repeated crashes

# Sony Ericsson

- Very common in Germany (22% market share)
- Test phones: w800i, w810i, w890i, Aino (May 2010)

- BUG
  - Certain (reserved) TP-PID value & >= certain length TP-UD

- Impact
  - Complete phone reboot
  - Disconnect phone from network (interrupting call)
  - Message ACK never reaches network (again, later...)
  - Message not visible on phone
  - Sometimes also completely freezes
  - Errm, one test phone bricked

# LG Electronics

- Test phone: LG GM360, likely more phones affected
- BUG
  - Classic buffer overflow in various MMS notification fields
- Impact
  - Phone reboots
  - If PIN set → phone locked (permanently offline)
  - Disconnects from network (interrupting calls)
  - Same happens on opening the message
- Good target for future work (reversing/code execution)

# Samsung 1/2

- Test phones: S5230 Star, B5310 CorbyPro
- BUG
  - Multipart: chunk id madness
- Impact
  - Displayed message size huuuge
  - Phone crashes on opening message
  - Network disconnect
  - User interaction required :-/

# Samsung 2/2

- Test phones: S5230 Star, B5310 CorbyPro
- BUG
  - Modified version of the payload
- Impact
  - Phone denies every SMS with Protocol error (***wink* Curse of Silence**)
  - One silent message (no user interaction)
  - SMS application won't open again (Messages loading...)
  - Phone application won't open again

# Motorola

- Test Phones: Razr, Rokr, SVLR L7
- BUG
  - Internet Electronic Mail interworking (0x32) + certain payload
- Impact
  - Flashing white screen
  - User interface restart
  - Network disconnect (interrupt calls)

- Rather fragile devices, couldn't test in-depth due full memory, weird behavior...

# Micromax

- Number three (3) manufacturer in India!
- Test phone: X114 (tested briefly, last arrived phone)

- BUG
  - Multipart assembly madness again (this time Flash)
  - Reference id has to be unused (no problem)

- IMPACT
  - Few seconds after receipt → black screen
  - Network disconnect (interrupt calls)
  - Message is silent

# Demo Video

Feature Phone SMS Security Analysis
Nico Golde, Collin Mulliner
SECT Security IN TELECOMMUNICATIONS
micromax
LG
Eingang
Keine Nachrichten
NOKIA
Musik-Player
Radio
So 20.04.2008
Keine ansteh. Notizen
Favoriten
Menü
Namen
Sony Ericsson
MOTOROLA
NOKIA
Go to
Menu
Apps.

# Notifying Vendors

- Nokia
  - no problem, got contacts from the past
- Sony Ericsson
  - email was #fail, but I ran into one of them at a con #win
- Motorola
  - security@motorola.com does not really work that well
- Samsung
  - Got contacted in Jan 2011 after initial presentation
- LG
  - Haven't found a security contact
- Micromax
  - Haven't found a security contact

# The Special “early” Crash

- Some bugs crash the phone before ACKing the SMS to the net
  - Nokia + Sony Ericsson
- Results: Network believes SMS was not received
- Action: SMSC tries to re-transmit message
  - Phone crashes again
  - Repeat...
  - Fix: move SIM card to non affected phone

# The Special “early” Crash

- Some bugs crash the phone before ACKing the SMS to the net
  - Nokia + Sony Ericsson
- Results: Network believes SMS was not received
- Action: SMSC tries to re-transmit message
  - Phone crashes again
  - Repeat...
  - Fix: move SIM card to non affected phone
- **Conclusion: Abuse behavior for attack amplification**
  - Send one message → network makes phone crash multiple times
  - Let's see how often and in what interval this happens...

# Testing SMS Re-Transmits Timings

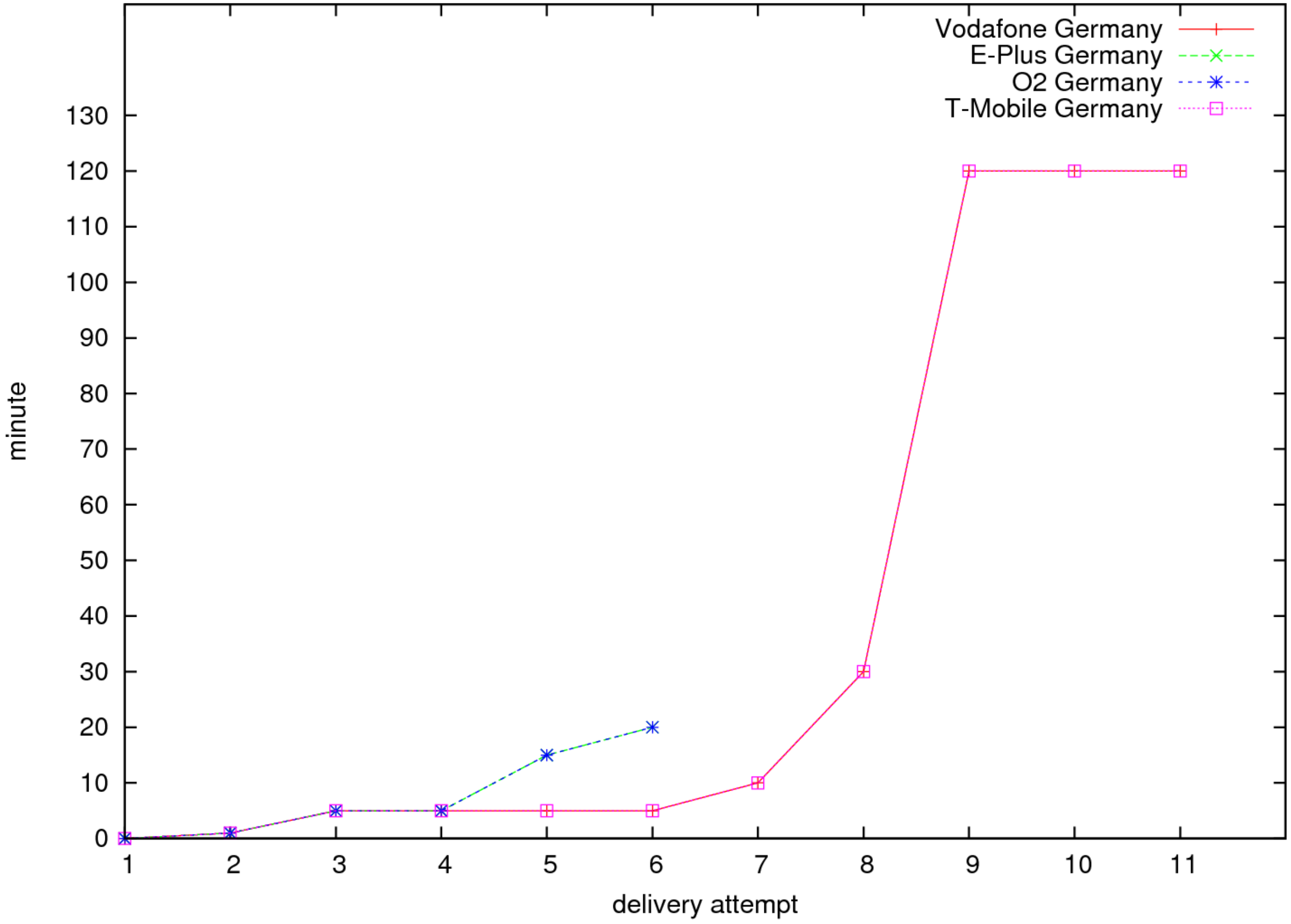
- Linux PC with Bluetooth dongle + Sony Ericsson phone

- Monitor phone using Bluetooth RFCOMM link
  - Connect to “Dialup Networking Service”
  - Wait until Bluetooth link gets disconnected (phone reboots!)

- Attack phone, count reboots
  - Let it run for a few days (swap SIM cards in between)

# SMS Re-Transmit Timings for German MNOs

- Additional tried 20/24 hours after last try shown in graph



# Attacks

- Clearly we can (ab)use our bugs for attacks
- Disconnect calls
  - With just 1 SMS, to either side of the call (if both are mobile)
- Make sure you are not reachable
  - Send you an SMS every few seconds
  - Maybe costs a lot, but maybe you are worth it?
  - If we get your phone to switch off it will be cheap (Nokia)

# Large Scale Attacks... possible

- **Mobile Network Operator** (MNO) → disconnect his customers
  - Make him look bad (fun)
  - Extort him (organized crime)
    (customers might claim their phone to be broken)
  - Will 10.000 reconnecting phones kill the operators infrastructure?

- **Manufacturer** → attack random people owning specific brand
  - Make them look bad (fun)
  - Extort him (organized crime)

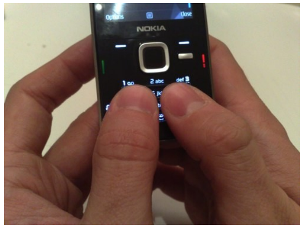
- **Public Distress** → disconnect a lot of people
  - Next big outdoor event (protest, festival, etc...)
  - Police often relies on mobile phones
  - Remember Estonia 2007?
    (okay … will become expensive)

# Sending large Quantities of SMS Messages

- Using a few normal phones wont work
  - Very slow, pricey, easily traceable, ...

- Bulk SMS operators (the guys you go to for SMS spam)
  - Cheap, no-questions asked, high injection rate (fun!!) (our favorites: HSL, Clickatell, Routomessaging, ...)

- Smart/mobile phone botnets
  - Cheap (free!), fast if you have a large botnet (remember all those jailbroken iPhones with SSH and default root password?)



- SS7 Access
  - SPEED, good price, hard to trace, no content limitations (you are/know an operator, know somebody...)

# Feature Phones and Firmware Updates

- Price
  - Phones are quite cheap → manufacturers don't offer updates
- Branding
  - Phones are branded by operators → firmware can only be updated with branded firmware image
- Net-Lock
  - Phones can often not be updated → updates can be used to remove the net-lock
- Installing the Update
  - How do you know there is one? Your phone doesn't tell you
  - Need a desktop computer? Or even go to a special store

# Counter measures: SMS filtering by MNOs

- Mobile Network Operators can obviously filter SMS messages
- Filter software seems not well prepared for binary
  - Mostly designed to fight sms spam and filter political content
- How to configure filters?
  - We don't want to publish payloads (deal with manufacturers!)
  - We compiled a white paper that tells you what to filter
  - White paper will be available from:

    http://tinyurl.com/smssecurity/

# Conclusions

- With openness on the GSM network side one can find bugs in the “closed” mobile phones
- Bugs in all major feature phone platforms!
- Large scale attacks are totally possible with this bug arsenal
- SMS re-transmit by operator helps you with attacks
- Attack against users possibly leads to attack against operator
- Manufacturers need to provide updates for feature phones

# The End: Q & A

Thank you for listening!
Question?

- Contact:
  - nico@sec.t-labs.tu-berlin.de
  - collin@sec.t-labs.tu-berlin.de    Twitter: @collinrm
  - http://www.sec.t-labs.tu-berlin.de

# Thanks and Greez

- Special Thanks
  - Ravii and Simon Schoar for buy / borrowing us phones!

- Greez (in no particular order)
  - Harald Welte
  - Dieter Spaar
  - ak
  - FX
  - Joernchen
  - Mumpi
  - scusi
  - ths
  - shadow
  - Charlie Miller
  - Martin Herfurt

# References

[1] http://openbsc.osmocom.org

[2] http://www.ipaccess.com/picocells

[3] http://www.3ggp.org

[4] http://www.micromaxinfo.com

[5] http://www.comscore.com/index.php/Press_Events_Press_Releases/2010/1/comScore_Reports_November_2009_German_Mobile_Market_Share

[6] Tomi Ahonen Almanac 2010 Mobile Telecoms Industry Review (Feb 2010)

[7] http://www.sec.t-labs.tu-berlin.de

[8] http://www.mulliner.org/blog

[9] http://nion.modprobe.de/blog