Free Software for GSM cellular telephony

OpenBSC, OsmoSGSN, OpenGGSN, OsmocomBB

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gnumonks.org
gpl-violations.org
osmocom.org
airprobe.org
hmw-consulting.de

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Outline

1. Researching GSM/3G security
2. OpenBSC
3. OsmocomBB Project
4. OpenBTS, airprobe and wireshark

About the speaker

- Using + playing with GNU/Linux since 1994
- Kernel / bootloader / driver / firmware development since 1999
- IT security expert, focus on network protocol security
- Core developer of Linux packet filter netfilter/iptables
- Trained as Electrical Engineer
- Always looking for interesting protocols (RFID, DECT, GSM)

Success of Free Software
depending on area of computing

- Free Software has proven to be successful in many areas of computing
  - Operating Systems (GNU/Linux)
  - Internet Servers (Apache, Sendmail, Exim, Cyrus, ...)
  - Desktop Computers (gnome, KDE, Firefox, LibreOffice, ...)
  - Mobile Devices
  - Embedded network devices (Router, Firewall, NAT, WiFi-AP)
- There are more areas to computing that people tend to forget. Examples in the communications area:
  - Cellular telephony networks (GSM, 3G, LTE)
  - Professional Mobile Radio (TETRA, TETRAPOL)
  - Cordless telephones (DECT)

Free specs / Free implementations

- 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 proprietary protocol stack implementations
  - GSM chip set 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
  - minimal network using standard components definitely in the 100,000s of EUR range

The closed GSM industry
Operator side

From my experience with Operators (prove me wrong!)

- Operators are mainly finance + marketing today
- Many operators outsources
  - Network servicing / deployment, even planning
  - Other aspects of business like Billing
- 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 free software 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 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
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
  - Also, using SDR (software defined radio) approach, special-purpose / closed hardware can be avoided

Security analysis of GSM
The bootstrapping process

- Read GSM specs day and night (> 1000 PDF documents)
- Gradually grow knowledge about the protocols
  - OpenBSC: Obtain actual GSM network equipment (BTS)
  - OpenBTS: Develop SDR based GSM Um Layer 1
- Try to get actual protocol traces as examples
- Start a complete protocol stack implementation from scratch
- Finally, go and play with GSM protocol security

Security analysis of GSM
The bootstrapping process

- Start to read GSM specs (> 1000 PDF documents!)
- Gradually grow knowledge about the protocols
- Obtain actual GSM network equipment (BTS)
- Try to get actual protocol traces as examples
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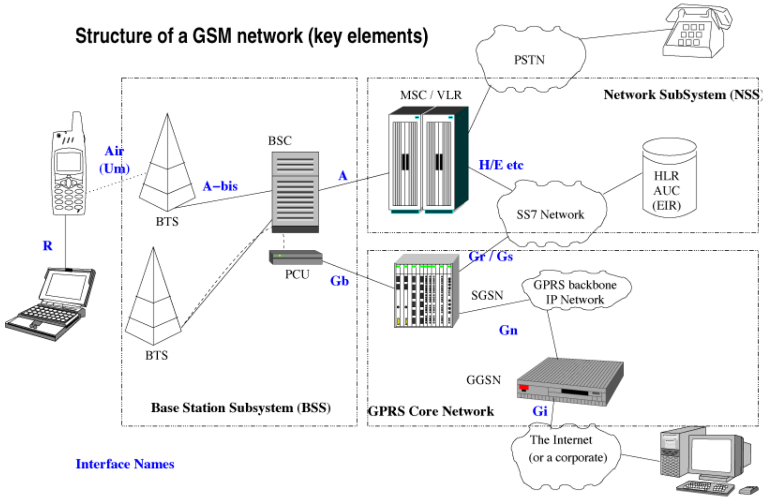
The GSM network



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, ...

GSM network protocols
On the A-bis interface

- Layer 1: Typically E1 line, TS 08.54
- Layer 2: A variant of ISDN LAPD with fixed TEI's, TS 08.56
- Layer 3: OML (Organization and Maintenance Layer, TS 12.21)
- Layer 3: RSL (Radio Signalling Link, TS 08.58)
- Layer 4+: transparent messages that are sent to the MS via Um

OpenBSC software

OpenBSC is a Open Source implementation of (not only) the BSC features of a GSM network.

- Support A-bis interface over E1 and IP
- Support for BTS vendor/model is modular, currently Siemens BS-11 and ip.access nanoBTS
- Multiple BTS models/vendors can be mixed!
- Can work as a *pure BSC* or as a full *network in a box*
- Supports mobility management, authentication, intra-BSC hand-over, SMS, voice calls (FR/EFR/AMR)
- GPRS + EDGE support if combined with OsmoSGSN and OpenGGSN

OpenBSC

- Supports Siemens BS-11 BTS (E1) and ip.access nanoBTS (IP based)
- Has classic 2G signalling, voice and SMS support
- Implements various GSM protocols like
  - A-bis RSL (TS 08.58) and OML (TS 12.21)
  - TS 04.08 Radio Resource, Mobility Management, Call Control
  - TS 04.11 Short Message Service
- Telnet console with Cisco-style interface

OpenBSC software architecture

- Implemented in pure C, similarities to Linux kernel
  - Linked List handling, Timer API, coding style
- Single-threaded event-loop / state machine design
- Telnet based command line interface *Cisco-style*
- Input driver abstraction (mISDN, Abis-over-IP)

OpenBSC: GSM network protocols

The A-bis interface

Layer 1	Typically E1 line, TS 08.54
Layer 2	A variant of ISDN LAPD with fixed TEI's, TS 08.56
Layer 3	OML (Organization and Maintenance Layer, TS 12.21)
Layer 3	RSL (Radio Signalling Link, TS 08.58)
Layer 4+	transparent messages that are sent to the MS via Um

OpenBSC: How it all started

- In 2006, I bought a Siemens BS-11 microBTS on eBay
  - This is GSM900 BTS with 2 TRX at 2W output power (each)
  - A 48kg monster with attached antenna
  - 200W power consumption, passive cooling
  - E1 physical interface
- I didn't have much time at the time (day job at Openmoko)
- Started to read up on GSM specs whenever I could
- Bought a HFC-E1 based PCI E1 controller, has mISDN kernel support
- Found somebody in the GSM industry who provided protocol traces

OpenBSC: Timeline

- November 2008: I started the development of OpenBSC
- December 2008: we did a first demo at 25C3
- January 2009: we had full voice call support
- Q1/2009: Add support for ip.access nanoBTS
- June 2009: I started with actual security related stuff
- August 2009: We had the first field test with 2BTS and > 860 phones
- Q1/2010: The first 25 OpenBSC instances running in a commercial network

OpenBSC: Field Test at HAR2009

OpenBSC in NITB mode

Network In a Box Mode

The `osmo-nitb` program

- implements the A-bis interface towards any number of BTS
- provides most typical features of a GSM network in one software
- no need for MSC, AuC, HLR, VLR, EIR, ...
  - HLR/VLR as SQLite3 table
  - Authentication + Ciphering support
  - GSM voice calls, MO/MT SMS
  - Hand-over between all BTS
  - Multiple Location Areas within one BSC

OpenBSC NITB features

OpenBSC NITB features

- Run a small GSM network with 1-n BTS and OpenBSC
- No need for MSC/HLR/AUC/...
- No need for your own SIM cards (unless crypto/auth rqd)
- Establish signalling and voice channels
- Make incoming and outgoing voice calls between phones
- Send/receive SMS between phones
- Connect to ISDN PBX or public ISDN via Linux Call Router

OpenBSC in NITB mode

Network In a Box Mode

The `osmo-nitb` program

- does not implement any other GSM interfaces apart from A-bis
- no SS7 / TCAP / MAP based protocols
- no integration (roaming) with existing traditional GSM networks
- wired telephony interfacing with ISDN PBX `lcr` (Linux Call Router)
- Has been tested with up to 800 subscribers on 5 BTS
- Intended for R&D use or private PBX systems

OpenBSC LCR integration

Interfacing with wired telephony

OpenBSC (NITB mode) can be linked into Linux Call Router (`lcr`)

- OpenBSC is compiled as libbsc.a
- libbsc.a includes full OpenBSC NITB mod code
- linking the library into `lcr` results in GSM *line interfaces* to become available inside `lcr`
- OpenBSC no longer takes care of call control, but simply hands everything off to `lcr`
- Dialling plan, etc. is now configure in `lcr` like for any other wired phones

OpenBSC in BSC-only mode

The `osmo-bsc` program

- behaves like a classic GSM BSC
- uses SCCP-Lite (ip.access multipex) to any SoftMSC like ADC
- used in production/commercial deployments (75 BSCs)
- mainly intended to replace proprietary BSC in traditional GSM networks

GPRS and OpenBSC

- The BSC doesn't really do anything related to GPRS
- GPRS implemented in separate SGSN and GGSN nodes
- GPRS uses its own Gb interface to RAN, independent of A-bis
- OpenBSC can configure the nanoBTS for GPRS+EDGE support via OML
- Actual SGSN and GGSN implemented as OsmoSGSN and OpenGGSN programs

OsmoSGSN

The Osmocom SGSN program implements

- basic/minimal SGSN functionality
- the Gb interface (NS/BSSGP/LLC/SNDCP)
- mobility management, session management

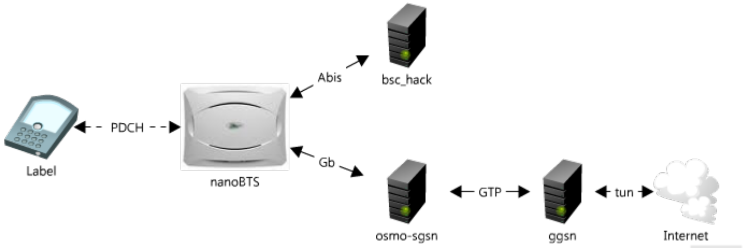
It’s a work in progress, many missing features

- no HLR integration yet
- no paging coordination with MSC/BSC
- no encryption support yet

OpenGGSN

- GPL licensed Linux program implementing GGSN node
- Implements GTP-U protocol between SGSN and GGSN
- User-configurable range/pool of IPv4 addresses for MS
- Uses `tun` device for terminating IP tunnel from MS
- provides GTP implementation as libgtp
- Experimental patches for IPv6 support

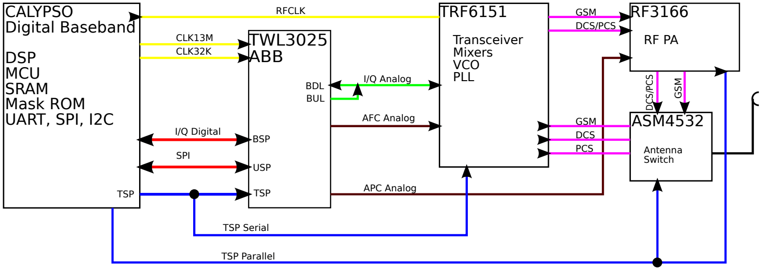
OpenBSC and OsmoSGSN based network



A GSM phone baseband processor

- 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

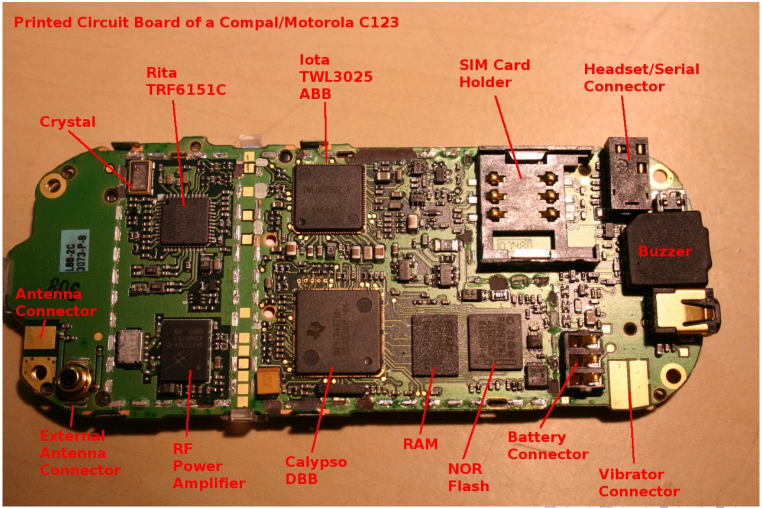
OsmocomBB Host Software

- 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 (since 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
  - Automatic Tx power control (APC)
  - Neighbor Cell Measurements (WIP)
  - In-call hand-over to other cells (WIP)
- 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
  - Has been used on real networks for 30+ minute calls!

OsmocomBB use cases

OsmocomBB can be used today for

- practical lab exercises in education on any level of GSM, from the radio modem through the protocol stack
- applied research in GSM protocols and GSM security
- penetration testing of GSM operator equipment
- measurement and exploration of real operator networks

With (your?) help, we can turn it into an actual mobile phone for regular users, i.e. bringing the freedom of Free Software into one of the most closed areas of computing.

What is OpenBTS?

- is *NOT* a BTS in the typical GSM sense
- is better described as a GSM-Um to SIP gateway
- implements the GSM Um (air interface) as SDR
- uses the USRP hardware as RF interface
- does not implement any of BSC, MSC, HLR, etc.
- bridges the GSM Layer3 protocol onto SIP
- uses SIP switch (like Asterisk) for switching calls + SMS
- is developed as C++ program and runs on Linux + MacOS

What is OpenBTS?

- Open implementation of Um L1 & L2, an all-software BTS.
- L1/L2 design based on an object-oriented dataflow approach.
- Includes L3 RR functions normally found in BSC.
- Uses SIP PBX for MM and CC functions, eliminating the conventional GSM network. L3 is like an ISDN/SIP gateway.
- Intended for use in low-cost and rapidly-deployed communications networks, but can be used for experiments (including by Chris Paget at Def Con).

OpenBTS Hardware

OpenBTS supports the following SDR hardware

- Ettus USRP(1) with two RFX 900 or RFX 1800 daughter boards
  - Modification for external clock input recommended
  - External 52 MHz precision clock recommended
- Kestrel Signal Processing / Range Networks custom radio
- Close Haul Communications / GAPfiller (work in progress)
- Ported to other radios by other clients

OpenBTS History + Tests

- Started work in August 2007, first call in January 2008, first SMS in December 2008.
- First public release in September 2008, assigned to FSF in October 2008.
- Tested 3-sector system with 10,000-20,000 handsets at September 2009 Burning Man event in Nevada.
- Tested 2-sector system with 40,000 handsets at September 2010 Burning Man event in Nevada.
- Release 2.5 is about 13k lines of C++.
- Part of GNU Radio project, distributed under GPLv3 (>= 2.6: AGPLv3)

OpenBTS Software Architecture

- `Transceiver` program
  - SDR processing for Layer 0
  - BTS-side GSM Um Layer 1 implementation
  - sends GSM burst data via UDP socket
- `OpenBTS` program
  - GSM Um Layer 2 (04.06) + 3 (04.08) implementation
  - SIP UA implementation
  - GSM Layer 3 CC to SIP bridge implementation

OpenBTS GSM <-> SIP mapping

- Location Updates mapped to SIP registration
  - Use IMSI as SIP user name
- Call Control mapped to SIP transactions
  - relatively straight-forward
- GSM Traffic Channels mapped to RTP channels
  - No transcoding inside OpenBTS, FR/EFR messages are simply relayed
- SMS mapped to SIP messaging according to RFC 3428
  - A separate `smqueue` daemon implements store+forward

OpenBTS USRP Clocking
Clock Stability

- USRP has regular XO (Crystal Oscillator) with 20ppm accuracy
- GSM requires 20ppb carrier clock accuracy
- possible solutions
  - use external VCTCXO clocking module
  - use external OCXO clocking module
  - use a software calibration program comparing USRP XO with real GSM BTS carrier clocks
- due to clock multiplication, absolute error in GSM1800 is higher than in GSM900

OpenBTS USRP Clocking
64 MHz vs. 52 MHz clock

- The USRP master clock is 64 Mhz
- In GSM, all clocks are derived from 13 MHz
- Thus, a poly-phase re-sampler is part of SDR software
- Alternative: use 52 MHz (13 MHz * 4) external clock
- OpenBTS has two transceiver programs, one for each 64 MHz and 52 MHz
    - Make sure to never use the wrong transceiver for your clock!

OpenBTS USRP Clocking
Software Calibration

Basic idea: Use real GSM cell as clock source

- Implemented by the *Kalibrator* (`kal`) program
- Acquire the FCCH burst of a real GSM cell
- Measure the clock difference between USRP XO and that cell
- Use the computed error as offset to USRP up/downconverter
- However, temperature and other drift will make clocks go out of sync over time
- Can only be used if a real-world GSM network is within range

OpenBTS – “Nevada Test Site” & 21m Mast

Burning Man 2010 Tower Base

OpenMS

- Subscriber side stack based on OpenBTS.
- Called MS, but just a BTS stack with data flows reversed and a different RR control logic.
- Behavior is more like a passive interceptor that can also transmit.
- Release 1.0 supports non-hopping multi-ARFCN networks.
- Most L3 control logic provided by the end user.
- A platform for
  - passive interceptors
  - custom subscriber-side applications
  - environment analysis
  - intelligent jamming
- NOT Open Source

Open Source GSM Tools: Airprobe

- *airprobe* is a collection of Um protocol analyzer tools using the USRP software defined radio
- A number of different Um receiver implementations

gssm	One of the two early Um receiver implementations (M&M clock recovery)
gsmsp	The other early Um receiver implementation
gsm-tvoid	For a long time the Um receiver with best performance
gsm-receiver	The latest generation of Um receiver

- Today, gsm-receiver seems to be the most popular choice

Open Source GSM Tools: Airprobe

- Some other airprobe tools

gsmdecode	A standalone text-mode Um L2 frame parser
wireshark	Dissector code for feeding Um frames into wireshark
gsmstack	An unfinished more modular implementation of a Rx-only L1
viterbi_gen	Generate C++ implementations of a viterbi decoder

- Still under development, no user friendly solution
  - gsmtap frame format needs to be added as clean wireshark interface
  - receivers need automatic frequency scanning
  - full solution needs proper UI

The wireshark protocol analyzer

- Software protocol analyzer for plethora of protocols
- Portable, works on most flavors of Unix and Windows
- Decode, display, search and filter packets with configurable level of detail
- Over 1000 protocol decoders
- Over 86000 display filters
- Live capturing from many different network media
- Import files from other capture programs
- Used to be called ethereal, but is now called wireshark
- `http://www.wireshark.org/`
- `http://www.wireshark.org/download/docs/user-guide-a4.pdf`

The wireshark protocol analyzer

GSM protocol dissectors in wireshark

- TCP/IP (transport layer for Abis/IP)
- E1 Layer 2 (LAPD)
- GSM Um Layer 2 (LAPDm)
- GSM Layer 3 (RR, MM, CC)
- A-bis Layer 3 (RSL)
    - A-bis OML for Siemens and ip.access in OpenBSC git
- GSMTAP pseudo-header (airprobe, OpenBTS, OsmocomBB)

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 a FOSS controlled phone to the network (OsmocomBB)
  - From an A-bis proxy to the network or the phones

TODO
Where we go from here

- The tools for fuzzing mobile phone protocol stacks are available
- 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 (free) man has gone before

Current Areas of Work / Future plans

- UMTS(3G) support for NodeB and femtocells
- SS7 / MAP integration (Erlang and C)
- Playing with SIM Toolkit from the operator side
- Playing with MMS
- More exploration of RRLP + SUPL

Further Reading

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