Running FOSS Cellular Networks on Linux

Harald Welte <laforge@gnumonks.org>

What this talk is about

- Implementing GSM/GPRS network elements as FOSS
- Applied Protocol Archeology
- Doing all of that on top of Linux (in userspace)
- If you expeccted kernel stuff, you'll be disappointed

Running your own Internet-style network

- use off-the-shelf hardware (x86, Ethernet card)
- use any random Linux distribution
- configure Linux kernel TCP/IP network stack
  - enjoy fancy features like netfilter/iproute2/tc
- use apache/lighttpd/nginx on the server
- use Firefox/chromium/konqueor/lynx on the client
- do whatever modification/optimization on any part of the stack

Running your own GSM network

Until 2009 the situation looked like this:

- go to Ericsson/Huawei/ZTE/Nokia/Alcatel/...
- spend lots of time convincing them that you're an eligible customer
- spend a six-digit figure for even the most basic full network
- end up with black boxes you can neither study nor improve
  - WTF?
  - I've grown up with FOSS and the Internet. I know a better world.

Why no cellular FOSS?

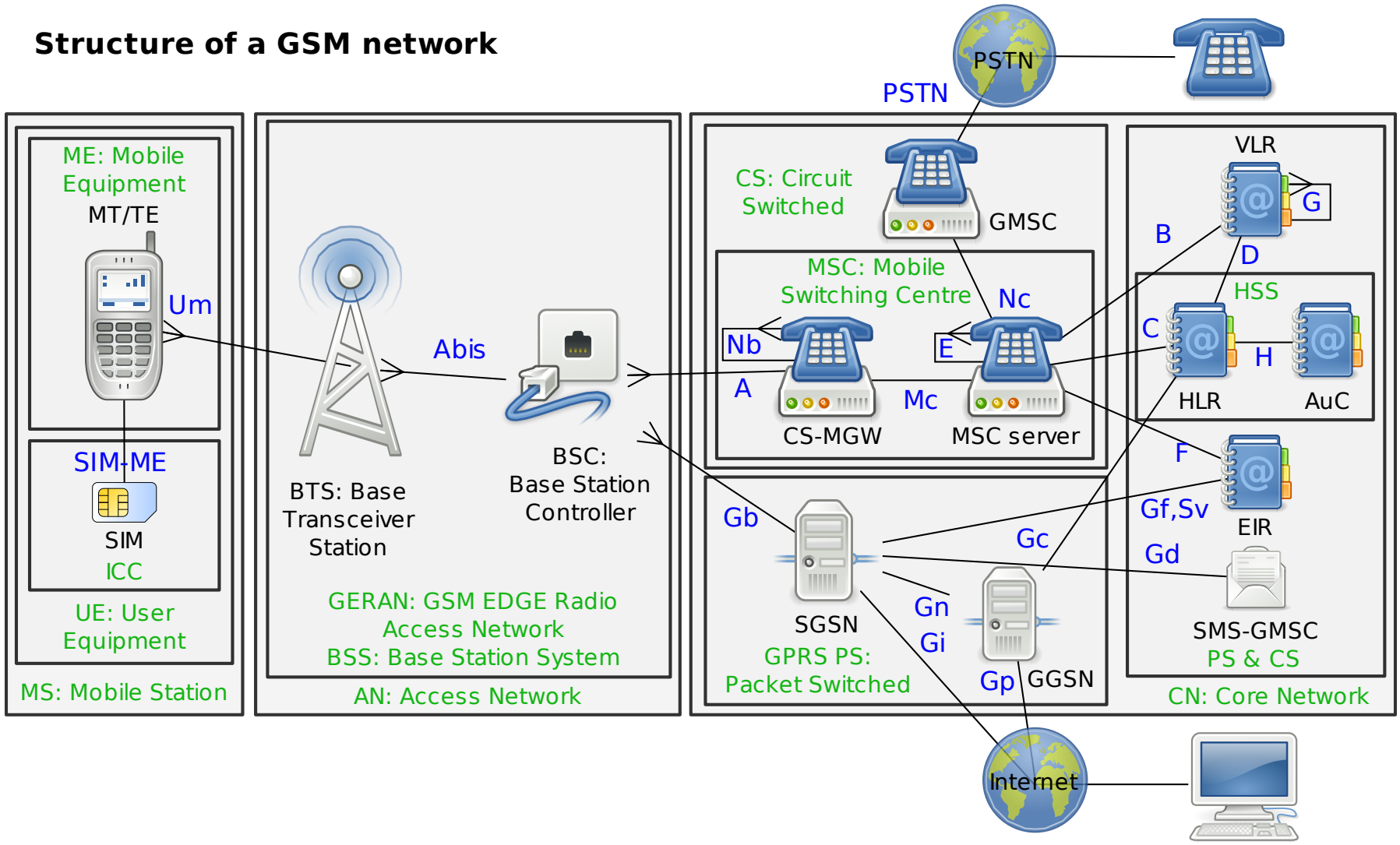
- both cellular (2G/3G/4G) and TCP/IP/HTTP protocol specs are publicly available for decades. Can you believe it?
- Internet protocol stacks have lots of FOSS implementations
- cellular protocol stacks have no FOSS implementations for the first almost 20 years of their existence?
- it's the classic conflict
  - classic circuit-switched telco vs. the BBS community
  - ITU-T/OSI/ISO vs. Arpanet and TCP/IP

Enter Osmocom

In 2008, some people started to write FOSS for GSM

- to boldly go where no FOSS hacker has gone before
  - where protocol stacks are deep
  - and acronyms are plentiful
  - we went from `bs11-abis` to `bsc_hack` to *OpenBSC*
  - many other related projects were created
  - finally leading to the *Osmocom* umbrella project

Classic GSM network architecture



GSM Acronyms, Radio Access Network

MS

Mobile Station (your phone)

BTS

Base Transceiver Station, consists of 1..n TRX

TRX

Transceiver for one radio channel, serves 8 TS

TS

Timeslots in the GSM radio interface; each runs a specific combination of logical channels

BSC

Base Station Controller

GSM Acronyms, Core Network

MSC

Mobile Switching Center; Terminates MM + CC Sub-layers

HLR

Home Location Register; Subscriber Database

SMSC

SMS Service Center

GSM Acronyms, Layer 2 + 3

LAPDm

Link Access Protocol, D-Channel. Like LAPD in ISDN

RR

Radio Resource (establish/release dedicated channels)

MM

Mobility Management (registration, location, authentication)

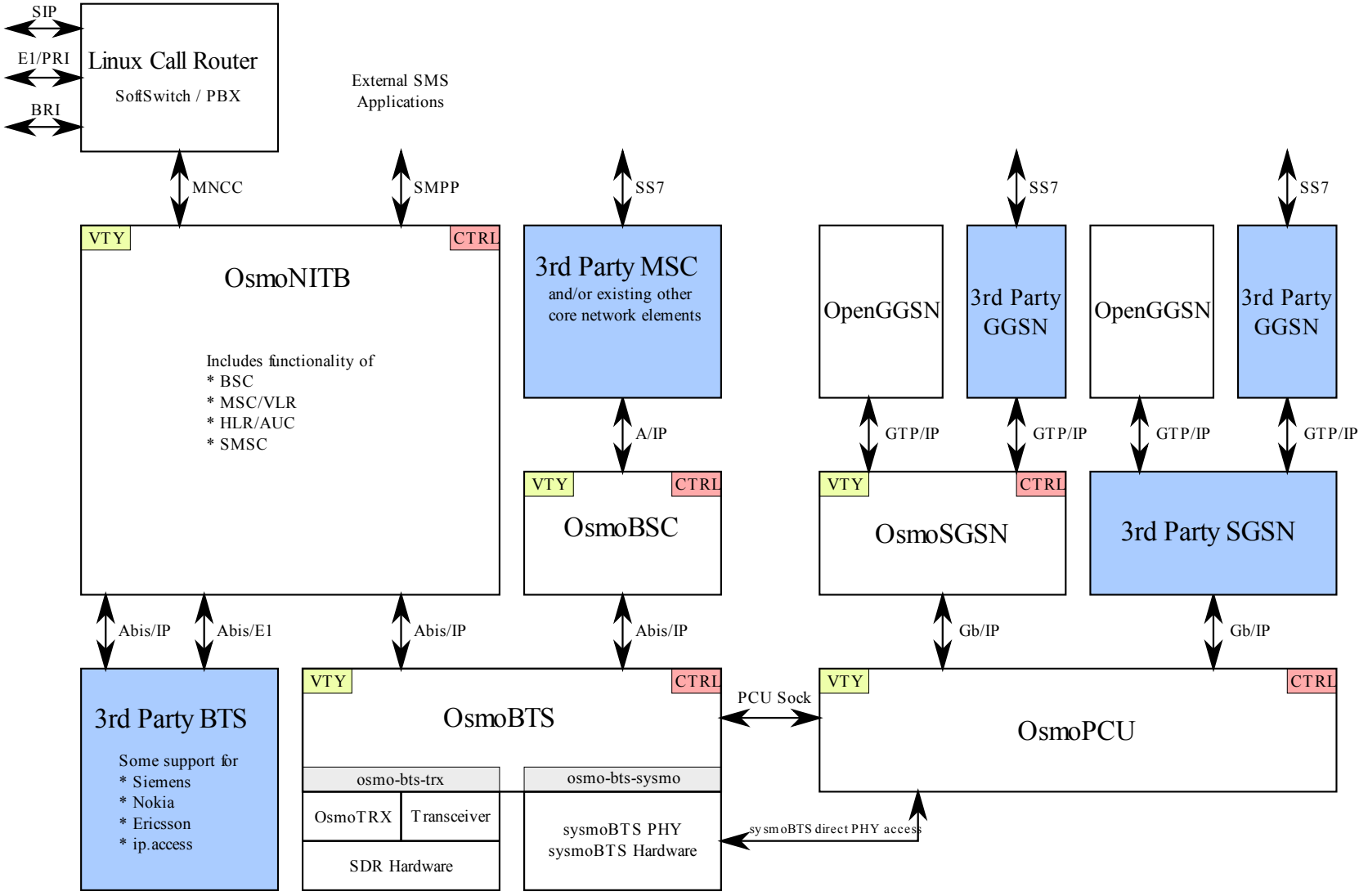
CC

Call Control (voice, circuit switched data, fax)

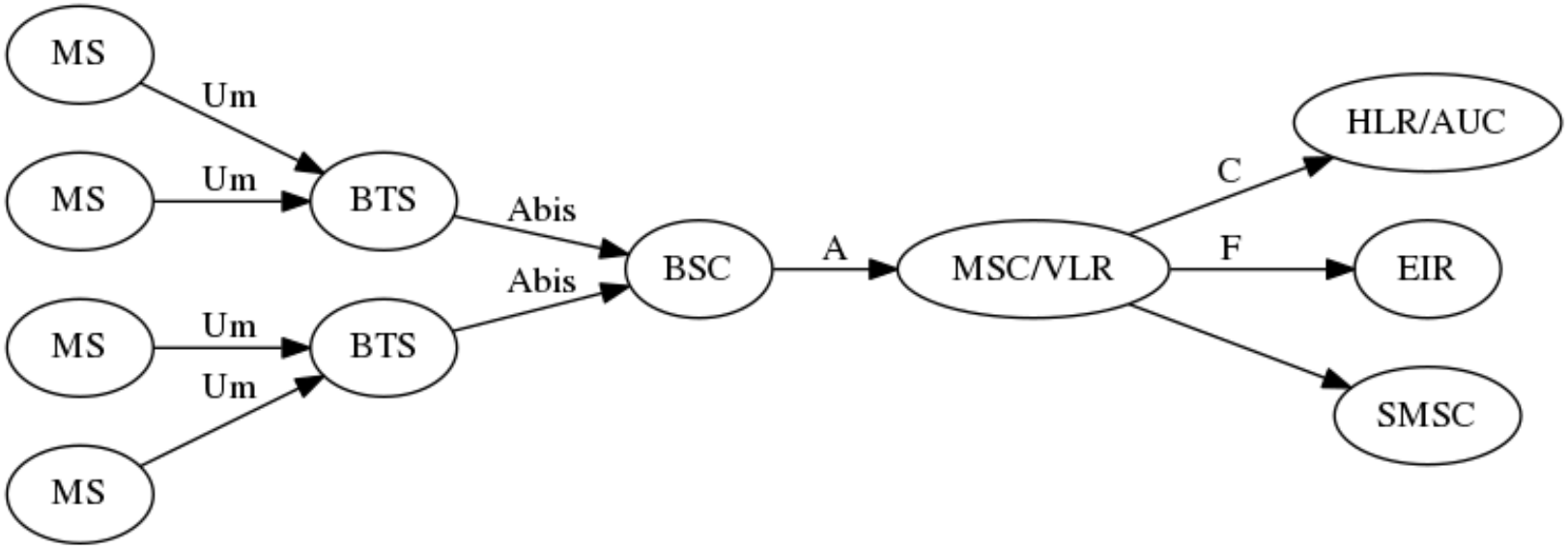
CM

Connection Management

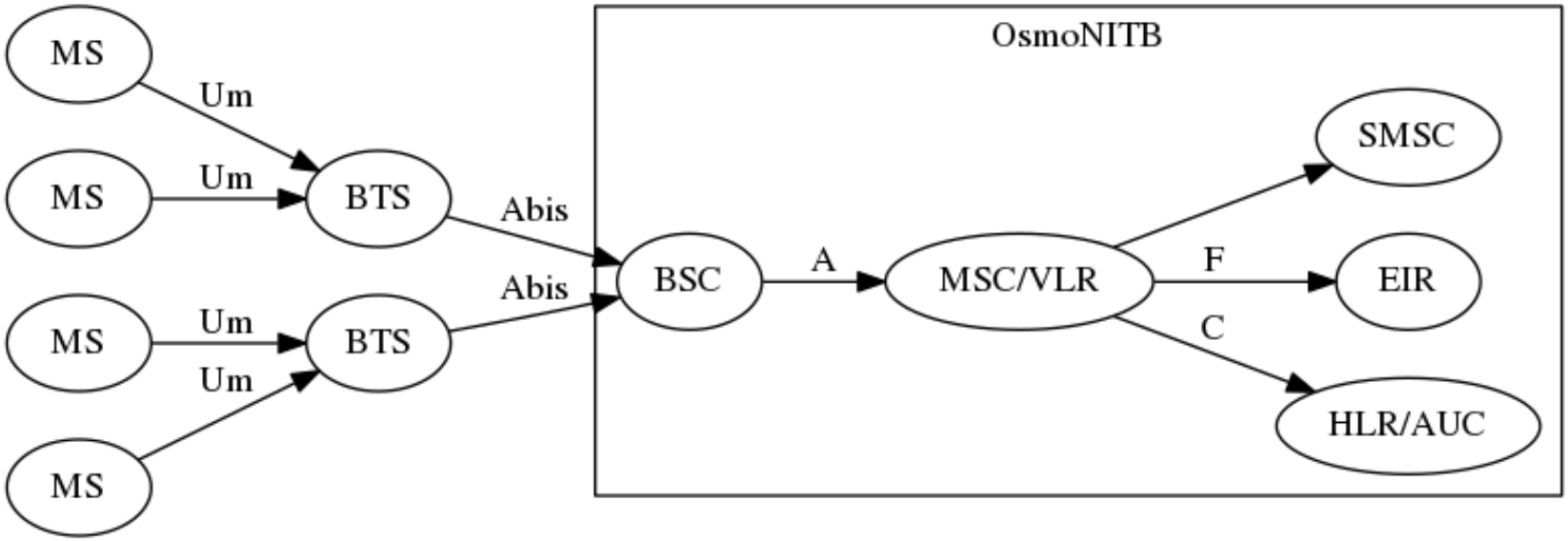
Osmocom GSM components


SIP
E1/PRI
BRI
Linux Call Router
SoftSwitch / PBX
External SMS
Applications
MNCC
SMPP
SS7
SS7
SS7
VTY
CTRL
OsmoNITB
Includes functionality of
* BSC
* MSC/VLR
* HLR/AUC
* SMSC
3rd Party MSC
and/or existing other
core network elements
OpenGGSN
3rd Party
GGSN
OpenGGSN
3rd Party
GGSN
A/IP
GTP/IP
GTP/IP
GTP/IP
GTP/IP
VTY
CTRL
OsmoBSC
VTY
CTRL
OsmoSGSN
3rd Party SGSN
Abis/IP
Abis/E1
Abis/IP
Abis/IP
Gb/IP
Gb/IP
3rd Party BTS
Some support for
* Siemens
* Nokia
* Ericsson
* ip.access
VTY
CTRL
OsmoBTS
PCU Sock
VTY
CTRL
OsmoPCU
osmo-bts-trx
osmo-bts-sysmo
OsmoTRX
Transceiver
SDR Hardware
sysmoBTS PHY
sysmoBTS Hardware
sysmoBTS direct PHY access

Classic GSM network as digraph



Simplified OsmoNITB GSM network



which further reduces to the following minimal setup:

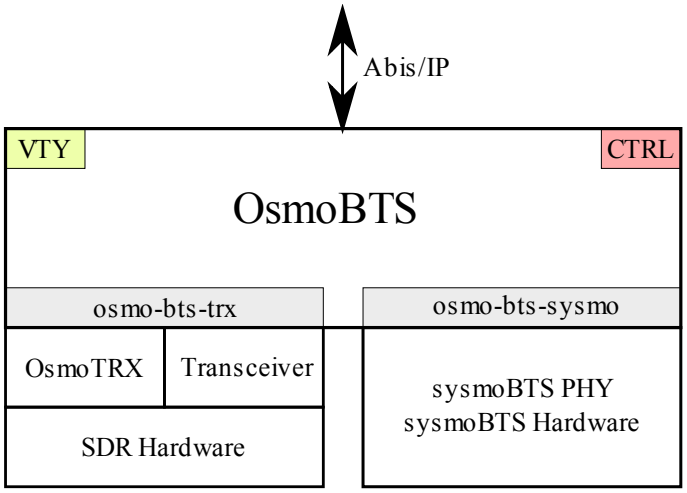
So our minimal setup is a *Phone*, a *BTS* and *OsmoNITB*.

Which BTS to use?

- Proprietary BTS of classic vendor
  - Siemens BS-11 is what we started with
  - Nokia, Ericsson, and others available 2nd hand
- *OsmoBTS* software implementation, running with
  - Proprietary HW + PHY (DSP): *sysmoBTS*, or
  - General purpose SDR (like USRP) + *OsmoTRX*

We assume a sysmoBTS in the following tutorial

OsmoBTS Overview



- Implementation of GSM BTS
- supports variety of hardware/PHY options
  - `osmo-bts-sysmo`: BTS family by sysmocom
  - `osmo-bts-trx`: Used with *OsmoTRX* + general-purpose SDR
  - `osmo-bts-octphy`: Octasic OCTBTS hardware / OCTSDR-2G PHY
  - `osmo-bts-litecell15`: Nutaq Litecell 1.5 hardware/PHY

Configuring Osmocom software

- all Osmo* GSM infrastructure programs share common architecture, as defined by various libraries *libosmo{core,gsm,vty,abis,netif,...}*
- part of this is configuration handling
  - interactive configuration via command line interface (**vty**), similar to Cisco routers
  - based on a fork of the VTY code from Zebra/Quagga, now *libosmovty*
- you can manually edit the config file,
- or use `configure terminal` and interactively change it

Configuring OsmoBTS

- *OsmoBTS* in our example scenario runs on the embedded ARM/Linux system inside the *sysmoBTS*
- we access the *sysmoBTS* via serial console or ssh
- we then edit the configuration file `/etc/osmocom/osmo-bts.cfg` as described in the following slide

Configuring OsmoBTS

```
bts 0
 band DCS1800 <1>
 ipa unit-id 1801 0 <2>
 oml remote-ip 192.168.100.11 <3>
```

1. the GSM frequency band in which the BTS operates
2. the unit-id by which this BTS identifies itself to the BSC
3. the IP address of the BSC (to establish the OML connection towards it)

Note All other configuration is downloaded by the BSC via OML. So most BTS settings are configured in the BSC/NITB configuration file.

Configuring OsmoNITB

- *OsmoNITB* is the `osmo-nitb` executable built from the `openbsc` source tree / git repository
- just your usual `git clone && autoreconf -fi && ./configure && make install`
  - (in reality, the `libosmo*` dependencies are required first...)
- *OsmoNITB* runs on any Linux system, like your speakers' laptop
  - you can actually also run it on the ARM/Linux of the *sysmoBTS* itself, having a literal *Network In The Box* with power as only external dependency

Configuring OsmoNITB

```
network
 network country code 1 <1>
 mobile network code 1 <2>
 shot name Osmocom <3>
 long name Osmocom
 auth policy closed <4>
 encryption a5 0 <5>
```

1. MCC (Country Code) e.g. 262 for Germany; 1 == Test
2. MNC (Network Code) e.g. mcc=262, mnc=02 == Vodafone; 1 == Test
3. Operator name to be sent to the phone **after** registration
4. Only accept subscribers (SIM cards) explicitly authorized in HLR
5. Use A5/0 (== no encryption)

Configuring BTS in OsmoNITB (BTS)

```
network
 bts 0
  type sysmobts <1>
  band DCS1800 <2>
  ms max power 33 <3>
  periodic location update 6 <4>
  ip.access unit_id 1801 0 <5>
  codec-support fr hr efr amr <6>
```

1. type of the BTS that we use (must match BTS)
2. frequency band of the BTS (must match BTS)
3. maximum transmit power phones are permitted (33 dBm == 2W)
4. interval at which phones should send periodic location update (6 minutes)
5. Unit ID of the BTS (must match BTS)
6. Voice codecs supported by the BTS

Configuring BTS in OsmoNITB (TRX)

```
network
 bts 0
  trx 0
   arfcn 871 <1>
   max_power_red 0 <2>
   timeslot 0
    phys_chan_config CCCH+SDCCH4 <3>
   timeslot 1
    phys_chan_config TCH/F <4>
    ...
   timeslot 7
    phys_chan_config PDCH <5>
```

1. The RF channel number used by this TRX
2. The maximum power **reduction** in dBm. 0 = no reduction
3. Every BTS needs need one timeslot with a CCCH
4. We configure TS1 to TS6 as TCH/F for voice
5. We configure TS6 as PDCH for GPRS

What a GSM phone does after power-up

- Check SIM card for last cell before switch-off
  - if that cell is found again, use that
  - if not, perform a netwok scan
    - try to find strong carriers, check if they contain BCCH
    - create a list of available cells + networks
    - if one of the networks MCC+MNC matches first digits of *IMSI*, this is the home network, which has preference over others
- perform *LOCATION UPDATE* (TYPE=IMSI ATTACH) procedure to network
- when network sends *LOCATION UPDATE ACCEPT*, **camp** on that cell

→ let's check if we can perform *LOCATION UPDATE* on our own network

Verifying our network

- look at stderr of *OsmoBTS* and *OsmoNITB*
  - *OsmoBTS* will terminate if Abis cannot be set-up
  - expected to be re-spawned by init / systemd
- use MS to search for networks, try manual registration
- observe registration attempts `logging level mm info`

→ should show *LOCATION UPDATE* request / reject / accept

- use the VTY to explore system state (`show *`)
- use the VTY to change subscriber parameters like extension number

Exploring your GSM networks services

- use `*#100#` from any registered MS to obtain own number
- voice calls from mobile to mobile
- SMS from mobile to mobile
- SMS to/from external applications (via SMPP)
- voice to/from external PBX (via MNCC)
- explore the VTY interfaces of all network elements
  - send SMS from the command line
  - experiment with *silent call* feature
  - experiment with logging levels
- use wireshark to investigate GSM protocols

Using the VTY

- The VTY can be used not only to configure, but also to interactively explore the system status (`show` commands)
- Every Osmo* program has its own telnet port

Program	Telnet Port
OsmoPCU	4240
OsmoBTS	4241
OsmoNITB	4242
OsmoSGSN	4245

- ports are bound to 127.0.0.1 by default
- try tab-completion, `?` and `list` commands

Using the VTY (continued)

- e.g. `show subsciber` to display data about subscriber:

```
OpenBSC> show subscriber imsi 901700000003804
    ID: 12, Authorized: 1
    Extension: 3804
    LAC: 0/0x0
    IMSI: 901700000003804
    TMSI: F2D4FA0A
    Expiration Time: Mon, 07 Dec 2015 09:45:16 +0100
    Paging: not paging Requests: 0
    Use count: 1
```

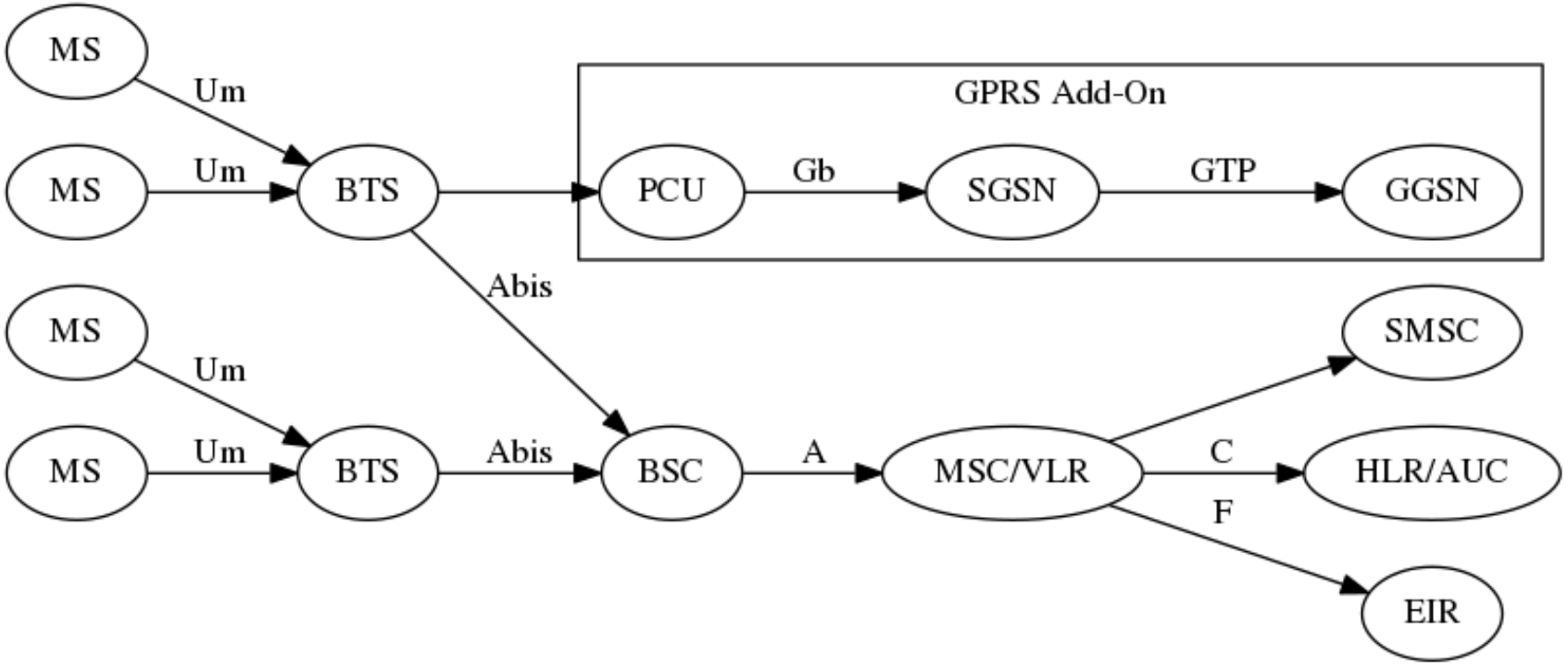
- try `show bts`, `show trx`, `show lchan`, `show statistics`, ...

Extending the network with GPRS

Now that GSM is working, up to the next challenge!

- Classic GSM is circuit-switched only
- Packet switched support introduced first with GPRS
- GPRS adds new network elements (PCU, SGSN, GGSN)
- tunnel for external packet networks like IP/Internet
- tunnel terminates in MS and on GGSN

Extending the network with GPRS support

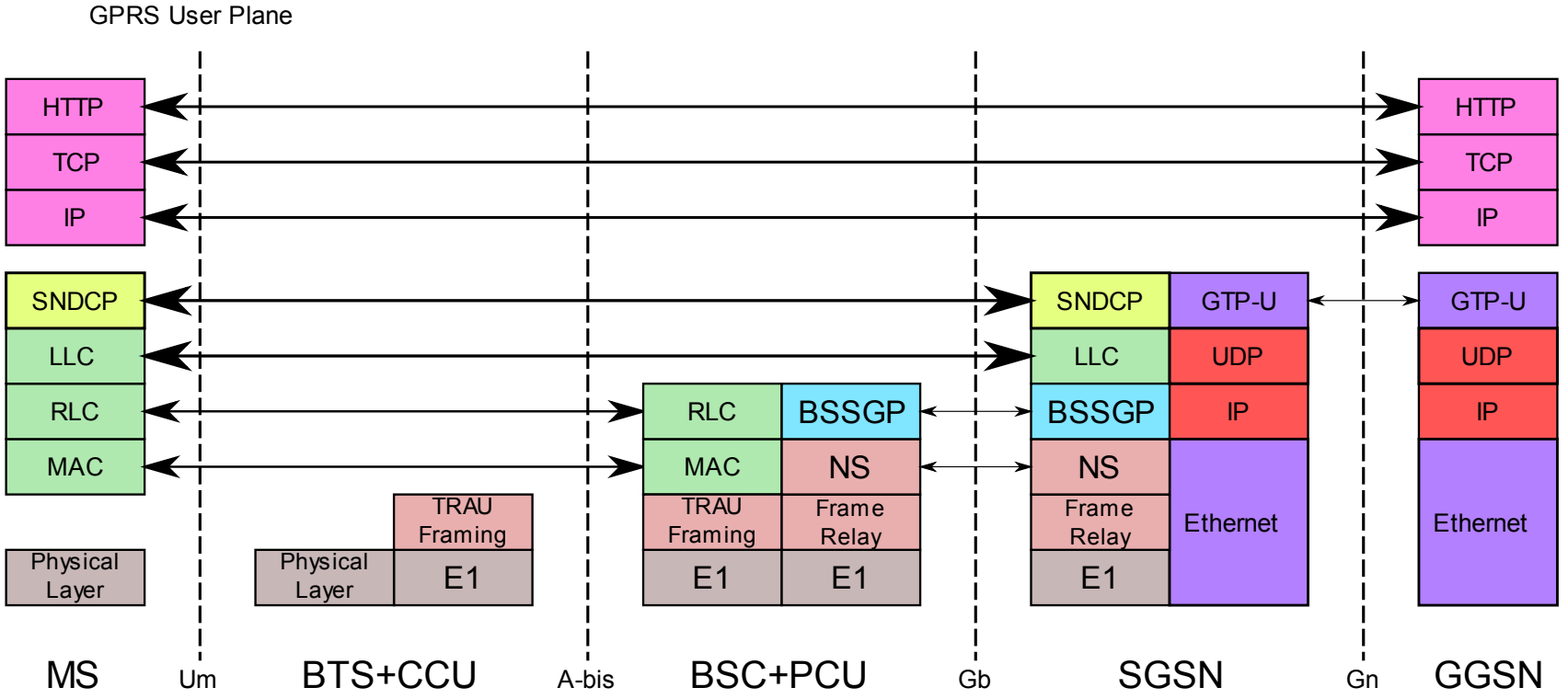


- *PCU*: Packet Control Unit. Runs RLC+MAC
- *SGSN*: Serving GPRS Support Node (like VLR/MSC)
- *GGSN*: Gateway GPRS Support Node (terminates tunnels)

GPRS Signalling basics

- GPRS Mobility Management (GMM)
  - just like GSM Mobility Management (MM)
    - *GPRS ATTACH*, *ROUTING AREA UPDATE*, *AUTHENTICATION*
- GPRS Session Management (SM)
  - establishment, management and tear-down of packet data tunnels
    - independent from IP, but typically IP(v4) is used
    - *PDP Context* (Activation | Deactivation | Modification)

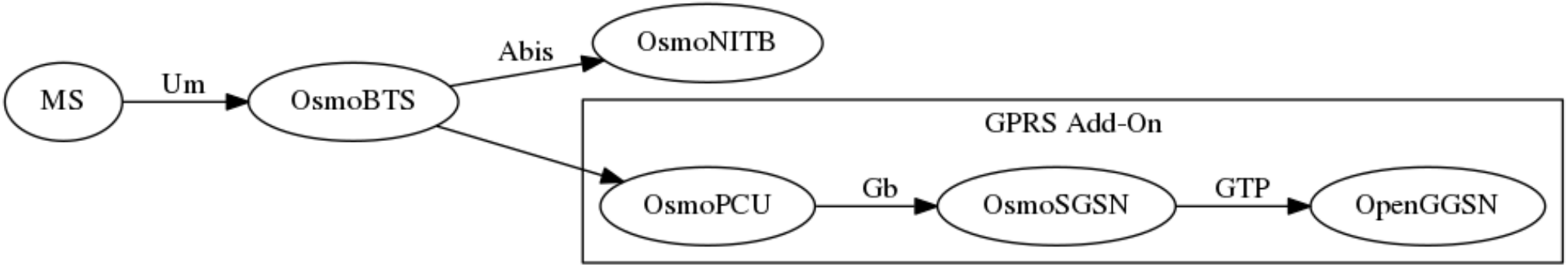
GPRS Protocol Stack


GPRS User Plane
HTTP
TCP
IP
SNDCP
LLC
RLC
MAC
Physical Layer
TRAU Framing
E1
BSSGP
NS
Frame Relay
GTP-U
UDP
Ethernet
MS
Um
BTS+CCU
A-bis
BSC+PCU
Gb
SGSN
Gn
GGSN

GPRS Acronyms, Protocol Stack

- Layer 3
  - *SM*: Session Management (PDP contexts)
  - *GMM*: GPRS Mobility Management (like MM)
- Layer 2
  - *MAC*: Medium Access Control
  - *LLC*: Link Layer Control (segmentation, compression, encryption)
  - *RLC*: Radio Link Control
  - *SNDCP*: Sub-Network Dependent Convergence Protocol
    - Scotty to the bridge: *You have to re-modulate the sub-network dependent convergence protocols!*

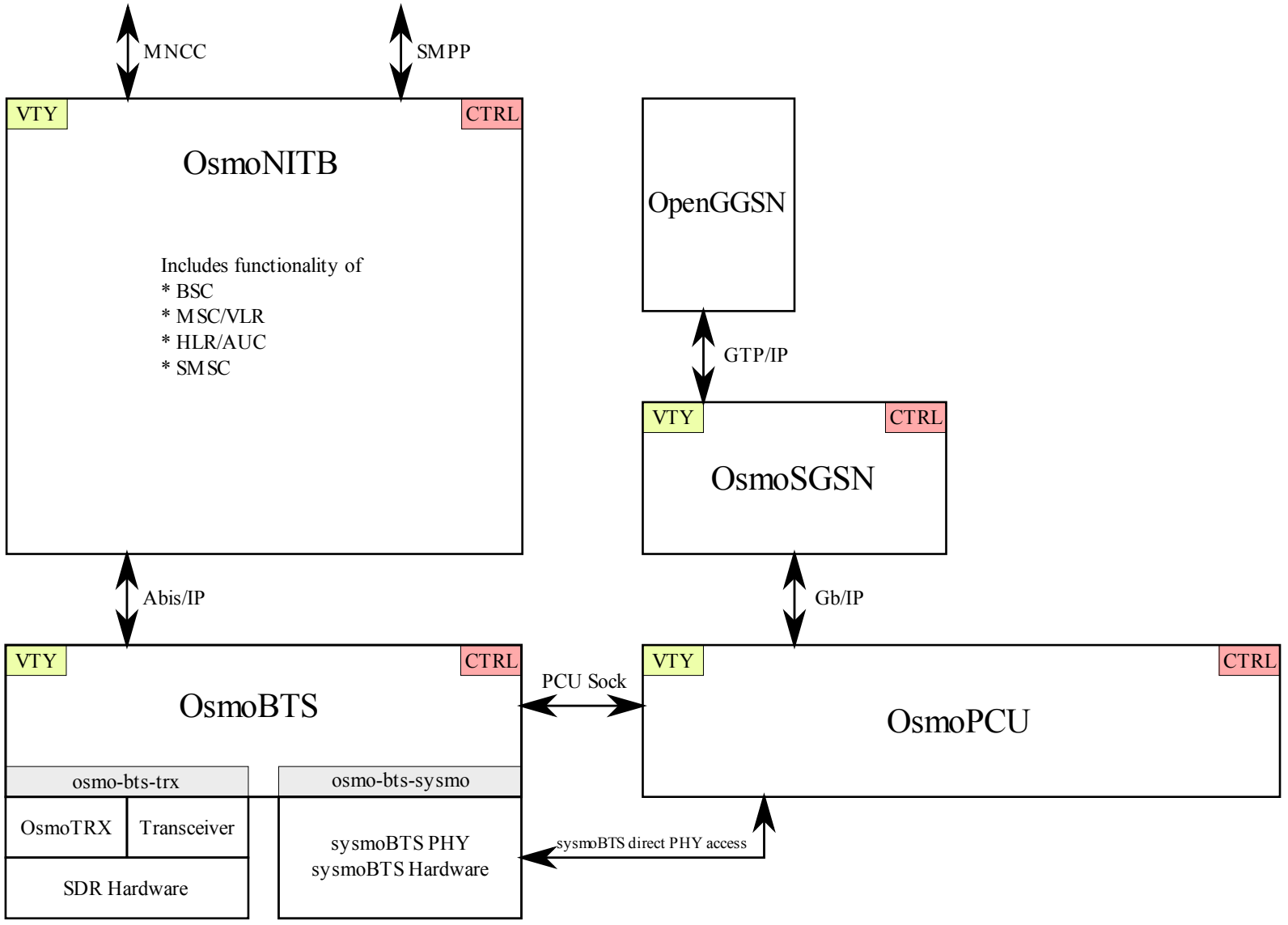
Simplified OsmoNITB network with GPRS



- *OsmoPCU* is co-located with *OsmoBTS*
  - connects over unix-domain PCU socket to BTS
- *OsmoSGSN* can run on any Linux machine
- *OpenGGSN* can run on any Linux machine
  - `tun` device is used for tunnel endpoints
- circuit-switched and packet-switched networks are completely separate

We need to configure those additional components to provide GPRS services.

Simplified OsmoNITB network with GPRS



Configuring OsmoPCU

We assume we have obtained and compiled the `osmo-pcu` from git://git.osmocom.org/osmo-pcu

- *OsmoPCU* runs co-located with *OsmoBTS* to access/share the same PHY + Radio
- *OsmoPCU* is primarily configured from *OsmoBTS*
- *OsmoBTS* receives relevant config via A-bis OML
- *OsmoNITB* sends those OML messages to OsmoBTS
  - we thus need to set the PCU configuration in the NITB config file!

BTS config for GPRS (in OsmoNITB)

```
bts 0
 gprs mode gprs <1>
 gprs nsei 1234 <2>
 gprs nsvc 0 nsvci 1234 <3>
 gprs nsvc 0 local udp port 23000 <4>
 gprs nsvc 0 remote ip 192.168.1.11 <5>
 gprs nsvc 0 remote udp port 23000 <6>
```

1. enable `gprs` or `egprs` mode
2. NSEI for the NS protocol layer (unique for each PCU in SGSN)
3. NSVCI for the NS protocol layer (unique for each PCU in SGSN)
4. UDP port on PCU side of Gb connection
5. IP address of SGSN side of Gb connection
6. UDP port on SGSN side of Gb connection

Configuring OsmoSGSN (Gb and GTP)

```
ns
 encapsulation udp local-ip 192.168.100.11 <1>
 encapsulation udp local-port 23000 <2>
sgsn
 gtp local-ip 127.0.0.2 <3>
 ggsn 0 remote-ip 127.0.0.1 <4>
 ggsn 0 gtp-version 1 <5>
 apn * ggsn 0 <6>
```

1. SGSN-local IP address for Gb connection from PCUs
2. SGSN-local UDP port number for Gb connection from PCUs
3. SGSN-local IP address for GTP connection to GGSN
4. remote IP address for GTP connection to GGSN
5. GTP protocol version for this GGSN
6. route all APN names to GGSN 0

Configuring OsmoSGSN (subscribers)

OsmoSGSN (still) has no access to the *OsmoNITB* HLR, thus all IMSIs permitted to use GPRS services need to be explicitly configured.

```
sgsn
 auth-policy closed <1>
 imsi-acl add 262778026147135 <2>
```

1. only allow explicitly authorized/white-listed subscribers
2. add given IMSI to the white-list of subscribers

Setting up OpenGGSN

In `ggsn.cfg` we need to set:

```
listen 172.0.0.1 <1>
net 10.23.24.0/24 <2>
dynip 10.23.42.0/24 <3>
pcodns1 8.8.8.8 <4>
```

1. IP address to bind GSN to.
2. network/mask of `tun` device
3. pool of dynamic IP addresses allocated to PDP contexts
4. IP address of DNS server (communicated to MS via signalling)

Testing GPRS

- Check if `osmo-pcu`, `osmo-sgsn`, `openggsn` are running
- Check if NS and BSSGP protocols are UNBLOCKED at SGSN
  - If not, check your NS/BSSGP configuration
- Check for GPRS registration using `logging level mm info` in SGSN

Osmocom beyond GSM/GPRS RAN + NITB

- Smalltalk implementation of SIGTRAN + TCAP/MAP
- Erlang implementation of SIGTRAN + TCAP/MAP
- Lots of special-purpose protocol mangling
  - `bsc-nat` to introduce NAT-like functionality on A (BSSAP/BSSMAP)
  - `mgw-nat` to transparently re-write MAP/ISUP/SCCP
- GSMTAP pseudo-header for feeding non-IP protocols into wireshark
- SIM card protocol tracer hardware + software
- Lots of non-GSM projects from hardware to protocol stacks (TETRA, GMR, DECT, OP25)
- check http://git.osmocom.org/ for full project list

So… I heard about OpenBTS?

- OpenBTS is completely unrelated to the Osmocom stack
- was independently developed by David Burgess & Harvind Simra
  - Kestrel Signal Processing → Range Networks
- doesn't follow GSM system architecture at all
  - no Abis, BSC, PCU, SGSN, GGSN
- is a bridge of the GSM air interface (Um) to SIP
- Osmocom follows classic GSM interfaces / system architecture
- *OsmoTRX* forked *OpenBTS* SDR code to use *OsmoBTS* with SDR hardware

Outlook on FOSS 2.75G (EDGE)

- EDGE extends GPRS with higher data rates
  - 8PSK instead of GMSK modulation
  - lots of new MAC/RLC features (larger windows, incremental redundancy)
  - No changes required in *OmsoSGSN* and *OsmoGGSN*
- *OsmoPCU* is extended with EDGE support
- First working minimal subset published last week

Outlook on FOSS 3G (UMTS/WCDMA)

- UMTS very similar to GSM/GPRS in principle
  - still, almost every interface and protocol stack has changed
  - all elements have been renamed → more acronyms to learn
- UMTS is ridiculously complex, particular PHY + Layer 2
  - however, control plane L3 (MM/CC/CM/SM/GMM) mostly the same
- Implementing all of that from scratch is a long journey
- We've already reached *Peak 3G*
- Osmocom 3G support strategy
  - Implement Iu interface in NITB and SGSN
  - Implement HNB-GW to offer Iuh interface
  - Use existing femtocell / small cell hardware with proprietary PHY, RLC and MAC
  - Status: Started in October 2015, WIP. Overall completion > 50%.

Outlook on FOSS 4G (LTE)

- LTE has nothing in common with 2G/3G
- various FOSS activities
  - *OpenAirInterface* has some code for a software eNodeB
    - but they switched from GPLv3 to *non-free* license :(
  - *srsLTE* (main focus on UE side, but large parts usable for eNodeB side)
  - *OpenLTE* is another active FOSS project
- No Osmocom involvement so far
  - team is small, project scope of cellular infrastructure is gigantic
  - most customer funding currently still on GSM/GPRS/EDGE
  - if we'd start, we'd start implementing MME + S-GW and use existing LTE cells

The End

- so long, and thanks for all the fish
- I hope you have questions!
- have fun exploring mobile technologies using Osmocom
- interested in working with more acronyms? Come join the project!
- Check out http://openbsc.osmocom.org/ and openbsc@lists.osmocom.org

Thanks to

- Pablo for running netdevconf and inviting me
- the entire Osmocom team for what they have achieved
  - notably Dieter Spaar, Holger Freyther, Andreas Eversberg, Sylvain Munaut
- last but not least: CEPT for making the GSM specs English
  - (who'd want to read French specs anyway?)