OsmocomBB

Running your own GSM stack on a phone

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http://bb.osmocom.org/

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Outline

GSM/3G protocol security

- Observation
  - Both GSM/3G and TCP/IP protocol specs are publicly available
  - The Internet protocol stack (Ethernet/Wifi/TCP/IP) receives lots of scrutiny
  - GSM networks are as widely deployed as the Internet
  - Yet, GSM/3G protocols receive no such scrutiny!
- There are reasons for that:
  - GSM industry is extremely closed (and closed-minded)
  - Only about 4 closed-source protocol stack implementations
  - GSM chipset makers never release any hardware documentation

The closed GSM industry

Handset manufacturing side

- Only very few companies build GSM/3.5G baseband chips today
  - Those companies buy the operating system kernel and the protocol stack from third parties
- Only very few handset makers are large enough to become a customer
  - Even they only get limited access to hardware documentation
  - Even they never really get access to the firmware source

The closed GSM industry

Network manufacturing side

- Only very few companies build GSM network equipment
  - Basically only Ericsson, Nokia-Siemens, Alcatel-Lucent and Huawei
  - Exception: Small equipment manufacturers for picocell / nanocell / femtocells / measurement devices and law enforcement equipment
- Only operators buy equipment from them
- Since the quantities are low, the prices are extremely high
  - e.g. for a BTS, easily 10-40k EUR

The closed GSM industry

Operator side

- Operators are mainly banks today
- Typical operator outsources
  - Billing
  - Network planning / deployment / servicing
- Operator just knows the closed equipment as shipped by manufacturer
- Very few people at an operator have knowledge of the protocol beyond what's needed for operations and maintenance

The closed GSM industry
Security implications

The security implications of the closed GSM industry are:

- Almost no people who have detailed technical knowledge outside the protocol stack or GSM network equipment manufacturers
- No independent research on protocol-level security
  - If there's security research at all, then only theoretical (like the A5/2 and A5/1 cryptanalysis)
  - Or on application level (e.g. mobile malware)
- No open source protocol implementations
  - which are key for making more people learn about the protocols
  - which enable quick prototyping/testing by modifying existing code

Security analysis of GSM

How would you get started?

If you were to start with GSM protocol level security analysis, where and how would you start?

- On the network side?
  - Difficult since equipment is not easily available and normally extremely expensive
  - However, network is very modular and has many standardized/documented interfaces
  - Thus, if equipment is available, much easier/faster progress
  - Has been done in 2008/2009: Project OpenBSC

Security analysis of GSM

How would you get started?

If you were to start with GSM protocol level security analysis, where and how would you start?

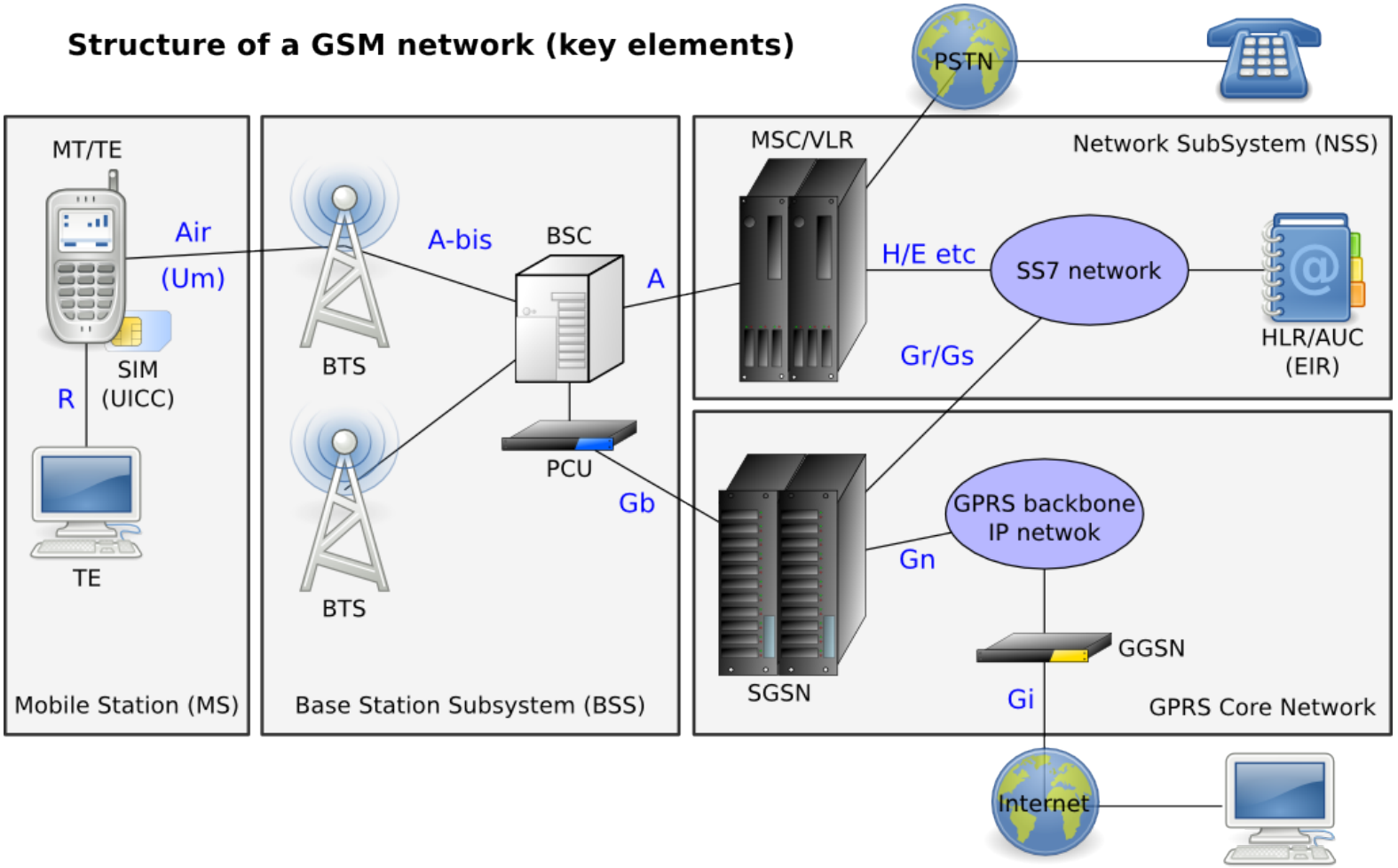
- On the handset side?
  - Difficult since GSM firmware and protocol stacks are closed and proprietary
  - Even if you want to write your own protocol stack, the layer 1 hardware and signal processing is closed and undocumented, too
  - Known attempts
    - The TSM30 project as part of the THC GSM project
    - mados, an alternative OS for Nokia DTC3 phones
  - none of those projects successful so far

Security analysis of GSM
The bootstrapping process

- Read GSM specs day and night (> 1000 PDF documents)
- Gradually grow knowledge about the protocols
- Obtain actual GSM network equipment (BTS, MS tester, ...)
- Try to get actual protocol traces as examples
- Start a complete protocol stack implementation from scratch
- Finally, go and play with GSM protocol security

The GSM network

Source: Wikipedia, User Tsaitgaist, Licensed under GPLv3



GSM network components

- The BSS (Base Station Subsystem)
  - MS (Mobile Station): Your phone
  - BTS (Base Transceiver Station): The *cell tower*
  - BSC (Base Station Controller): Controlling up to hundreds of BTS
- The NSS (Network Sub System)
  - MSC (Mobile Switching Center): The central switch
  - HLR (Home Location Register): Database of subscribers
  - AUC (Authentication Center): Database of authentication keys
  - VLR (Visitor Location Register): For roaming users
  - EIR (Equipment Identity Register): To block stolen phones

GSM network interfaces

- Um: Interface between MS and BTS
  - the only interface that is specified over radio
- A-bis: Interface between BTS and BSC
- A: Interface between BSC and MSC
- B: Interface between MSC and other MSC

GSM networks are a prime example of an asymmetric distributed network, very different from the end-to-end transparent IP network.

GSM network protocols
On the Um interface

- Layer 1: Radio Layer, TS 04.04
- Layer 2: LAPDm, TS 04.06
- Layer 3: Radio Resource, Mobility Management, Call Control: TS 04.08
- Layer 4+: for USSD, SMS, LCS, ...

Known GSM security problems

Scientific papers, etc

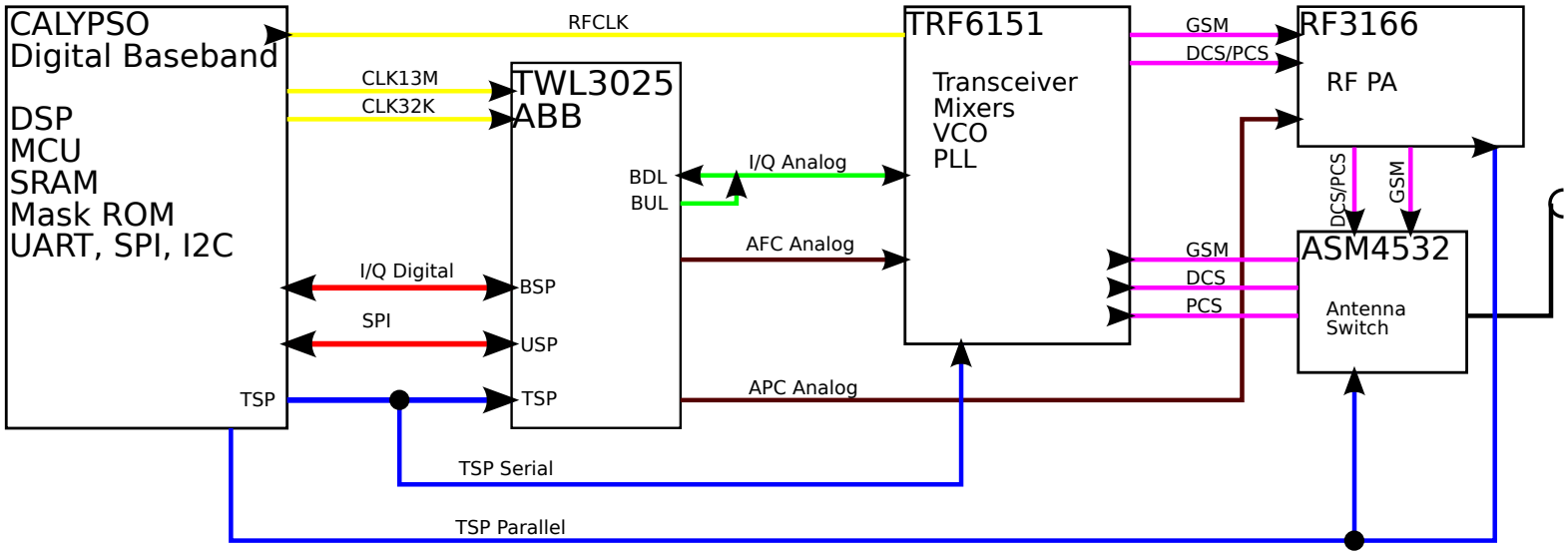
- No mutual authentication between phone and network
  - leads to rogue network attacks
  - leads to man-in-the-middle attacks
  - is what enables IMSI-catchers
- Weak encryption algorithms
- Encryption is optional, user does never know when it's active or not
- DoS of the RACH by means of channel request flooding
- RRLP (Radio Resource Location Protocol)
  - the network can obtain GPS fix or even raw GSM data from the phone
  - combine that with the network not needing to authenticate itself

Known GSM security problems

The Baseband side

- GSM protocol stack always runs in a so-called baseband processor (BP)
- What is the baseband processor
  - Typically ARM7 (2G/2.5G phones) or ARM9 (3G/3.5G phones)
    - Runs some RTOS (often Nucleus, sometimes L4)
    - No memory protection between tasks
  - Some kind of DSP, model depends on vendor
    - Runs the digital signal processing for the RF Layer 1
    - Has hardware peripherals for A5 encryption
- The software stack on the baseband processor
  - is written in C and assembly
  - lacks any modern security features (stack protection, non-executable pages, address space randomization, ..)

A GSM Baseband Chipset



http://laforge.gnumonks.org/papers/gsm_phone-anatomy-latest.pdf

Requirements for GSM security analysis

What do we need for protocol-level security analysis?

- A GSM MS-side baseband chipset under our control
- A Layer1 that we can use to generate arbitrary L1 frames
- A Layer2 protocol implementation that we can use + modify
- A Layer3 protocol implementation that we can use + modify

None of those components existed, so we need to create them!

A GSM baseband under our control

The two different DIY approaches

- Build something using generic components (DSP, CPU, ADC, FPGA)
  - No reverse engineering required
  - A lot of work in hardware design + debugging
  - Hardware will be low-quantity and thus expensive
- Build something using existing baseband chipset
  - Reverse engineering or leaked documents required
  - Less work on the 'Layer 0'
  - Still, custom hardware in low quantity

A GSM baseband under our control

Alternative 'lazy' approach

- Re-purpose existing mobile phone
  - Hardware is known to be working
  - No prototyping, hardware revisions, etc.
  - Reverse engineering required
  - Hardware drivers need to be written
  - But: More time to focus on the actual job: Protocol software
- Searching for suitable phones
  - As cheap as possible
  - Readily available: Many people can play with it
  - As old/simple as possible to keep complexity low
  - Baseband chipset with lots of leaked information

Baseband chips with leaked information

- Texas Instruments Calypso
  - DBB Documentation on cryptome.org and other sites
  - ABB Documentation on Chinese phone developer websites
  - Source code of GSM stack / drivers was on sf.net (tsm30 project)
  - End of life, no new phones with Calypso since about 2008
  - No cryptographic checks in bootloader
- Mediatek MT622x chipsets
  - Lots of Documentation on Chinese sites
  - SDK with binary-only GSM stack libraries on Chinese sites
  - 95 million produced/sold in Q1/2010

Initial choice: TI Calypso (GSM stack source available)

OsmocomBB Introduction

- Project was started only in January 2010 (9 months ago!)
- Implementing a GSM baseband software from scratch
- This includes
  - GSM MS-side protocol stack from Layer 1 through Layer 3
  - Hardware drivers for GSM Baseband chipset
  - Simple User Interface on the phone itself
  - Verbose User Interface on the PC
- Note about the strange project name
  - Osmocom = Open Source MObile COMmunication
  - BB = Base Band

OsmocomBB Software Architecture

- Reuse code from OpenBSC where possible (libosmocore)
  - We build libosmocore both for phone firmware and PC
- Initially run as little software in the phone
  - Debugging code on your host PC is so much easier
  - You have much more screen real-estate
  - Hardware drivers and Layer1 run in the phone
  - Layer2, 3 and actual phone application / MMI on PC
  - Later, L2 and L3 can me moved to the phone

OsmocomBB Software Interfaces

- Interface between Layer1 and Layer2 called L1CTL
  - Fully custom protocol as there is no standard
  - Implemented as message based protocol over Sercomm/HDLC/RS232
- Interface between Layer2 and Layer3 called RSLms
  - In the GSM network, Um Layer2 terminates at the BTS but is controlled by the BSC
  - Reuse this GSM 08.58 Radio Signalling Link
  - Extend it where needed for the MS case

OsmocomBB Target Firmware

- Firmware includes software like
  - Drivers for the Ti Calypso Digital Baseband (DBB)
  - Drivers for the Ti Iota TWL3025 Analog Baseband (ABB)
  - Drivers for the Ti Rita TRF6151 RF Transceiver
  - Drivers for the LCD/LCM of a number of phones
  - CFI flash driver for NOR flash
  - GSM Layer1 synchronous/asynchronous part
  - Sercomm - A HDLC based multiplexer for the RS232 to host PC

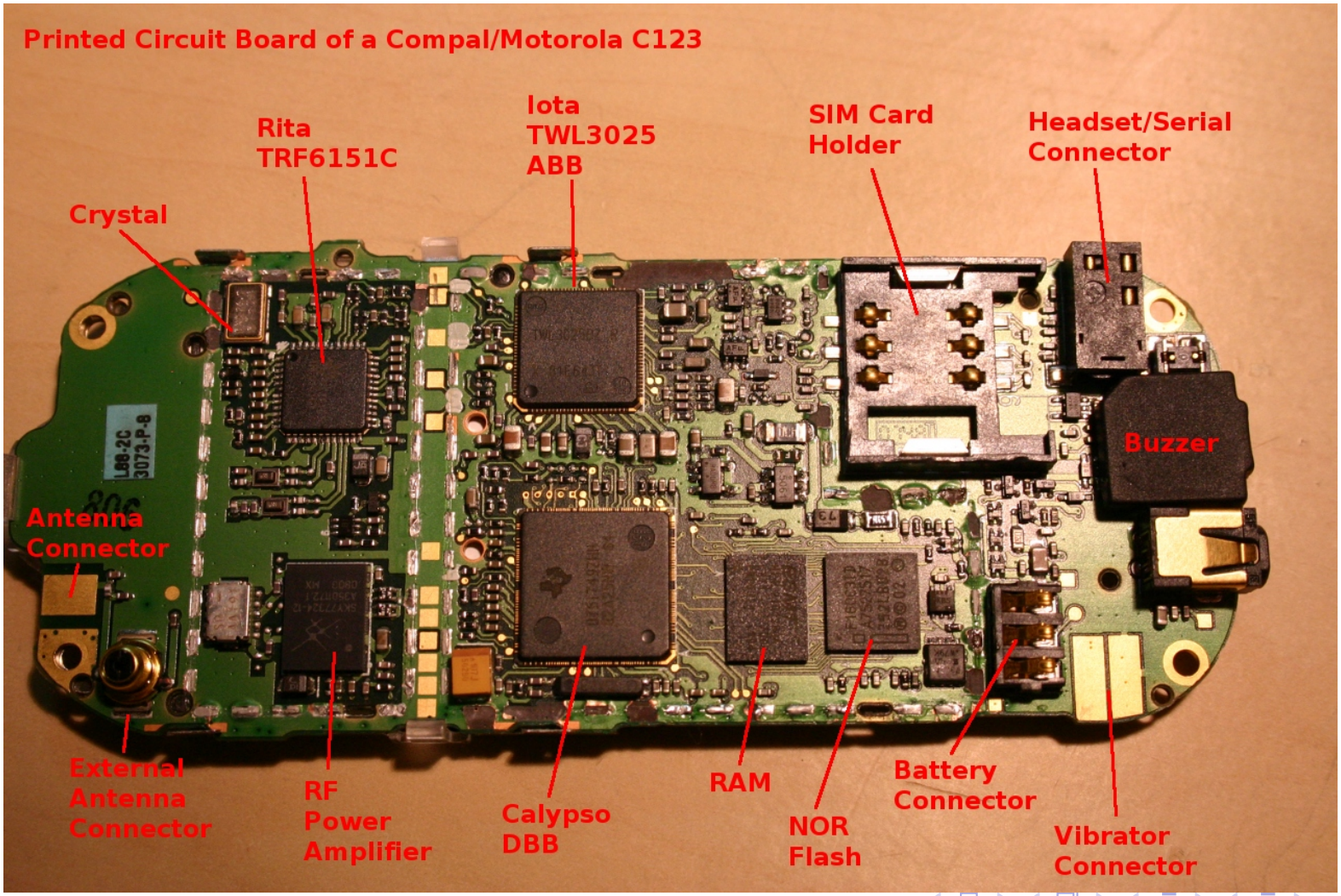
OsmocomBB Host Software

- Current working name: layer23
- Includes
  - Layer 1 Control (L1CTL) protocol API
  - GSM Layer2 implementation (LAPDm)
  - GSM Layer3 implementation (RR/MM/CC)
  - GSM Cell (re)selection
  - SIM Card emulation
  - Supports various 'apps' depending on purpose

OsmocomBB Supported Hardware

- Baseband Chipsets
  - TI Calypso/Iota/Rita
  - Some early research being done on Mediatek (MTK) MT622x
- Actual Phones
  - Compal/Motorola C11x, C12x, C13x, C14x and C15x models
  - Most development/testing on C123 and C155
  - GSM modem part of Openmoko Neo1973 and Freerunner
- All those phones are simple feature phones built on a ARM7TDMI based DBB

The Motorola/Compal C123



OsmocomBB Project Status: Working

- Hardware Drivers for Calypso/Iota/Rita very complete
- Drivers for Audio/Voice signal path
- Layer1
  - Power measurements
  - Carrier/bit/TDMA synchronization
  - Receive and transmit of normal bursts on SDCCH
  - Transmit of RACH bursts
  - Automatic Rx gain control (AGC)
  - Frequency Hopping
- Layer2 UI/SABM/UA frames and ABM mode
- Layer3 Messages for RR / MM / CC
- Cell (re)selection according GSM 03.22

OsmocomBB Project Status: Working (2/2)

OsmocomBB can now do GSM Voice calls (08/2010)

- Very Early Assignment + Late Assignment
- A3/A8 Authentication of SIM
- A5/1 + A5/2 Encryption
- Full Rate (FR) and Enhanced Full Rate (EFR) codec

OsmocomBB Project Status: Not working

- Layer1
  - Neighbor Cell Measurements
  - In-call hand-over to other cells
- Actual UI on the phone
- Circuit Switched Data (CSD) calls
- GPRS (packet data)
- No Type Approval for the stack!

OsmocomBB Project Status: Executive Summary

- We can establish control/signalling channels to both hopping and non-hopping GSM cells
  - Control over synthesizer means we can even go to GSM-R band
- We can send arbitrary data on those control channels
  - RR messages to BSC
  - MM/CC messages to MSC
  - SMS messages to MSC/SMSC
- TCH (Traffic Channel) support for voice calls
  - Dieter Spaar and Andreas Eversberg have made multiple 20 minute call with current master branch
  - Some people have tried alpha code on real networks for real 30+ minute calls!

The `mobile` app

- implementation of a mobile phone
  - cell (re)selection, mobility management
  - voice calls (only full rate)
  - SMS
- both mobile originated and mobile terminated calls work
- VTY (telnet) interface to configure and call control
- optional interface to linux call router PBX

cell_log

The `cell_log` app

- scanning and logging application for cell beacon information
- send RACH to all cells to get the timing advance (distance)
- logs the GPS position of where the cell was found

gsmmap

The `gsmmap` app

- parses the logs generated by cell_log
- uses triangulation to calculate estimated cell position
- exports a .kml file for Google Earth

bcch_scan

The `bcch_scan` app

- iterates over full spectrum and does power scan
- tunes to ARFCN in order of received signal strength
- acquires BCCHs and dumps all SYSTEM INFO to wireshark

cbch_sniff

The `cbch_sniff` app

- dumps cell broadcast messages to wireshark
- some operators include GPS location of cell inside CB

There are some more apps, mostly R&D related.
We are looking forward to **your contribution**, e.g. the *scapy fuzzing gateway app*.

Summary
What we've learned

- The GSM industry is making security analysis very difficult
- It is well-known that the security level of the GSM stacks is very low
- We now have multiple solutions for sending arbitrary protocol data
  - From a rogue network to phones (OpenBSC, OpenBTS)
  - From an A-bis proxy to the network or the phones
  - From custom GSM phone baseband firmware to the network

TODO

Where we go from here

- The basic tools for fuzzing mobile networks are available
- No nice interface/integration from OsmocomBB to scapy yet
- It is up to the security community to make use of those tools (!)
- Don't you too think that TCP/IP security is boring
- Join the GSM protocol security research projects
- Boldly go where no man has gone before

Thanks

I would like to express my thanks to

- The OsmocomBB development team, most notably
  - Dieter Spaar (invaluable dedication to this project!)
  - Andreas Eversberg (layer 3, cell selection, etc.)
  - Sylvain Munaut (layer1, dsp, misc.)
- Other developers working on Open Source GSM stuff
  - g3gg0 (MADos)
  - David Burgess, Harvind Simra (OpenBTS)
  - Holger Freyther (OpenBSC)

Further Reading

- http://laforge.gnumonks.org/papers/gsm_phone-anatomy-latest.pdf
- http://bb.osmocom.org/
- http://openbsc.gnumonks.org/
- http://openbts.sourceforge.net/
- http://airprobe.org/