# sysmocom

sysmocom - s.f.m.c. GmbH



# OsmoSTP User Manual

by Harald Welte

DRAFT

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.3 or any later version published by the Free Software Foundation; with the Invariant Sections being just 'Foreword', 'Acknowledgements' and 'Preface', with no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

The Asciidoc source code of this manual can be found at http://git.osmocom.org/osmo-gsm-manuals/

| HISTORY | | | |
|---|---|---|---|
| NUMBER | DATE | DESCRIPTION | NAME |
| 1 | April 16, 2017 | Initial OsmoSTP manual | HW |

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

# Contents

**1 Foreword** **1**
1.1 Acknowledgements . . . 1

**2 Preface** **2**
2.1 FOSS lives by contribution! . . . 2
2.2 Osmocom and sysmocom . . . 2
2.3 Corrections . . . 3
2.4 Legal disclaimers . . . 3
2.4.1 Spectrum License . . . 3
2.4.2 Software License . . . 3
2.4.3 Trademarks . . . 3
2.4.4 Liability . . . 3

**3 Introduction** **4**
3.1 Required Skills . . . 4
3.2 Getting assistance . . . 4

**4 Signaling Networks: SS7 and SIGTRAN** **4**
4.1 Physical Layer . . . 5
4.2 Message Transfer Part (MTP) . . . 5
4.2.1 Point Codes . . . 5
4.3 Higher-Layer Protocols . . . 5
4.4 Signaling Connection Control Part (SCCP) . . . 6
4.4.1 SCCP Addresses . . . 6
4.4.2 Global Titles . . . 6
4.4.3 Global Title Translation (GTT) . . . 7
4.4.4 Peculiarities of Connection Oriented SCCP . . . 7
4.5 SIGTRAN - SS7 over IP Networks . . . 7
4.5.1 SIGTRAN Concepts / Terminology . . . 8
4.5.1.1 Signaling Gateway (SG) . . . 8
4.5.1.2 Application Server (AS) . . . 8
4.5.1.3 Application Server Process (ASP) . . . 8
4.5.2 SIGTRAN variants / stackings . . . 8
4.5.2.1 MTP3 User Adaptation (M3UA) . . . 8
4.5.2.2 SCCP User Adaptation (SUA) . . . 8
4.5.2.3 MTP2 User Adaptation (M2UA) . . . 9
4.5.2.4 MTP2-User Peer-to-Peer Adaptation (M2PA) . . . 9
4.5.3 SIGTRAN security . . . 9

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

4.5.4 IPv6 support . . . 9
4.5.5 SCTP multi-homing in SIGTRAN . . . 9
4.5.6 SCTP Primary Address . . . 9
4.5.7 SCTP Peer Primary Address . . . 10
4.5.8 SCTP INIT Parameters . . . 11
4.5.9 SCTP role . . . 11
4.5.10 M3UA/SUA role . . . 11
4.5.11 Traffic Modes in SIGTRAN . . . 12

**5 Osmocom SS7 + SIGTRAN support 12**
5.1 History / Background . . . 12
5.1.1 The Past (before 2017) . . . 12
5.1.2 The present (2017) . . . 12
5.2 Osmocom extensions to SIGTRAN . . . 13
5.2.1 Osmocom M3UA Routing Key Management Extensions . . . 13
5.2.2 IPA / SCCPlite backwards compatibility . . . 14
5.3 Minimal Osmocom SIGTRAN configurations for small networks . . . 14
5.3.1 A minimal 2G configuration to get started . . . 14
5.3.2 A minimal 3G configuration to get started . . . 15
5.4 Osmocom SS7 Instances . . . 16
5.5 Osmocom SS7 xUA Server . . . 16
5.6 Osmocom SS7 Users . . . 16
5.7 Osmocom SS7 Links . . . 17
5.8 Osmocom SS7 Linksets . . . 17
5.9 Osmocom SS7 Application Servers . . . 17
5.10 Osmocom SS7 Application Server Processes . . . 17
5.11 Osmocom SS7 Routes . . . 18
5.12 Osmocom SCCP Instances . . . 18
5.13 Osmocom SCCP User . . . 18
5.14 Osmocom SCCP Connection . . . 19
5.15 Osmocom SCCP User SAP . . . 19
5.16 Osmocom MTP User SAP . . . 19

**6 The Osmocom VTY Interface 19**
6.1 Accessing the telnet VTY . . . 20
6.2 VTY Nodes . . . 20
6.3 Interactive help . . . 21
6.3.1 The question-mark (`?`) command . . . 21
6.3.2 TAB completion . . . 22
6.3.3 The `list` command . . . 23
6.3.4 The attribute system . . . 24
6.3.5 The expert mode . . . 26

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**7 libosmocore Logging System** **26**
7.1 Log categories . . . 27
7.2 Log levels . . . 27
7.3 Log printing options . . . 27
7.4 Log filters . . . 28
7.5 Log targets . . . 28
7.5.1 Logging to the VTY . . . 28
7.5.2 Logging to the ring buffer . . . 29
7.5.3 Logging via gsmtap . . . 29
7.5.4 Logging to a file . . . 31
7.5.5 Logging to syslog . . . 31
7.5.6 Logging to systemd-journal . . . 32
7.5.7 Logging to stderr . . . 34

**8 VTY Process and Thread management** **34**
8.1 Scheduling Policy . . . 34
8.2 CPU-Affinity Mask . . . 34

**9 Glossary** **36**

**A Osmocom TCP/UDP Port Numbers** **44**

**B Bibliography / References** **45**
B.0.0.0.1 References . . . 45

**C GNU Free Documentation License** **50**
C.1 PREAMBLE . . . 50
C.2 APPLICABILITY AND DEFINITIONS . . . 50
C.3 VERBATIM COPYING . . . 51
C.4 COPYING IN QUANTITY . . . 51
C.5 MODIFICATIONS . . . 51
C.6 COMBINING DOCUMENTS . . . 53
C.7 COLLECTIONS OF DOCUMENTS . . . 53
C.8 AGGREGATION WITH INDEPENDENT WORKS . . . 53
C.9 TRANSLATION . . . 53
C.10 TERMINATION . . . 53
C.11 FUTURE REVISIONS OF THIS LICENSE . . . 54
C.12 RELICENSING . . . 54
C.13 ADDENDUM: How to use this License for your documents . . . 54

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

# 1 Foreword

Digital cellular networks based on the GSM specification were designed in the late 1980s and first deployed in the early 1990s in Europe. Over the last 25 years, hundreds of networks were established globally and billions of subscribers have joined the associated networks.

The technological foundation of GSM was based on multi-vendor interoperable standards, first created by government bodies within CEPT, then handed over to ETSI, and now in the hands of 3GPP. Nevertheless, for the first 17 years of GSM technology, the associated protocol stacks and network elements have only existed in proprietary *black-box* implementations and not as Free Software.

In 2008 Dieter Spaar and I started to experiment with inexpensive end-of-life surplus Siemens GSM BTSs. We learned about the A-bis protocol specifications, reviewed protocol traces and started to implement the BSC-side of the A-bis protocol as something originally called `bs11-abis`. All of this was *just for fun*, in order to learn more and to boldly go where no Free Software developer has gone before. The goal was to learn and to bring Free Software into a domain that despite its ubiquity, had not yet seen any Free / Open Source software implementations.

`bs11-abis` quickly turned into `bsc-hack`, then *OpenBSC* and its *OsmoNITB* variant: A minimal implementation of all the required functionality of an entire GSM network, exposing A-bis towards the BTS. The project attracted more interested developers, and surprisingly quickly also commercial interest, contribution and adoption. This allowed adding support for more BTS models.

After having implemented the network-side GSM protocol stack in 2008 and 2009, in 2010 the same group of people set out to create a telephone-side implementation of the GSM protocol stack. This established the creation of the Osmocom umbrella project, under which OpenBSC and the OsmocomBB projects were hosted.

Meanwhile, more interesting telecom standards were discovered and implemented, including TETRA professional mobile radio, DECT cordless telephony, GMR satellite telephony, some SDR hardware, a SIM card protocol tracer and many others.

Increasing commercial interest particularly in the BSS and core network components has lead the way to 3G support in Osmocom, as well as the split of the minimal *OsmoNITB* implementation into separate and fully featured network components: OsmoBSC, OsmoMSC, OsmoHLR, OsmoMGW and OsmoSTP (among others), which allow seamless scaling from a simple "Network In The Box" to a distributed installation for serious load.

It has been a most exciting ride during the last eight-odd years. I would not have wanted to miss it under any circumstances.

— Harald Welte, Osmocom.org and OpenBSC founder, December 2017.

## 1.1 Acknowledgements

My deep thanks to everyone who has contributed to Osmocom. The list of contributors is too long to mention here, but I'd like to call out the following key individuals and organizations, in no particular order:

- Dieter Spaar for being the most amazing reverse engineer I've met in my career
- Holger Freyther for his many code contributions and for shouldering a lot of the maintenance work, setting up Jenkins - and being crazy enough to co-start sysmocom as a company with me ;)
- Andreas Eversberg for taking care of Layer2 and Layer3 of OsmocomBB, and for his work on OsmoBTS and OsmoPCU
- Sylvain Munaut for always tackling the hardest problems, particularly when it comes closer to the physical layer
- Chaos Computer Club for providing us a chance to run real-world deployments with tens of thousands of subscribers every year
- Bernd Schneider of Netzing AG for funding early ip.access nanoBTS support
- On-Waves ehf for being one of the early adopters of OpenBSC and funding a never ending list of features, fixes and general improvement of pretty much all of our GSM network element implementations
- sysmocom, for hosting and funding a lot of Osmocom development, the annual Osmocom Developer Conference and releasing this manual.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

- Jan Luebbe, Stefan Schmidt, Daniel Willmann, Pablo Neira, Nico Golde, Kevin Redon, Ingo Albrecht, Alexander Huemer, Alexander Chemeris, Max Suraev, Tobias Engel, Jacob Erlbeck, Ivan Kluchnikov
- NLnet Foundation, for providing funding for a number of individual work items within the Osmocom universe, such as LTE support in OsmoCBC or GPRS/EGPRS support for Ericsson RBS6000.
- WaveMobile Ltd, for many years of sponsoring.

May the source be with you!

— Harald Welte, Osmocom.org and OpenBSC founder, January 2016.

# 2 Preface

First of all, we appreciate your interest in Osmocom software.

Osmocom is a Free and Open Source Software (FOSS) community that develops and maintains a variety of software (and partially also hardware) projects related to mobile communications.

Founded by people with decades of experience in community-driven FOSS projects like the Linux kernel, this community is built on a strong belief in FOSS methodology, open standards and vendor neutrality.

## 2.1 FOSS lives by contribution!

If you are new to FOSS, please try to understand that this development model is not primarily about "free of cost to the GSM network operator", but it is about a collaborative, open development model. It is about sharing ideas and code, but also about sharing the effort of software development and maintenance.

If your organization is benefiting from using Osmocom software, please consider ways how you can contribute back to that community. Such contributions can be many-fold, for example

- sharing your experience about using the software on the public mailing lists, helping to establish best practises in using/operating it,
- providing qualified bug reports, workarounds
- sharing any modifications to the software you may have made, whether bug fixes or new features, even experimental ones
- providing review of patches
- testing new versions of the related software, either in its current "master" branch or even more experimental feature branches
- sharing your part of the maintenance and/or development work, either by donating developer resources or by (partially) funding those people in the community who do.

We're looking forward to receiving your contributions.

## 2.2 Osmocom and sysmocom

Some of the founders of the Osmocom project have established *sysmocom - systems for mobile communications GmbH* as a company to provide products and services related to Osmocom.

sysmocom and its staff have contributed by far the largest part of development and maintenance to the Osmocom mobile network infrastructure projects.

As part of this work, sysmocom has also created the manual you are reading.

At sysmocom, we draw a clear line between what is the Osmocom FOSS project, and what is sysmocom as a commercial entity. Under no circumstances does participation in the FOSS projects require any commercial relationship with sysmocom as a company.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

## 2.3 Corrections

We have prepared this manual in the hope that it will guide you through the process of installing, configuring and debugging your deployment of cellular network infrastructure elements using Osmocom software. If you do find errors, typos and/or omissions, or have any suggestions on missing topics, please do take the extra time and let us know.

## 2.4 Legal disclaimers

### 2.4.1 Spectrum License

As GSM and UMTS operate in licensed spectrum, please always double-check that you have all required licenses and that you do not transmit on any ARFCN or UARFCN that is not explicitly allocated to you by the applicable regulatory authority in your country.



**Warning**
Depending on your jurisdiction, operating a radio transmitter without a proper license may be considered a felony under criminal law!

### 2.4.2 Software License

The software developed by the Osmocom project and described in this manual is Free / Open Source Software (FOSS) and subject to so-called *copyleft* licensing.

Copyleft licensing is a legal instrument to ensure that this software and any modifications, extensions or derivative versions will always be publicly available to anyone, for any purpose, under the same terms as the original program as developed by Osmocom.

This means that you are free to use the software for whatever purpose, make copies and distribute them - just as long as you ensure to always provide/release the *complete and corresponding* source code.

Every Osmocom software includes a file called `COPYING` in its source code repository which explains the details of the license. The majority of programs is released under GNU Affero General Public License, Version 3 (AGPLv3).

If you have any questions about licensing, don't hesitate to contact the Osmocom community. We're more than happy to clarify if your intended use case is compliant with the software licenses.

### 2.4.3 Trademarks

All trademarks, service marks, trade names, trade dress, product names and logos appearing in this manual are the property of their respective owners. All rights not expressly granted herein are reserved.

For your convenience we have listed below some of the registered trademarks referenced herein. This is not a definitive or complete list of the trademarks used.

*Osmocom*® and *OpenBSC*® are registered trademarks of Holger Freyther and Harald Welte.

*sysmocom*® and *sysmoBTS*® are registered trademarks of *sysmocom - systems for mobile communications GmbH*.

*ip.access*® and *nanoBTS*® are registered trademarks of *ip.access Ltd.*

### 2.4.4 Liability

The software is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the License text included with the software for more details.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

# 3 Introduction

## 3.1 Required Skills

Please note that even while the capital expenses of running mobile networks has decreased significantly due to Osmocom software and associated hardware like sysmoBTS, GSM networks are still primarily operated by large GSM operators.

Neither the GSM specification nor the GSM equipment was ever designed for networks to be installed and configured by anyone but professional GSM engineers, specialized in their respective area like radio planning, radio access network, back-haul or core network.

If you do not share an existing background in GSM network architecture and GSM protocols, correctly installing, configuring and optimizing your GSM network will be tough, irrespective whether you use products with Osmocom software or those of traditional telecom suppliers.

GSM knowledge has many different fields, from radio planning through site installation to core network configuration/administration.

The detailed skills required will depend on the type of installation and/or deployment that you are planning, as well as its associated network architecture. A small laboratory deployment for research at a university is something else than a rural network for a given village with a handful of cells, which is again entirely different from an urban network in a dense city.

Some of the useful skills we recommend are:

- general understanding about RF propagation and path loss in order to estimate coverage of your cells and do RF network planning.
- general understanding about GSM network architecture, its network elements and key transactions on the Layer 3 protocol
- general understanding about voice telephony, particularly those of ISDN heritage (Q.931 call control)
- understanding of GNU/Linux system administration and working on the shell
- understanding of TCP/IP networks and network administration, including tcpdump, tshark, wireshark protocol analyzers.
- ability to work with text based configuration files and command-line based interfaces such as the VTY of the Osmocom network elements

## 3.2 Getting assistance

If you do have a support package / contract with sysmocom (or want to get one), please contact support@sysmocom.de with any issues you may have.

If you don't have a support package / contract, you have the option of using the resources put together by the Osmocom community at https://projects.osmocom.org/, checking out the wiki and the mailing-list for community-based assistance. Please always remember, though: The community has no obligation to help you, and you should address your requests politely to them. The information (and software) provided at osmocom.org is put together by volunteers for free. Treat them like a friend whom you're asking for help, not like a supplier from whom you have bought a service.

If you would like to obtain professional/commercial support on Osmocom CNI, you can always reach out to sales@sysmocom.de to discuss your support needs. Purchasing support from sysmocom helps to cover the ongoing maintenance of the Osmocom CNI software stack.

# 4 Signaling Networks: SS7 and SIGTRAN

Classic digital telephony networks (whether wired or wireless) use the ITU-T SS7 (Signaling System 7) to exchange signaling information between network elements.

Most of the ETSI/3GPP interfaces in the GSM and UMTS network are also based on top of [parts of] SS7. This includes, among others, the following interfaces:

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

- *A* interface between BSC and MSC
- *IuCS* interface between RNC (or HNB-GW) and MSC
- *IuPS* interface between RNC (or HNB-GW) and SGSN

**Note**
This does not include the A-bis interface between BTS and BSC. While Abis traditionally is spoken over the same physical TDM circuits as SS7, the protocol stack from L2 upwards is quite different (Abis uses LAPD, while SS7 uses MTP)!

## 4.1 Physical Layer

The traditional physical layer of SS7 is based on TDM (time division multiplex) links of the PDH/SDH family, as they were common in ISDN networks. Some people may know their smallest incarnation as so-called E1/T1 links. It can run either on individual 64kBps timeslots of such a link, or on entire 2Mbps/1.5MBps E1/T1 links.

There are also specifications for SS7 over ATM, though it is unclear to the author if this is actually still used anywhere.

On top of the Physical Layer is the Message Transfer Part (MTP).

## 4.2 Message Transfer Part (MTP)

MTP is the lower layer of the SS7 protocol stack. It is comprised of two sub-layers, called MTP2 and MTP3.

Nodes in a MTP network are addressed by their unique PC (Point Code).

A *MTP Routing Label* is in the MTP header and indicates the *Originationg Point Code* (OPC) as well as the *Destination Point Code* (DPC) and the *Service Indicator Octet* (SIO). The SIO is used to de-multiplex between different upper-layer protocol such as ISUP, TUP or SCCP.

Routing is performed by means of routers with routing tables, similar to routing is performed in IP networks. Even the concept of a *point code mask* analogous to the *netmask* exists.

Routers are connected with one another over one or more *Link Sets*, each comprised of one or multiple *Links*. Multiple Links in a Linkset exist both for load sharing as well as for fail over purposes.

### 4.2.1 Point Codes

The length of point codes depends on the particular MTP dialect that is used. In the 1980s, when international telephony signaling networks were established, most countries had their own national dialects with certain specifics.

Today, mostly the ITU and ANSI variants survive. The ITU variant uses 14bit point codes, while the ANSI variant uses 24 bit point code length.

Point Codes can be represented either as unsigned integers, or grouped. Unfortunately there is no standard as to their representation. In ITU networks, the *3.8.3* notation is commonly used, i.e. one decimal for the first 3 bits, followed by one decimal for the center 8 bits, followed by another decimal for the final 3 bits.

**Example**
The Point Code **1.5.3** (in 3.8.3 notation) is $1*2^{11} + 5*2^3 + 3$ = **2091 decimal**.

## 4.3 Higher-Layer Protocols

There are various higher-layer protocols used on top of MTP3, such as TUP, ISUP, BICC as well as SCCP. Those protocols exist side-by-side on top of MTP3, similar to e.g. ICMP, TCP and UDP existing side-by-side on top of IP.

In the context of cellular networks, SCCP is the most relevant part.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

## 4.4 Signaling Connection Control Part (SCCP)

SCCP runs on top of MTP3 and creates something like an overlay network on top of it. SCCP communication can e.g. span multiple different isolated MTP networks, each with their own MTP dialect and addressing.

SCCP provides both connectionless (datagram) and connection-oriented services. Both are used in the context of cellular networks.

### 4.4.1 SCCP Addresses

SCCP Addresses are quite complex. This is due to the fact that it is not simply one address format, but in fact a choice of one or multiple different types of addresses.

SCCP Addresses exist as *Calling Party* and *Called Party* addresses. In the context of connectionless datagram services, the sender is always the Calling Party, and the receiver the Called Party. In connection-oriented SCCP, they resemble the initiator and recipient of the connection.

Table 2: SCCP Address Parts

| Acronym | Name | Description |
|---|---|---|
| SSN | Sub-System Number | Describes a given application such as e.g. a GSM MSC, BSC or HLR. Can be compared to port numbers on the Internet |
| PC | Point Code | The Point Code of the underlying MTP network |
| GT | Global Title | What most people would call a "phone number". However, Global Titles come in many different numbering plans, and only one of them (E.164) resembles actual phone numbers. |
| RI | Routing Indicator | Determines if message shall be routed on PC+SSN or on GT basis |

### 4.4.2 Global Titles

A Global Title is a (typically) globally unique address in the global telephony network. The body of the Global Title consists of a series of BCD-encoded digits similar to what everyone knows as phone numbers.

A GT is however not only the digits of the "phone number", but also some other equally important information, such as the *Numbering Plan* as well as the *Nature of Address Indication*.

Table 3: Global Title Parts

| Acronym | Name | Description |
|---|---|---|
| GTI | Global Title Indicator | Determines the GT Format. Ranges from no GT (0) to GT+TT+NP+ES+NAI (4) |
| NAI | Nature of Address Indicator | Exists in GTI=1 and is sort of a mixture of TON + NPI |
| TT | Translation Type | Used as a look-up key in Global Title Translation Tables |
| NP | Numbering Plan | Indicates ITU Numbering Plan, such as E.164, E.212, E.214 |
| ES | Encoding Scheme | Just a peculiar way to indicate the length of the digits |
| - | Signals | The actual "phone number digits" |

For more information about SCCP Addresses and Global Titles, please refer to [itu-t-q713]

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 4.4.3 Global Title Translation (GTT)

Global Title Translation is a process of re-writing the Global Title on-the-fly while a signaling message passes a STP.

Basically, a SCCP message is first transported by MTP3 on the MTP level to the Destination Point Code indicated in the MTP Routing Label. This process uses MTP routing and is transparent to SCCP.

Once the SCCP message arrives at the MTP End-Node identified by the Destination Point Code, the message is handed up to the local SCCP stack, which then may implement Global Title Translation.

The input to the GTT process is

- the destination address of the SCCP message
- a local list/database of Global Title Translation Rules

The successful output of he GTT includes

- A new Routing Indicator
- The Destination Point Code to which the message is forwarded on MTP level
- a Sub-system Number (if RI is set to "Route on SSN")
- a new Global Title (if RI is set to "Route on GT"), e.g. with translated digits.

Between sender and recipient of a signaling message, there can be many instances of Global Title Translation (up to 15 as per the hop counter).

For more information on Global Title Translation, please refer to [itu-t-q714].

#### 4.4.4 Peculiarities of Connection Oriented SCCP

Interestingly, Connection-Oriented SCCP messages carry SCCP Addresses **only during connection establishment**. All data messages during an ongoing connection do not contain a Called or Calling Party Address. Instead, they are routed only by the MTP label, which is constructed from point code information saved at the time the connection is established.

This means that connection-oriented SCCP can not be routed across MTP network boundaries the same way as connectionless SCCP messages. Instead, an STP would have to perform *connection coupling*, which is basically the equivalent of an application-level proxy between two SCCP connections, each over one of the two MTP networks.

This is probably mostly of theoretical relevance, as connection-oriented SCCP is primarily used between RAN and CN of cellular network inside one operator, i.e. not across multiple MTP networks.

### 4.5 SIGTRAN - SS7 over IP Networks

At some point, IP based networks became more dominant than classic ISDN networks, and 3GPP as well as IETF were working out methods in which telecom signaling traffic can be adapted over IP based networks.

Initially, only the edge of the network (i.e. the applications talking to the network, such as HLR or MSC) were attached to the existing old SS7 backbone by means as SUA and M3UA. Over time, even the links of the actual network backbone networks became more and more IP based.

In order to replace existing TDM-based SS7 links/linksets with SIGTRAN, the M2UA or M2PA variants are used as a kind of drop-in replacement for physical links.

All SIGTRAN share that while they use IP, they don't use TCP or UDP but operate over a (then) newly-introduced Layer 4 transport protocol on top of IP: SCTP (Stream Control Transmission Protocol).

Despite first being specified in October 2000 as IETF RFC 2960, it took a long time until solid implementations of SCTP ended up in general-purpose operating systems. SCTP is not used much outside the context of SIGTRAN, which means implementations often suffer from bugs, and many parts of the public Internet do not carry SCTP traffic due to restrictive firewalls and/or ignorant network administrators.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 4.5.1 SIGTRAN Concepts / Terminology

Like every protocol or technology, SIGTRAN brings with it its own terminology and concepts. This section tries to briefly introduce them. For more information, please see the related IETF RFCs.

##### 4.5.1.1 Signaling Gateway (SG)

The Signaling Gateway (SG) interconnects the SS7 network with external applications. It translates (parts of) the SS7 protocol stack into an IP based SIGTRAN protocol stack. Which parts at which level of the protocol stack are translated to what depends on the specific SIGTRAN dialect.

A SG is traditionally attached to the TDM-Based SS7 network and offers SIGTRAN/IP based applications a way to remotely attach to the SS7 network.

A SG typically has STP functionality built-in, but it is not mandatory.

##### 4.5.1.2 Application Server (AS)

An Application Server is basically a logical entity representing one particular external application (from the SS7 point of view) which is interfaced with the SS7 network by means of one of the SIGTRAN protocols.

An Application Server can have one or more Application Server Processes associated with it. This functionality can be used for load-balancing or fail-over scenarios.

##### 4.5.1.3 Application Server Process (ASP)

An Application Server Process represents one particular SCTP connection used for SIGTRAN signaling between an external application (e.g. a BSC) and the Signaling Gateway (SG).

One Application Server Process can route traffic for multiple Application Servers. In order to differentiate traffic for different Application Servers, the Routing Context header is used.

#### 4.5.2 SIGTRAN variants / stackings

SIGTRAN is the name of an IETF working group, which has released an entire group of different protocol specifications. So rather than one way of transporting classic telecom signaling over IP, there are now half a dozen different ones, and all can claim to be an official IETF standard.

FIXME: Overview picture comparing the different stackings

##### 4.5.2.1 MTP3 User Adaptation (M3UA)

M3UA basically "chops off" everything up to and including the MTP3 protocol layer of the SS7 protocol stack and replaces it with a stack comprised of M3UA over SCTP over IP.

M3UA is specified in [ietf-rfc4666].

M3UA is the SIGTRAN variant chosen by 3GPP for A, IuCs and IuPS interfaces over IP.

##### 4.5.2.2 SCCP User Adaptation (SUA)

SUA basically "chops off" everything up to and including the SCCP protocol layer of the SS7 protocol stack and replaces it with a stack comprised of SUA over SCTP over IP.

This means that SUA can only be used for SCCP based signaling, but not for other SS7 protocols like e.g. TUP and ISUP.

SUA is specified in [ietf-rfc3868].

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 4.5.2.3 MTP2 User Adaptation (M2UA)

M2UA is specified in [ietf-rfc3331].

**Note**
M2UA is not supported in Osmocom SIGTRAN up to this point. Let us know if we can implement it for you!

#### 4.5.2.4 MTP2-User Peer-to-Peer Adaptation (M2PA)

M2PA is specified in [ietf-rfc4165].

**Note**
M2PA is not supported in Osmocom SIGTRAN up to this point. Let us know if we can implement it for you!

### 4.5.3 SIGTRAN security

There simply is none. There are some hints that TLS shall be used over SCTP in order to provide authenticity and/or confidentiality for SIGTRAN, but this is not widely used.

As telecom signaling is not generally carried over public networks, private networks/links by means of MPLS, VLANs or VPNs such as IPsec are often used to isolate and/or secure SIGTRAN.

Under no circumstances should you use unsecured SIGTRAN with production data over the public internet!

### 4.5.4 IPv6 support

SCTP (and thus all the higher layer protocols of the various SIGTRAN stackings) operates on top of both IPv4 and IPv6. As the entire underlying IP transport is transparent to the SS7/SCCP applications, there is no restriction on whether to use SIGTRAN over IPv4 or IPv6.

### 4.5.5 SCTP multi-homing in SIGTRAN

SCTP, unlike more traditional IP L4 protocols (TCP, UDP) doesn't work based on a *connection* between source IP:port and Destination IP:port.

Instead, SCTP creates *associations* between two endpoints, both of which can have any number of IP addresses. This means that in case of network outage, traffic can continue to flow through any of the IP addresses of that association.

The Linux kernel by default advertises all IP addresses of the local system to the peer. This can be seen when inspecting the SCTP INIT chunk e.g. in wireshark. While this may be a reasonable default in some use cases, it is not always the best idea. Imagine addresses of internal/private IP networks, for example local bridge devices between lxc or docker containers, or local VMs. Such addresses have no significance beyond the local machine.

Subsequently, libosmo-sigtran allows the user to explicitly select which local IP addresses shall be used in SCTP multi-homing for the SIGTRAN associations it manages. The user can achieve this by specifying multiple `local-ip` VTY commands within one `asp` (SCTP client role) or within one `listen m3ua 2905` (SCTP server role).

### 4.5.6 SCTP Primary Address

SCTP has the concept of "primary address" in an association. The primary address is a remote address selected from those announced by the peer, and it is the "active" one chosen to transmit user data. The other remote addresses, that are not used, are kept as backups. They are in general only used to transmit user data whenever the SCTP implementation decides to change the primary address, be it due to user policy configuration change or due to the previous primary link becoming unusable. Only confirmed remote addresses (through HEARTBEAT mechanism) are electable to be used as primary address.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

By default, the Linux kernel SCTP stack implementation will probably take the first remote address provided at connect() time in order to start the initial handshake, and continue with next provided remote addresses if the first one fails to confirm the handshake. The remote address which successfully confirmed the handshake is then used as a primary address (since it's likely the only confirmed so far), and will be kept until the link is considered down.

Some deployment setups may have requirements on preferred links to be used when transmitting data (eg. network setups with primary and secondary paths). This can be accomplished by explicitly notifying the kernel to use one of the remote addresses through the SCTP_PRIMARY_ADDR sockopt, plus monitoring the address availability changes on the socket and re-enforcing the primary address when it becomes available again. This is supported in the Osmocom SIGTRAN stack by using the `primary` parameter in one of the `remote-ip` commands under the `asp` node:

```
cs7 instance 0
 asp my-asp 2905 0 m3ua
  remote-ip 10.11.12.13
  remote-ip 16.17.18.19 primary ❶
  ...
```

❶ Use 16.17.18.19 as primary address for the SCTP association. User data will be in general transmitted over this path.

#### 4.5.7 SCTP Peer Primary Address

The SCTP extension ASCONF (RFC5061) allows, when negotiated and supported by both peers, to dynamically announce to the peer the addition or deletion of IP addresses to the association. It also allows one peer announcing to the other peer the desired IP address it should be using as a primary address when sending data to it.

In the Linux kernel SCTP stack, this is accomplished by setting the sockopt SCTP_SET_PEER_PRIMARY_ADDR, which will trigger an ASCONF SCTP message to the peer with the provided local IP address. This is supported in the Osmocom SIGTRAN stack by using the `primary` parameter in one of the `local-ip` commands under the `asp` node:

```
cs7 instance 0
 asp my-asp 2905 0 m3ua
  local-ip 10.11.12.13
  local-ip 16.17.18.19 primary ❶
  ...
```

❶ Announce 16.17.18.19 to the peer as the primary address to be used when transmitting user data to us.

In order to be able to use this feature, the SCTP association peer must support the ASCONF extension. The extension support is negotiated during the INIT handshake of the association. Furthermore, for ASCONF features to work properly, the assoc also needs to announce/use the AUTH extension, as per RFC5061 section 4.2.7. Otherwise, the peer receiving an SCTP INIT with `ExtensionFeatures=ASCONF,ASCONF_ACK` but without AUTH, will reject the association with an ABORT since it's not complying with specifications (this behavior can be tweaked through sysctl "net.sctp.addip_noauth_enable").

As of the time of writing this documentation (linux 6.4.12) and since basically ever, those extensions are runtime-disabled by default. They can be enabled per socket using the kernel sockopts SCTP_ASCONF_SUPPORTED and SCTP_AUTH_SUPPORTED, and that's what the Osmocom stack is currently doing for all its SCTP sockets.

However, those sockopts are farily new (linux v5.4), which means user running older kernels will see in the logs setting those sockopts fail, but connection will keep ongoing, simply without those features available (so setting `primary` in the configuration won't have any effect here). On those older kernels, if this feature is still desired, it can be used by means of enabling the SCTP extensions in all socket system-wide through sysctl:

```
net.sctp.auth_enable=1
net.sctp.addip_enable=1
```

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 4.5.8 SCTP INIT Parameters

Several SCTP INIT parameters can be configured through VTY, which will be passed to the Linux Kernel SCTP stack and used whenever an association is being established.

On the client side (see Section 4.5.9), the parameters are configured in the `asp` node:

```
cs7 instance 0
 asp my-asp 2905 0 m3ua
  sctp-role client
  sctp-param init num-ostreams 250 ❶
  sctp-param init max-instreams 300 ❷
  sctp-param init max-attempts 3 ❸
  sctp-param init timeout 10000 ❹
  ...
```

❶ The number of streams from the server to the client. This value is transmitted during SCTP INIT ACK packet.

❷ Announce to the server that a maximum of up to 300 inbound SCTP streams are supported. This value is transmitted during SCTP INIT packet.

❸ Initial SCTP handshake will be attempted 3 times before considering the connection failed.

❹ Retransmit an SCTP INIT message after 10000 ms if no answer is received.

On the server side (see Section 4.5.9), the parameters are configured in the `listen` node:

```
cs7 instance 0
 asp my-asp 2905 0 m3ua
  sctp-role server
 listen m3ua 2905
  sctp-param init num-ostreams 250 ❶
  sctp-param init max-instreams 300 ❷
  ...
```

❶ Announce to the server that up to 250 outbound SCTP streams (server to client) may be requested. This value is transmitted during SCTP INIT packet, and should be equal or lower to the `max-instreams` value received from the client during SCTP INIT packet.

❷ Announce to the server that a maximum of up to 300 inbound SCTP streams are supported. This value is transmitted during SCTP INIT ACK packet.

#### 4.5.9 SCTP role

The *SCTP role* defines which of the two L4 protocol roles SCTP assumes:

- The *SCTP server* role binds to a local port and handles incoming connections from clients
- The *SCTP client* role connects to a remote SCTP sever.

#### 4.5.10 M3UA/SUA role

The *M3UA role* (or *SUA role*) determines which role a given peer of a M3UA connection implements. 3GPP specifies the following role:

- *SGP* (Signaling Gateway): The entity connected to the larger SS7 network
- *ASP* (Application Server Process): A client application that connects to the SGW to talk to the SS7 network
- *IPSP* (IP Server Process): M3UA in point-to-point mode

Osmocom (libosmo-sigtran) implements both the SGP and ASP roles, but not the IPSP role.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 4.5.11 Traffic Modes in SIGTRAN

Whenever an AS consists of multiple ASPs, the traffic mode expresses how messages are distributed between those ASPs.

- *Override*: There is always one active ASP and multiple hot standby ASPs. If the active ASP fails, one of the remaining ASPs will become the new active ASP.
- *Loadshare*: The messages will be distributed between the different ASPs in a way to distribute the load among them. Details are implementation specific.
- *Broadcast*: A copy of every incoming signaling message is sent to *all* the ASPs in broadcast traffic mode.

Osmocom (libosmo-sigtran) implements all above-mentioned traffic modes.

# 5 Osmocom SS7 + SIGTRAN support

## 5.1 History / Background

If you're upgrading from earlier releases of the Osmocom stack, this section will give you some background about the evolution.

### 5.1.1 The Past (before 2017)

In the original implementation of the GSM BSC inside Osmocom (the OsmoBSC program, part of OpenBSC), no SS7 support was included.

This is despite the fact that ETSI/3GPP mandated the use of SCCP over MTP over E1/T1 TDM lines for the A interface at that time.

Instead of going down to the TDM based legacy physical layers, OsmoBSC implemented something called an IPA multiplex, which apparently some people also refer to as SCCPlite. We have never seen any specifications for this interface, but implemented it from scratch using protocol traces.

The IPA protocol stack is based on a minimal sub-set of SCCP (including connection oriented SCCP) wrapped into a 3-byte header to packetize a TCP stream.

The IPA/SCCPlite based A interface existed at a time when the ETSI/3GPP specifications did not offer any IP based transport for the A interface. An official as added only in Release FIXME of the 3GPP specifications.

The A interface BSSMAP protocol refers to voice circuits (E1/T1 timeslots) using circuit identity codes (CICs). As there are no physical timeslots on a TCP/IP based transport layer, the CICs get mapped to RTP streams for circuit-switched data using out-of-band signaling via MGCP, the IETF-standardized Media Gateway Control Protocol.

### 5.1.2 The present (2017)

In 2017, sysmocom was tasked with implementing a 3GPP AoIP compliant A interface. This meant that a lot of things had to change in the existing code:

- removal of the existing hard-wired SCCPlite/IPA code from OsmoBSC
- introduction of a formal SCCP User SAP at the lower boundary of BSSMAP
- introduction of libosmo-sigtran, a comprehensive SS7 and SIGTRAN library which includes a SCCP implementation for connectionless and connection-oriented procedures, offering the SCCP User SAP towards BSSAP
- introduction of an A interface in OsmoMSC (which so far offered Iu only)
- port of the existing SUA-based IuCS and IuPS over to the SCCP User SAP of libosmo-sigtran.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

- Implementation of ETSI M3UA as preferred/primary transport layer for SCCP
- Implementation of an IPA transport layer inside libosmo-sigtran, in order to keep backwards-compatibility.

This work enables the Osmocom universe to become more compliant with modern Releases of 3GPP specifications, which enables interoperability with other MSCs or even BSCs. However, this comes at a price: Increased complexity in set-up and configuration.

Using SS7 or SIGTRAN based transport of the A interface adds an entirely new domain that needs to be understood by system and network administrators setting up cellular networks based on Osmocom.

One of the key advantages of the Osmocom architecture with OsmoNITB was exactly this simplification and reduction of complexity, enabling more people to set-up and operate cellular networks.

So we have put some thought into how we can achieve compatibility with SS7/SIGTRAN and the 3GPP specifications, while at the same time enabling some degree of auto-configuration where a small network can be set up without too many configuration related to the signaling network. We have achieved this by "abusing" (or extending) the M3UA Routing Key Management slightly.

## 5.2 Osmocom extensions to SIGTRAN

Osmocom has implemented some extensions to the SIGTRAN protocol suite. Those extensions will be documented below.

### 5.2.1 Osmocom M3UA Routing Key Management Extensions

In classic M3UA, a peer identifies its remote peer based on IP address and port details. So once an ASP connects to an SG, the SG will check if there is any configuration that matches the source IP (and possibly source port) of that connection in order to understand which routing context is used - and subsequently which traffic is to be routed to this M3UA peer.

This is quite inflexible, as it means that every BSC in a GSM network needs to be manually pre-configured at the SG/STP, and that configuration on the BSC and MSC must match to enable communication.

M3UA specifies an optional Routing Key Management (RKM) sub-protocol. Using RKM, an ASP can dynamically tell the SG/STP, which traffic it wants to receive. However, the idea is still that the SG has some matching configuration.

In OsmoSTP based on libosmo-sigtran, we decided to (optionally) enable fully dynamic registration. This means that any ASP can simply connect to the SG and request the dynamic creation of an ASP and AS with a corresponding routing key for a given point code. As long as the SG doesn't already have a route to this requested point code, The SG will simply trust any ASP and set a corresponding route.

To enable dynamic creation of ASPs within an AS from any source IP/port, the corresponding xUA Server (Section 5.5) must be configured with `accept-asp-connections dynamic-permitted`.

To enable dynamic registration of routing keys via RKM, the corresponding SS7 Instance (Section 5.4) must be configured with `xua rkm routing-key-allocation dynamic-permitted`.

This is of course highly insecure and can only be used in trusted, internal networks. However, it is quite elegant in reducing the amount of configuration complexity. All that is needed, is that an unique point code is configured at each of the ASPs (application programs) that connect to the STP.

To put things more concretely: Each BSC and MSC connecting to OsmoSTP simply needs to be configured to have a different point code, and to know to which IP/port of the STP to connect. There's no other configuration required for a small, autonomous, self-contained network. OsmoSTP will automatically install ASP, AS and route definitions on demand, and route messages between all connected entities.

The same above of course also applies to HNB-GW and OsmoSGSN in the case of Iu interfaces.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

#### 5.2.2 IPA / SCCPlite backwards compatibility

The fundamental problem with IPA/SCCPlite is that there's no MTP routing label surrounding the SCCP message. This is generally problematic in the context of connection-oriented SCCP, as there is no addressing information inside the SCCP messages after the connection has been established. Instead, the messages are routed based on the MTP label, containing point codes established during connection set-up time.

This means that even if the SCCP messages did contain Called/Calling Party Addresses with point codes or global titles, it would only help us for routing connectionless SCCP. The A interface, however, is connection-oriented.

So in order to integrate IPA/SCCPlite with a new full-blown SS7/SIGTRAN stack, there are the following options:

1. implement SCCP connection coupling. This is something like a proxy for connection-oriented SCCP, and is what is used in SS7 to route beyond a given MTP network (e.g. at gateways between different MTP networks).
2. consider all SCCP messages to be destined for the local point code of the receiver. This then means that the SG functionality must be included inside the MSC, and the MSC be bound to the SSN on the local point code.
3. hard-code some DPC when receiving a message from an IPA connection. It could be any remote PC and we'd simply route the message towards that point code.

But then we also have the return direction:

1. We could "assign" a unique SPC to each connected IPA client (BSC), and then announce that PC towards the SS7 side. Return packets would then end up at our IPA-server-bearing STP, which forwards them to the respective IPA connection and thus BSC. On the transmit side, we'd simply strip the MTP routing label and send the raw SCCP message over IPA.
2. If the IPA server / SGW resides within the MSC, one could also have some kind of handle/reference to the specific TCP connection through which the BSC connected. All responses for a given peer would then have to be routed back to the same connection. This is quite ugly as it completely breaks the concepts of the SCCP User SAP, where a user has no information (nor to worry about ) any "physical" signaling links.

### 5.3 Minimal Osmocom SIGTRAN configurations for small networks

If you're not an SS7 expert, and all you want is to run your own small self-contained cellular network, this section explains what you need to do.

In general, you can consider OsmoSTP as something like an IP router. On the application layer (in our case the BSSAP/BSSMAP or RANAP protocols between Radio Access Network and Core Network), it is completely invisible/transparent. The BSC connects via SCCP to the MSC. It doesn't know that there's an STP in between, and that this STP is performing some routing function. Compares this to your web browser not knowing about IP routers, it just establishes an http connection to a web server.

This is also why most GSM network architecture diagrams will not explicitly show an STP. It is not part of the cellular network. Rather, one or many STPs are part of the underlying SS7 signaling transport network, on top of which the cellular network elements are built.

#### 5.3.1 A minimal 2G configuration to get started

You will be running the following programs:

- OsmoBSC as the base-station controller between your BTS (possibly running OsmoBTS) and the MSC
- OsmoMSC as the mobile switching center providing SMS and telephony service to your subscribers
- OsmoSTP as the signal transfer point, routing messages between one or more BSCs and the MSC

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

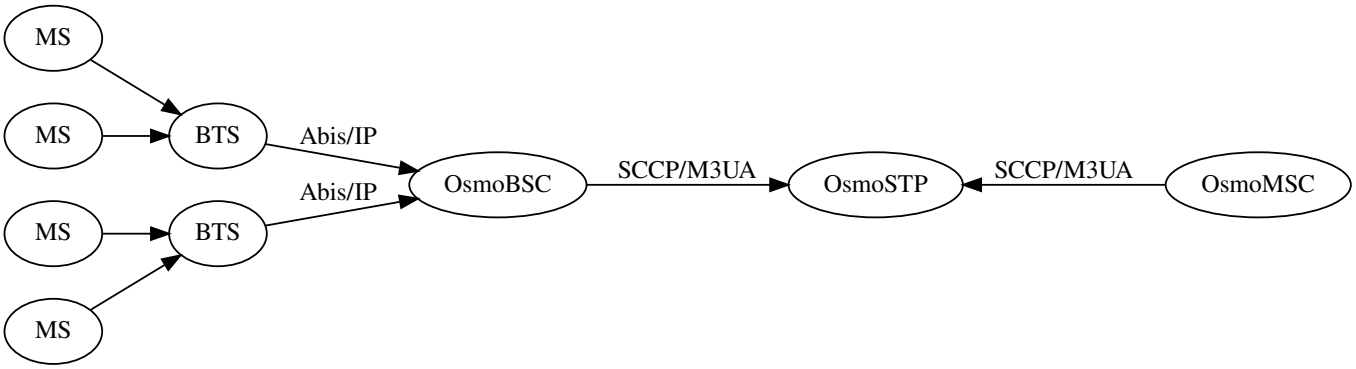



Figure 1: Simple signaling network for 2G (GSM)

You can use the OsmoSTP fully dynamic registration feature, so the BSCs and the MSC will simply register with their point codes to the STP, and the STP will create most configuration on the fly.

All you need to make sure is:

- to assign one unique point code to each BSC and MSC
- to point all BSCs and the MSC to connect to the IP+Port of the STP
- to configure the point code of the MSC in the BSCs

#### 5.3.2 A minimal 3G configuration to get started

You will be running the following programs:

- OsmoHNBGW as the homeNodeB Gateway between your femtocells / small cells and the MSC+SGSN
- OsmoMSC as the mobile switching center providing SMS and telephony service to your subscribers
- OsmoSGSN as the Serving GPRS Support Node, providing packet data (internet) services to your subscribers
- OsmoSTP as the signal transfer point, routing messages between one or more HNBGWs and the MSC and SGSN

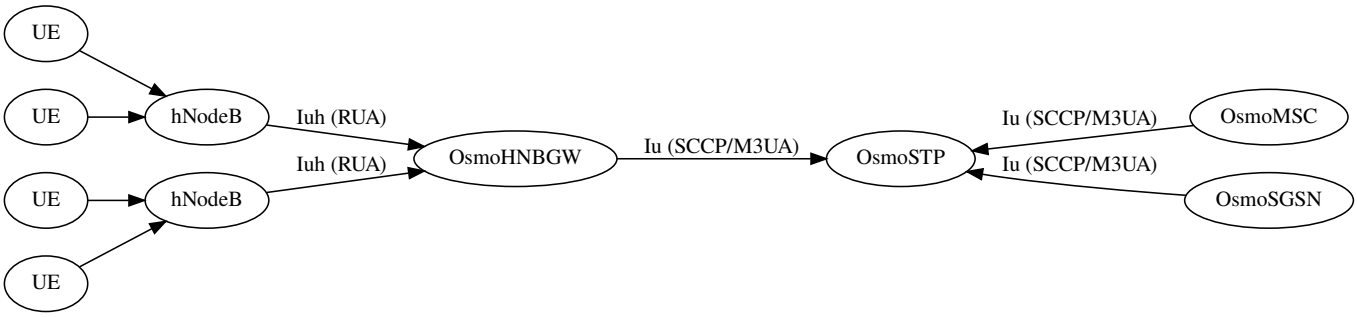



Figure 2: Simple signaling network for 3G (UMTS)

You can use the OsmoSTP fully dynamic registration feature, so the HNBGWs, the MSC and the SGSN will simply register with their point codes to the STP, and the STP will create most configuration on the fly.

All you need to make sure is:

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

- to assign one unique point code to each HNBGW, MSC and SGSN
- to point all HNBGWs and the MSC and SGSN to connect to the IP+Port of STP
- to configure the point code of the MSC in the HNBGWs
- to configure the point code of the SGSN in the HNBGWs

## 5.4 Osmocom SS7 Instances

The entire SS7 stack can be operated multiple times within one application/program by means of so-called SS7 Instances.

There can be any number of SS7 Instances, and each instance has its own set of XUA Servers, ASPs, ASs, Routes, etc.

Each SS7 Instance can have different point code formats / lengths.

Table 4: Major Attributes of an Osmocom SS7 Instance

| Name | VTY Command | Description |
|---|---|---|
| ID | (config)# cs7 instance ID | The numeric identifier of this instance |
| Name | (config-cs7)# name NAME | A human-readable name for this instance |
| Description | (config-cs7)# description DESC | More verbose description |
| Primary PC | (config-cs7)# point-code PC | Primary local point code |
| Network Indicator | (config-cs7)# network-indicator | Network Indicator used in MTP3 Routing Label |
| Point Code Format | (config-cs7)# point-code format | Point Code Format (Default: 3.8.3) |
| Point Code Delimiter | (config-cs7)# point-code delimiter | Point Code Delimiter: . or - |

## 5.5 Osmocom SS7 xUA Server

A **xUA Server** is a server that binds + listens to a given SCTP (SIGTRAN) or TCP (IPA) port and accepts connections from remote peers (ASPs).

There can be any number of xUA Servers within one SS7 Instance, as long as they all run on a different combination of IP address and port.

Table 5: Major Attributes of an Osmocom SS7 xUA Server

| Name | Description |
|---|---|
| Local IP | Local Port Number to which the server shall bind/listen |
| Local Port | Local IP Address to which the server shall bind/listen |
| Protocol | Protocol (M3UA, SUA, IPA) to be operated by this server |
| Accept Dynamic ASPs | Should we accept connections from ASPs that are not explicitly pre-configured with their source IP and port? |

## 5.6 Osmocom SS7 Users

A SS7 User is part of a program that binds to a given MTP-Layer Service Indicator (SI). The Osmocom SS7 stack offers an API to register SS7 Users, as well as the VTY command `show cs7 instance <0-15> users` to list the currently registered users.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

## 5.7 Osmocom SS7 Links

Conceptually, SS7 links are on the same level as SIGTRAN ASPs. The details of SS7 Links in the Osmocom implementation are TBD.

## 5.8 Osmocom SS7 Linksets

Conceptually, SS7 Linksets are on the same level as SIGTRAN ASs. The details of SS7 Links in the Osmocom implementation are TBD.

## 5.9 Osmocom SS7 Application Servers

This corresponds 1:1 to the SIGTRAN concept of an Application Server, i.e. a given external Application that interfaces the SS7 network via a SS7 protocol variant such as M3UA.

In the context of Osmocom, for each program connecting to a STP (like a BSC or MSC), you will have one Application Server definition.

An AS has the following properties:

Table 6: Major Attributes of an Osmocom SS7 Application Server

| Name | Description |
|---|---|
| Name | A human-readable name for this instance |
| Description | More verbose description (for human user only) |
| Protocol | Protocol (M3UA, SUA, IPA) to be operated by this server |
| Routing Key | Routing Key (mostly Point Code) routed to this AS |
| Traffic Mode | Broadcast, Loadshare or Override |
| Recovery Timeout | Duration of the AS T(r) recovery timer. During this time, outgoing messages are queued. If the AS is ACTIVE before timer expiration, the queue is drained. At expiration, the queue is flushed. |
| State | Application Server State (Down, Inactive, Active, Pending) |
| ASPs | Which ASPs are permitted to transfer traffic for this AS |

## 5.10 Osmocom SS7 Application Server Processes

An Application Server Process corresponds to a given SCTP (or TCP) connection. From the STP/SG (Server) point-of-view, those are incoming connections from Application Servers such as the BSCs. From the ASP (Client) Point of view, it has one `osmo_ss7_asp` object for each outbound SIGTRAN connection.

An ASP has the following properties:

Table 7: Major Attributes of an Osmocom SS7 Application Server Process

| Name | Description |
|---|---|
| Name | A human-readable name for this instance |
| Description | More verbose description (for human user only) |
| Protocol | Protocol (M3UA, SUA, IPA) to be operated by this server |
| Role | Server (SG) or Client (ASP)? |
| Local Port | Port Number of the local end of the connection |
| Local IP | IP Address of the local end of the connection |

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

Table 7: (continued)

| Name | Description |
|---|---|
| Remote Port | Port Number of the remote end of the connection |
| Remote IP | IP Address of the remote end of the connection |
| State | ASP State (Down, Inactive, Active) |

## 5.11 Osmocom SS7 Routes

An Osmocom SS7 Route holds information to route traffic with a matching destination point code and point code mask (similar to IP Address + Netmask) towards a specified SS7 Linkset or Application Server. The Linkset or Application Servers are identified by their name.

Routes are inserted in a routing table, where they are ordered first based on prefix mask length (longest prefix first) and then on priority (lowest value first). As a result, more specific routes (eg. a single Point Code) will match and be used before more generic ones (eg. a subnet).

Table 8: Major Attributes of an Osmocom SS7 Application Server Process

| Name | Description |
|---|---|
| Point Code | Destination Point Code for this route |
| Mask | Destination Mask for this route (like an IP netmask) |
| Linkset/AS Name | Destination Linkset or AS, identified by name |
| Priority | Priority of the route in the routing table; lower value means higher priority |

The `show cs7 instance <0-15> route` command can be used on the VTY to obtain the list of routes inserted in the system routing table.

The `show cs7 instance <0-15> route-lookup <DPC> from <OPC> sls <SLS>` command can be used on the VTY to test and debug routing of specific traffic on the currently running routing table, similar to what `ip route get` linux command does in the IP world.

## 5.12 Osmocom SCCP Instances

An Osmocom SCCP Instance can be bound to an Osmocom SS7 Instance. It will register/bind for the ITU-standard Service Indicator (SI).

## 5.13 Osmocom SCCP User

An Program (like a BSC) will *bind* itself to a given well-known sub-system number (SSN) in order to receive SCCP messages destined for this SSN.

There is an API to bind a program to a SSN, which implicitly generates an SCCP User object.

The `show cs7 instance <0-15> sccp users` command can be used on the VTY to obtain a list of currently bound SCCP users, as well as their corresponding SSNs.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

### 5.14 Osmocom SCCP Connection

This is how Osmocom represents each individual connection of connection-oriented SCCP.

To illustrate the practical application: For the common use case of the A or Iu interfaces, this means that every dedicated radio channel that is currently active to any UE/MS has one SCCP connection to the MSC and/or SGSN.

The `show cs7 instance <0-15> sccp connections` command can be used on the VTY to obtain a list of currently active SCCP connections, as well as their source/destination and current state.

### 5.15 Osmocom SCCP User SAP

The Osmocom SCCP User SAP (Service Access Point) is the programming interface between the SCCP Provider (libosmo-sigtran) and the SCCP User (such as osmo-bsc, osmo-msc, osmo-hnbgw, etc.). It follows primitives as laid out in [itu-t-q711], encapsulated in `osmo_prim` structures.

### 5.16 Osmocom MTP User SAP

The Osmocom MTP User SAP (Service Access Point) is the programming interface between the MTP Provider and the MTP User (e.g. SCCP). It follows primitives as laid out in [itu-t-q711], encapsulated in `osmo_prim` structures.

## 6 The Osmocom VTY Interface

All human interaction with Osmocom software is typically performed via an interactive command-line interface called the *VTY*.

---

**Note**

Integration of your programs and scripts should **not** be done via the telnet VTY interface, which is intended for human interaction only: the VTY responses may arbitrarily change in ways obvious to humans, while your scripts' parsing will likely break often. For external software to interact with Osmocom programs (besides using the dedicated protocols), it is strongly recommended to use the Control interface instead of the VTY, and to actively request / implement the Control interface commands as required for your use case.

---

The interactive telnet VTY is used to

- explore the current status of the system, including its configuration parameters, but also to view run-time state and statistics,
- review the currently active (running) configuration,
- perform interactive changes to the configuration (for those items that do not require a program restart),
- store the current running configuration to the config file,
- enable or disable logging; to the VTY itself or to other targets.

The Virtual Tele Type (VTY) has the concept of *nodes* and *commands*. Each command has a name and arguments. The name may contain a space to group several similar commands into a specific group. The arguments can be a single word, a string, numbers, ranges or a list of options. The available commands depend on the current node. there are various keyboard shortcuts to ease finding commands and the possible argument values.

Configuration file parsing during program start is actually performed the VTY's CONFIG node, which is also available in the telnet VTY. Apart from that, the telnet VTY features various interactive commands to query and instruct a running Osmocom program. A main difference is that during config file parsing, consistent indenting of parent vs. child nodes is required, while the interactive VTY ignores indenting and relies on the *exit* command to return to a parent node.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**Note**
In the *CONFIG* node, it is not well documented which commands take immediate effect without requiring a program restart. To save your current config with changes you may have made, you may use the `write file` command to **overwrite** your config file with the current configuration, after which you should be able to restart the program with all changes taking effect.

This chapter explains most of the common nodes and commands. A more detailed list is available in various programs' VTY reference manuals, e.g. see [vty-ref-osmomsc].

There are common patterns for the parameters, these include IPv4 addresses, number ranges, a word, a line of text and choice. The following will explain the commonly used syntactical patterns:

Table 9: VTY Parameter Patterns

| Pattern | Example | Explanation |
|---|---|---|
| `A.B.C.D` | `127.0.0.1` | An IPv4 address |
| `A.B.C.D/M` | `192.168.1.0/24` | An IPv4 address and mask |
| `X:X::X:X` | `::1` | An IPv6 address |
| `X:X::X:X/M` | `::1/128` | An IPv6 address and mask |
| `TEXT` | `example01` | A single string without any spaces, tabs |
| `.TEXT` | `Some information` | A line of text |
| `(OptionA\|OptionB\|OptionC)` | `OptionA` | A choice between a list of available options |
| `<0-10>` | `5` | A number from a range |

## 6.1 Accessing the telnet VTY

The VTY of a given Osmocom program is implemented as a telnet server, listening to a specific TCP port.

Please see Appendix A to check for the default TCP port number of the VTY interface of the specific Osmocom software you would like to connect to.

As telnet is insecure and offers neither strong authentication nor encryption, the VTY by default only binds to localhost (127.0.0.1) and will thus not be reachable by other hosts on the network.



**Warning**
By default, any user with access to the machine running the Osmocom software will be able to connect to the VTY. We assume that such systems are single-user systems, and anyone with local access to the system also is authorized to access the VTY. If you require stronger security, you may consider using the packet filter of your operating system to restrict access to the Osmocom VTY ports further.

## 6.2 VTY Nodes

The VTY by default has the following minimal nodes:

**VIEW**
When connecting to a telnet VTY, you will be on the *VIEW* node. As its name implies, it can only be used to view the system status, but it does not provide commands to alter the system state or configuration. As long as you are in the non-privileged *VIEW* node, your prompt will end in a > character.

**ENABLE**
The *ENABLE* node is entered by the `enable` command, from the *VIEW* node. Changing into the *ENABLE* node will unlock all kinds of commands that allow you to alter the system state or perform any other change to it. The *ENABLE* node and its children are signified by a # character at the end of your prompt.
You can change back from the *ENABLE* node to the *VIEW* node by using the `disable` command.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**CONFIG**

The *CONFIG* node is entered by the `configure terminal` command from the *ENABLE* node. The config node is used to change the run-time configuration parameters of the system. The prompt will indicate that you are in the config node by a `(config)#` prompt suffix.
You can always leave the *CONFIG* node or any of its children by using the `end` command.
This node is also automatically entered at the time the configuration file is read. All configuration file lines are processed as if they were entered from the VTY *CONFIG* node at start-up.

**Other**

Depending on the specific Osmocom program you are running, there will be few or more other nodes, typically below the *CONFIG* node. For example, the OsmoBSC has nodes for each BTS, and within the BTS node one for each TRX, and within the TRX node one for each Timeslot.

## 6.3 Interactive help

The VTY features an interactive help system, designed to help you to efficiently navigate is commands.

**Note**
The VTY is present on most Osmocom GSM/UMTS/GPRS software, thus this chapter is present in all the relevant manuals. The detailed examples below assume you are executing them on the OsmoMSC VTY. They will work in similar fashion on the other VTY interfaces, while the node structure will differ in each program.

### 6.3.1 The question-mark (?) command

If you type a single `?` at the prompt, the VTY will display possible completions at the exact location of your currently entered command.

If you type `?` at an otherwise empty command (without having entered even only a partial command), you will get a list of the first word of all possible commands available at this node:

**Example: Typing ? at start of OsmoMSC prompt**

```
OsmoMSC> ❶
  show         Show running system information
  list         Print command list
  exit         Exit current mode and down to previous mode
  help         Description of the interactive help system
  enable       Turn on privileged mode command
  terminal     Set terminal line parameters
  who          Display who is on vty
  logging      Configure logging
  no           Negate a command or set its defaults
  sms          SMS related commands
  subscriber   Operations on a Subscriber
```

❶ Type `?` here at the prompt, the `?` itself will not be printed.

If you have already entered a partial command, `?` will help you to review possible options of how to continue the command. Let's say you remember that `show` is used to investigate the system status, but you don't remember the exact name of the object. Hitting `?` after typing `show` will help out:

**Example: Typing ? after a partial command**

```
OsmoMSC> show ❶
  version          Displays program version
  online-help      Online help
  history          Display the session command history
```

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

```
  cs7              ITU-T Signaling System 7
  logging          Show current logging configuration
  alarms           Show current logging configuration
  talloc-context   Show talloc memory hierarchy
  stats            Show statistical values
  asciidoc         Asciidoc generation
  rate-counters    Show all rate counters
  fsm              Show information about finite state machines
  fsm-instances    Show information about finite state machine instances
  sgs-connections  Show SGs interface connections / MMEs
  subscriber       Operations on a Subscriber
  bsc              BSC
  connection       Subscriber Connections
  transaction      Transactions
  statistics       Display network statistics
  sms-queue        Display SMSqueue statistics
  smpp          SMPP Interface
```

❶ Type `?` after the `show` command, the `?` itself will not be printed.

You may pick the `bsc` object and type `?` again:

**Example: Typing ? after show bsc**

```
OsmoMSC> show bsc
  <cr>
```

By presenting `<cr>` as the only option, the VTY tells you that your command is complete without any remaining arguments being available, and that you should hit enter, a.k.a. "carriage return".

### 6.3.2 TAB completion

The VTY supports tab (tabulator) completion. Simply type any partial command and press `<tab>`, and it will either show you a list of possible expansions, or completes the command if there's only one choice.

**Example: Use of <tab> pressed after typing only s as command**

```
OsmoMSC> s❶
show       sms        subscriber
```

❶ Type `<tab>` here.

At this point, you may choose `show`, and then press `<tab>` again:

**Example: Use of <tab> pressed after typing show command**

```
OsmoMSC> show ❶
version    online-help history    cs7        logging    alarms
talloc-context stats      asciidoc   rate-counters fsm        fsm-instances
sgs-connections subscriber bsc        connection transaction statistics
sms-queue smpp
```

❶ Type `<tab>` here.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

### 6.3.3 The `list` command

The `list` command will give you a full list of all commands and their arguments available at the current node:

**Example: Typing list at start of OsmoMSC VIEW node prompt**

```
OsmoMSC> list
  show version
  show online-help
  list
  exit
  help
  enable
  terminal length <0-512>
  terminal no length
  who
  show history
  show cs7 instance <0-15> users
  show cs7 (sua|m3ua|ipa) [<0-65534>]
  show cs7 instance <0-15> asp
  show cs7 instance <0-15> as (active|all|m3ua|sua)
  show cs7 instance <0-15> sccp addressbook
  show cs7 instance <0-15> sccp users
  show cs7 instance <0-15> sccp ssn <0-65535>
  show cs7 instance <0-15> sccp connections
  show cs7 instance <0-15> sccp timers
  logging enable
  logging disable
  logging filter all (0|1)
  logging color (0|1)
  logging timestamp (0|1)
  logging print extended-timestamp (0|1)
  logging print category (0|1)
  logging print category-hex (0|1)
  logging print level (0|1)
  logging print file (0|1|basename) [last]
  logging set-log-mask MASK
  logging level (rll|cc|mm|rr|mncc|pag|msc|mgcp|ho|db|ref|ctrl|smpp|ranap|vlr|iucs|bssap| ↩
      sgs|lglobal|llapd|linp|lmux|lmi|lmib|lsms|lctrl|lgtp|lstats|lgsup|loap|lss7|lsccp|lsua ↩
      |lm3ua|lmgcp|ljibuf|lrspro) (debug|info|notice|error|fatal)
  logging level set-all (debug|info|notice|error|fatal)
  logging level force-all (debug|info|notice|error|fatal)
  no logging level force-all
  show logging vty
  show alarms
  show talloc-context (application|all) (full|brief|DEPTH)
  show talloc-context (application|all) (full|brief|DEPTH) tree ADDRESS
  show talloc-context (application|all) (full|brief|DEPTH) filter REGEXP
  show stats
  show stats level (global|peer|subscriber)
  show asciidoc counters
  show rate-counters
  show fsm NAME
  show fsm all
  show fsm-instances NAME
  show fsm-instances all
  show sgs-connections
  show subscriber (msisdn|extension|imsi|tmsi|id) ID
  show subscriber cache
  show bsc
  show connection
  show transaction
  sms send pending
```

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

```
  sms delete expired
  subscriber create imsi ID
  subscriber (msisdn|extension|imsi|tmsi|id) ID sms sender (msisdn|extension|imsi|tmsi|id)  ↩
      SENDER_ID send .LINE
  subscriber (msisdn|extension|imsi|tmsi|id) ID silent-sms sender (msisdn|extension|imsi| ↩
      tmsi|id) SENDER_ID send .LINE
  subscriber (msisdn|extension|imsi|tmsi|id) ID silent-call start (any|tch/f|tch/any|sdcch)
  subscriber (msisdn|extension|imsi|tmsi|id) ID silent-call stop
  subscriber (msisdn|extension|imsi|tmsi|id) ID ussd-notify (0|1|2) .TEXT
  subscriber (msisdn|extension|imsi|tmsi|id) ID ms-test close-loop (a|b|c|d|e|f|i)
  subscriber (msisdn|extension|imsi|tmsi|id) ID ms-test open-loop
  subscriber (msisdn|extension|imsi|tmsi|id) ID paging
  show statistics
  show sms-queue
  logging filter imsi IMSI
  show smpp esme
```

**Tip**

Remember, the list of available commands will change significantly depending on the Osmocom program you are accessing, its software version and the current node you're at. Compare the above example of the OsmoMSC *VIEW* node with the list of the OsmoMSC *NETWORK* config node:

**Example: Typing list at start of OsmoMSC NETWORK config node prompt**

```
OsmoMSC(config-net)# list
  help
  list
  write terminal
  write file
  write memory
  write
  show running-config
  exit
  end
  network country code <1-999>
  mobile network code <0-999>
  short name NAME
  long name NAME
  encryption a5 <0-3> [<0-3>] [<0-3>] [<0-3>]
  authentication (optional|required)
  rrlp mode (none|ms-based|ms-preferred|ass-preferred)
  mm info (0|1)
  timezone <-19-19> (0|15|30|45)
  timezone <-19-19> (0|15|30|45) <0-2>
  no timezone
  periodic location update <6-1530>
  no periodic location update
```

#### 6.3.4 The attribute system

The VTY allows to edit the configuration at runtime. For many VTY commands the configuration change is immediately valid but for some commands a change becomes valid on a certain event only. In some cases it is even necessary to restart the whole process.

To give the user an overview, which configuration change applies when, the VTY implemets a system of attribute flags, which can be displayed using the `show` command with the parameter `vty-attributes`

**Example: Typing show vty-attributes at the VTY prompt**

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

```
OsmoBSC> show vty-attributes
  Global attributes:
    ^  This command is hidden (check expert mode)
    !  This command applies immediately
    @  This command applies on VTY node exit
  Library specific attributes:
    A  This command applies on ASP restart
    I  This command applies on IPA link establishment
    L  This command applies on E1 line update
  Application specific attributes:
    o  This command applies on A-bis OML link (re)establishment
    r  This command applies on A-bis RSL link (re)establishment
    l  This command applies for newly created lchans
```

The attributes are symbolized through a single ASCII letter (flag) and do exist in three levels. This is more or less due to the technical aspects of the VTY implementation. For the user, the level of an attribute has only informative purpose.

The global attributes, which can be found under the same attribute letter in every osmocom application, exist on the top level. The Library specific attributes below are used in various osmocom libraries. Like with the global attributes the attribute flag letter stays the same throughout every osmocom application here as well. On the third level one can find the application specific attributes. Those are unique to each osmocom application and the attribute letters may have different meanings in different osmocom applications. To make the user more aware of this, lowercase letters were used as attribute flags.

The `list` command with the parameter `with-flags` displays a list of available commands on the current VTY node, along with attribute columns on the left side. Those columns contain the attribute flag letters to indicate to the user how the command behaves in terms of how and when the configuration change takes effect.

**Example: Typing list with-flags at the VTY prompt**

```
OsmoBSC(config-net-bts)# list with-flags
  . ...  help
  . ...  list [with-flags]
  . ...  show vty-attributes
  . ...  show vty-attributes (application|library|global)
  . ...  write terminal
  . ...  write file [PATH]
  . ...  write memory
  . ...  write
  . ...  show running-config ❶
  . ...  exit
  . ...  end
  . o..  type (unknown|bs11|nanobts|rbs2000|nokia_site|sysmobts) ❷
  . ...  description .TEXT
  . ...  no description
  . o..  band BAND
  . .r.  cell_identity <0-65535> ❸
  . .r.  dtx uplink [force]
  . .r.  dtx downlink
  . .r.  no dtx uplink
  . .r.  no dtx downlink
  . .r.  location_area_code <0-65535>
  . o..  base_station_id_code <0-63>
  . o..  ipa unit-id <0-65534> <0-255>
  . o..  ipa rsl-ip A.B.C.D
  . o..  nokia_site skip-reset (0|1)
  ! ...  nokia_site no-local-rel-conf (0|1) ❹
  ! ...  nokia_site bts-reset-timer  <15-100> ❺
```

❶ This command has no attributes assigned.

❷ This command applies on A-bis OML link (re)establishment.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

❸ This command applies on A-bis RSL link (re)establishment.

❹, ❺ This command applies immediately.

There are multiple columns because a single command may be associated with multiple attributes at the same time. To improve readability each flag letter gets a dedicated column. Empty spaces in the column are marked with a dot (".")

In some cases the listing will contain commands that are associated with no flags at all. Those commands either play an exceptional role (interactive commands outside "configure terminal", vty node navigation commands, commands to show / write the config file) or will require a full restart of the overall process to take effect.

### 6.3.5 The expert mode

Some VTY commands are considered relatively dangerous if used in production operation, so the general approach is to hide them. This means that they don't show up anywhere but the source code, but can still be executed. On the one hand, this approach reduces the risk of an accidental invocation and potential service degradation; on the other, it complicates intentional use of the hidden commands.

The VTY features so-called *expert* mode, that makes the hidden commands appear in the interactive help, as well as in the XML VTY reference, just like normal ones. This mode can be activated from the *VIEW* node by invoking the `enable` command with the parameter `expert-mode`. It remains active for the individual VTY session, and gets disabled automatically when the user switches back to the *VIEW* node or terminates the session.

A special attribute in the output of the `list with-flags` command indicates whether a given command is hidden in normal mode, or is a regular command:

**Example: Hidden commands in the output of the list with-flags command**

```
OsmoBSC> enable expert-mode ❶
OsmoBSC# list with-flags
  ...
  ^   bts <0-255> (activate-all-lchan|deactivate-all-lchan) ❷
  ^   bts <0-255> trx <0-255> (activate-all-lchan|deactivate-all-lchan) ❸
  .   bts <0-255> trx <0-255> timeslot <0-7> sub-slot <0-7> mdcx A.B.C.D <0-65535> ❹
  ^   bts <0-255> trx <0-255> timeslot <0-7> sub-slot <0-7> (borken|unused) ❺
  .   bts <0-255> trx <0-255> timeslot <0-7> sub-slot <0-7> handover <0-255> ❻
  .   bts <0-255> trx <0-255> timeslot <0-7> sub-slot <0-7> assignment ❼
  .   bts <0-255> smscb-command (normal|schedule|default) <1-4> HEXSTRING ❽
  ...
```

❶ This command enables the *expert* mode.

❷, ❸, ❺ This is a hidden command (only shown in the *expert* mode).

❹, ❻, ❼, ❽ This is a regular command that is always shown regardless of the mode.

# 7 libosmocore Logging System

In any reasonably complex software it is important to understand how to enable and configure logging in order to get a better insight into what is happening, and to be able to follow the course of action. We therefore ask the reader to bear with us while we explain how the logging subsystem works and how it is configured.

Most Osmocom Software (like `osmo-bts`, `osmo-bsc`, `osmo-nitb`, `osmo-sgsn` and many others) uses the same common logging system.

This chapter describes the architecture and configuration of this common logging system.

The logging system is composed of

- log targets (where to log),

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

- log categories (who is creating the log line),
- log levels (controlling the verbosity of logging), and
- log filters (filtering or suppressing certain messages).

All logging is done in human-readable ASCII-text. The logging system is configured by means of VTY commands that can either be entered interactively, or read from a configuration file at process start time.

## 7.1 Log categories

Each sub-system of the program in question typically logs its messages as a different category, allowing fine-grained control over which log messages you will or will not see. For example, in OsmoBSC, there are categories for the protocol layers `rsl`, `rr`, `mm`, `cc` and many others. To get a list of categories interactively on the vty, type: `logging level ?`

## 7.2 Log levels

For each of the log categories (see Section 7.1), you can set an independent log level, controlling the level of verbosity. Log levels include:

**fatal**
Fatal messages, causing abort and/or re-start of a process. This *shouldn't happen*.

**error**
An actual error has occurred, its cause should be further investigated by the administrator.

**notice**
A noticeable event has occurred, which is not considered to be an error.

**info**
Some information about normal/regular system activity is provided.

**debug**
Verbose information about internal processing of the system, used for debugging purpose. This will log the most.

The log levels are inclusive, e.g. if you select *info*, then this really means that all events with a level of at least *info* will be logged, i.e. including events of *notice*, *error* and *fatal*.

So for example, in OsmoBSC, to set the log level of the Mobility Management category to info, you can use the following command: `log level mm info`.

There is also a special command to set all categories as a one-off to a desired log level. For example, to silence all messages but those logged as notice and above issue the command: `log level set-all notice`

Afterwards you can adjust specific categories as usual.

A similar command is `log level force-all <level>` which causes all categories to behave as if set to log level <level> until the command is reverted with `no log level force-all` after which the individually-configured log levels will again take effect. The difference between `set-all` and `force-all` is that `set-all` actually changes the individual category settings while `force-all` is a (temporary) override of those settings and does not change them.

## 7.3 Log printing options

The logging system has various options to change the information displayed in the log message.

**log color 1**
With this option each log message will log with the color of its category. The color is hard-coded and can not be changed. As with other options a *0* disables this functionality.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**log timestamp 1**
Includes the current time in the log message. When logging to syslog this option should not be needed, but may come in handy when debugging an issue while logging to file.

**log print extended-timestamp 1**
In order to debug time-critical issues this option will print a timestamp with millisecond granularity.

**log print category 1**
Prefix each log message with the category name.

**log print category-hex 1**
Prefix each log message with the category number in hex (<*000b*>).

**log print level 1**
Prefix each log message with the name of the log level.

**log print file 1**
Prefix each log message with the source file and line number. Append the keyword `last` to append the file information instead of prefixing it.

## 7.4 Log filters

The default behavior is to filter out everything, i.e. not to log anything. The reason is quite simple: On a busy production setup, logging all events for a given subsystem may very quickly be flooding your console before you have a chance to set a more restrictive filter.

To request no filtering, i.e. see all messages, you may use: `log filter all 1`

In addition to generic filtering, applications can implement special log filters using the same framework to filter on particular context.

For example in OsmoBSC, to only see messages relating to a particular subscriber identified by his IMSI, you may use: `log filter imsi 262020123456789`

## 7.5 Log targets

Each of the log targets represent certain destination for log messages. It can be configured independently by selecting levels (see Section 7.2) for categories (see Section 7.1) as well as filtering (see Section 7.4) and other options like `logging timestamp` for example.

### 7.5.1 Logging to the VTY

Logging messages to the interactive command-line interface (VTY) is most useful for occasional investigation by the system administrator.

Logging to the VTY is disabled by default, and needs to be enabled explicitly for each such session. This means that multiple concurrent VTY sessions each have their own logging configuration. Once you close a VTY session, the log target will be destroyed and your log settings be lost. If you re-connect to the VTY, you have to again activate and configure logging, if you wish.

To create a logging target bound to a VTY, you have to use the following command: `logging enable` This doesn't really activate the generation of any output messages yet, it merely creates and attaches a log target to the VTY session. The newly-created target still doesn't have any filter installed, i.e. *all log messages will be suppressed by default*

Next, you can configure the log levels for desired categories in your VTY session. See Section 7.1 for more details on categories and Section 7.2 for the log level details.

For example, to set the log level of the Call Control category to debug, you can use: `log level cc debug`

Finally, after having configured the levels, you still need to set the filter as it's described in Section 7.4.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**Tip**
If many messages are being logged to a VTY session, it may be hard to impossible to still use the same session for any commands. We therefore recommend to open a second VTY session in parallel, and use one only for logging, while the other is used for interacting with the system. Another option would be to use different log target.

To review the current vty logging configuration, you can use: `show logging vty`

### 7.5.2 Logging to the ring buffer

To avoid having separate VTY session just for logging output while still having immediate access to them, one can use `alarms` target. It lets you store the log messages inside the ring buffer of a given size which is available with `show alarms` command.

It's configured as follows:

```
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log alarms 98
OsmoBSC(config-log)#
```

In the example above 98 is the desired size of the ring buffer (number of messages). Once it's filled, the incoming log messages will push out the oldest messages available in the buffer.

### 7.5.3 Logging via gsmtap

GSMTAP is normally a pseudo-header format that enables the IP-transport of GSM (or other telecom) protocols that are not normally transported over IP. For example, the most common situation is to enable GSMTAP in OsmoBTS or OsmoPCU to provide GSM-Um air interface capture files over IP, so they can be analyzed in wireshark.

GSMTAP logging is now a method how Osmocom software can also encapsulate its own log output in GSMTAP frames. We're not trying to re-invent rsyslog here, but this is very handy When debugging complex issues. It enables the reader of the pcap file containing GSMTAP logging together with other protocol traces to reconstruct exact chain of events. A single pcap file can then contain both the log output of any number of Osmocom programs in the same timeline of the messages on various interfaces in and out of said Osmocom programs.

It's configured as follows:

```
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log gsmtap 192.168.2.3 ❶
OsmoBSC(config-log)#
```

❶ Configure a GSMTAP logging target recording to 192.168.2.3

The hostname/ip argument is optional: if omitted the default 127.0.0.1 will be used. The log strings inside GSMTAP are already supported by Wireshark. Capturing for `port 4729` on appropriate interface will reveal log messages including source file name and line number as well as application. This makes it easy to consolidate logs from several different network components alongside the air frames. You can also use Wireshark to quickly filter logs for a given subsystem, severity, file name etc.

The GSMTAP logging target also has different implementation I/O modes, which can be configured during the VTY "log gmstap" VTY command:

**nonblocking-io**
Use non-blocking, synchronous I/O. This is the default mode. It will set the GSMTAP source socket as non-blocking, and attempt synchronous write to the UDP socket, discarding a message if the UDP socket's send buffer is full during write.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**blocking-io**
: Use blocking, synchronous I/O. It will use the GSMTAP source socket in blocking mode, and attempt synchronous write to the UDP socket, blocking the entire thread if the UDP socket's send buffer is full during write. This I/O mode should not be used in any osmocom program driven by an event loop (which includes any program using a VTY), since it may block the thread for an unspecified (potentially long or even infinite) amount of time and hence prevent the event loop to run and process events. This I/O mode should only be used under specific circumstances, like debugging a crash, in which case it's interesting to get the logging output to the UDP socket and hence recorded before the program crashes.

**wq**
: Workqueue mode: Use non-blocking, asynchronous I/O. It will set the GSMTAP source socket as non-blocking, and attempt asynchronous write to the UDP socket by means of a work queue driven by the process poll event loop, delaying writing to the UDP socket until there's enough free space in its send buffer. Since the workqueue has a maximum size, messages will be discarded similar to *nonblocking-io* once the UDP socket's send buffer **and** the GSMTAP log target workqueue are full. This I/O mode provides some extra buffering space in the userspace workqueue, at the expense of extra overhead and delay to transmit messages asynchronously waiting for POLLOUT event from the UDP socket.

In any of the I/O modes above, the UDP socket send buffer size of the GSMTAP log target influences where messages may be dropped (*nonblocking-io*\|*wq*) or the process blocked (*blocking-io*) whenever a high number of messages or test are transmitted in a short time. For that reason, the GSMTAP log target will attempt to set the `SO_SNDBUF` sockopt of the UDP socket to 4MB. In Linux, the `SO_SNDBUF` value being set on the socket will be trimmed by the kernel to a maximum allowed by sysctl `net.core.wmem_max`. Hence, if you want to be on a safer side minimizing dropping messages or blocking the process (depending on the I/O mode set), make sure sysctl `net.core.wmem_max` on your system is set to `4194304` (4MB) or more.

---

**Note**

Linux Kernel used to have a `net.core.wmem_max` of `212992`(208KB) until recently (2025, a6d4f25888b83b8300aef28d9ee22765c1cc9b34), where it was increased to `4194304` (4MB) .

---

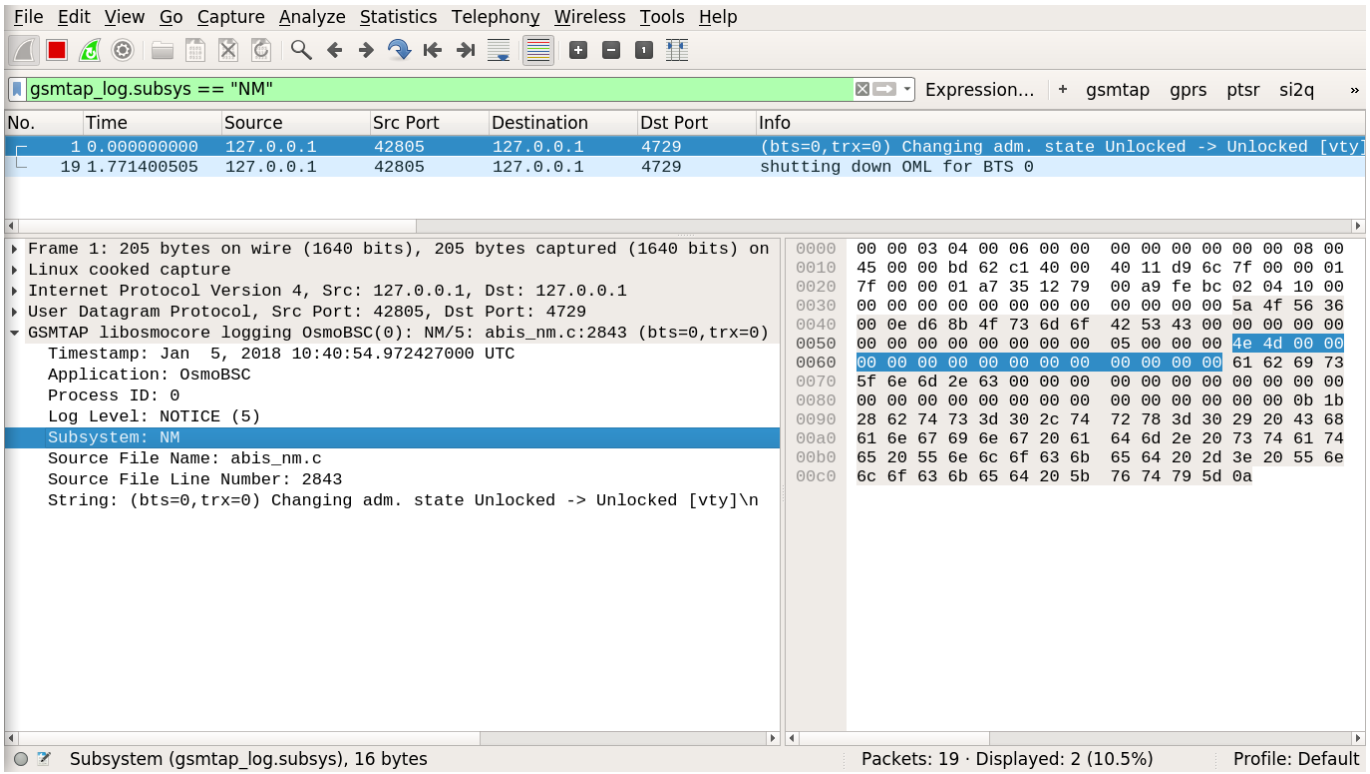



Figure 3: Wireshark with logs delivered over GSMTAP

**Note**
Every time you generate GSMTAP messages and send it to a unicast (non-broadcast/multicast) IP address, please make sure that the destination IP address actually has a socket open on the specified port, or drops the packets in its packet filter. If unicast GSMTAP messages arrive at a closed destination UDP port, the operating system will likely generate ICMP port unreachable messages. Those ICMP messages in turn will, when arriving at the source (the host on which you run the Osmocom software sending GSMTAP), suppress generation of further GSMTAP messages for some time, resulting in incomplete files. In case of doubt, either send GSMTAP to multicast IP addresses, or run something like `nc -l -u -p 4729 > /dev/null` on the destination host to at the GSMTAP port and discard anything arriving at it. If the GSMTAP recording address is identified as a local address, upon creation of the GSMTAP log target, an attempt will be made to create a dummy sink socket to avoid such problems automatically.

### 7.5.4 Logging to a file

As opposed to Logging to the VTY, logging to files is persistent and stored in the configuration file. As such, it is configured in sub-nodes below the configuration node. There can be any number of log files active, each of them having different settings regarding levels / subsystems.

To configure a new log file, enter the following sequence of commands:

```
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log file /path/to/my/file ❶
OsmoBSC(config-log)#
```

❶ Configure a file logging target writing to /path/to/my/file

This leaves you at the config-log prompt, from where you can set the detailed configuration for this log file. The available commands at this point are identical to configuring logging on the VTY, they include `logging filter`, `logging level` as well as `logging color` and `logging timestamp`.

The file logging target will by default use a synchronous non-blocking I/O write. If writing cannot be performed synchronously (would block), the message is stored in a workqueue where asynchronous write (driven by poll event loop) will be performed at a later stage. The file logging target can be configured during the VTY `log file` VTY command to perform blocking I/O with the `blocking-io` parameter. This I/O mode should not be used in any osmocom program driven by an event loop (which includes any program using a VTY), since it may block the thread for an unspecified (potentially long or even infinite) amount of time and hence prevent the event loop to run and process events. This I/O mode should only be used under specific circumstances, like debugging a crash, in which case it's interesting to get the logging output to the UDP socket and hence recorded before the program crashes.

**Tip**
Don't forget to use the `copy running-config startup-config` (or its short-hand `write file`) command to make your logging configuration persistent across application re-start.

**Note**
libosmocore provides file close-and-reopen support by SIGHUP, as used by popular log file rotating solutions such as https://github.com/logrotate/logrotate found in most GNU/Linux distributions.

### 7.5.5 Logging to syslog

syslog is a standard for computer data logging maintained by the IETF. Unix-like operating systems like GNU/Linux provide several syslog compatible log daemons that receive log messages generated by application programs.

libosmocore based applications can log messages to syslog by using the syslog log target. You can configure syslog logging by issuing the following commands on the VTY:

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

```
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log syslog daemon
OsmoBSC(config-log)#
```

This leaves you at the config-log prompt, from where you can set the detailed configuration for this log file. The available commands at this point are identical to configuring logging on the VTY, they include `logging filter`, `logging level` as well as `logging color` and `logging timestamp`.

**Tip**
Syslog daemons will normally automatically prefix every message with a time-stamp, so you should disable the libosmocore time-stamping by issuing the `logging timestamp 0` command.

**Note**
Typical syslog implementations (such as glibc's one) write to *AF_UNIX* socket in `/dev/log` in a synchronous blocking I/O fashion, which means transmitting a big amount of messages or text over it in a short amount of time (before syslogd has time to read it) could potentially block the osmocom program's thread issuing the logging. It is hence advised avoiding use of this log target to log notable amounts of information in any osmocom program driven by an event loop (which includes any program using a VTY), since it may block the thread for an unspecified (potentially long or even infinite) amount of time and hence prevent the event loop to run and process events.

### 7.5.6 Logging to systemd-journal

systemd has been adopted by the majority of modern GNU/Linux distributions. Along with various daemons and utilities it provides systemd-journald [1] - a daemon responsible for event logging (syslog replacement). libosmocore based applications can log messages directly to systemd-journald.

The key difference from other logging targets is that systemd based logging allows to offload rendering of the meta information, such as location (file name, line number), subsystem, and logging level, to systemd-journald. Furthermore, systemd allows to attach arbitrary meta fields to the logging messages [2], which can be used for advanced log filtering.

[1] https://www.freedesktop.org/software/systemd/man/systemd-journald.service.html [2] https://www.freedesktop.org/software/-systemd/man/systemd.journal-fields.html

It was decided to introduce libsystemd as an optional dependency, so it needs to be enabled explicitly at configure/build time:

```
$ ./configure --enable-systemd-logging
```

**Note**
Recent libosmocore packages provided by Osmocom for Debian and CentOS are compiled **with** libsystemd (https://gerrit.osmocom.org/c/libosmocore/+/22651).

You can configure systemd based logging in two ways:

**Example: systemd-journal target with offloaded rendering**

```
log systemd-journal raw ❶
 logging filter all 1
 logging level set-all notice
```

❶ `raw` logging handler, rendering offloaded to systemd.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

In this example, logging messages will be passed to systemd without any meta information (time, location, level, category) in the text itself, so all the printing parameters like `logging print file` will be ignored. Instead, the meta information is passed separately as *fields* which can be retrieved from the journal and rendered in any preferred way.

```
# Show Osmocom specific fields
$ journalctl --fields | grep OSMO

# Filter messages by logging subsystem at run-time
$ journalctl OSMO_SUBSYS=DMSC -f

# Render specific fields only
$ journalctl --output=verbose \
        --output-fields=SYSLOG_IDENTIFIER,OSMO_SUBSYS,CODE_FILE,CODE_LINE,MESSAGE
```

See `man 7 systemd.journal-fields` for a list of default fields, and `man 1 journalctl` for general information and available formatters.

**Example: systemd-journal target with libosmocore based rendering**

```
log systemd-journal ❶
 logging filter all 1
 logging print file basename
 logging print category-hex 0
 logging print category 1
 logging print level 1
 logging timestamp 0 ❷
 logging color 1 ❸
 logging level set-all notice
```

❶ Generic logging handler, rendering is done by libosmocore.

❷ Disable timestamping, systemd will timestamp every message anyway.

❸ Colored messages can be rendered with `journalctl --output=cat`.

In this example, logging messages will be pre-processed by libosmocore before being passed to systemd. No additional fields will be attached, except the logging level (`PRIORITY`). This mode is similar to *syslog* and *stderr*.

---

**Note**

systemd-journal logging target uses libsystemd, which implements *Native Journal Protocol* (*AF_UNIX _DATAGRAM* socket). That socket is internally configured in synchronous blocking I/O mode, which means transmitting a big amount of messages or text over it in a short amount of time (before systemd-journald has time to read it) could potentially block the osmocom program's thread issuing the logging. libsystemd currently sets the *AF_UNIX* socket `SO_SNDBUF` to 8MB. In Linux, the `SO_SNDBUF` value being set on the socket will be trimmed by the kernel to a maximum allowed by sysctl `net.core.wmem_max`. Hence, if you want to be on a safer side minimizing dropping messages or blocking the process (depending on the I/O mode set), make sure sysctl `net.core.wmem_max` on your system is set to `8388608` (8MB) or more. Besides, the kernel limits the amount of messages queued in *AF_UNIX* sockets to value set in sysctl `net.unix.max_dgram_qlen`, so you may also want to increase that one to be on the safe side if planning to log with a high frequency.

---

---

**Note**

Linux Kernel used to have a `net.core.wmem_max` of `212992`(208KB) until recently (2025, a6d4f25888b83b8300aef28d9ee22765c1cc9b34), where it was increased to `4194304` (4MB) .

---

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

### 7.5.7 Logging to stderr

If you're not running the respective application as a daemon in the background, you can also use the stderr log target in order to log to the standard error file descriptor of the process.

In order to configure logging to stderr, you can use the following commands:

```
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log stderr
OsmoBSC(config-log)#
```

The stderr logging target can be configured during the VTY `log stderr` VTY command to perform blocking I/O with the `blocking-io` parameter. See Section 7.5.4 for more information.

# 8 VTY Process and Thread management

Most Osmocom programs provide, some support to tune some system settings related to the running process, its threads, its scheduling policies, etc.

All of these settings can be configured through the VTY, either during startup by means of usual config files or through direct human interaction at the telnet VTY interface while the process is running.

## 8.1 Scheduling Policy

The scheduler to use as well as some of its properties (such as realtime priority) can be configured at any time for the entire process. This sort of functionality is useful in order to increase priority for processes running time-constrained procedures, such as those acting on the Um interface, like *osmo-trx* or *osmo-bts*, where use of this feature is highly recommended.

**Example: Set process to use RR scheduler**

```
cpu-sched
 policy rr 1 ❶
```

❶ Configure process to use *SCHED_RR* policy with real time priority 1

**Note**
Running a process under real time priority requires CAP_SYS_NICE capabilities. In order to avoid running the process as *root* user, you can either modify the binary permissions with `setcap "CAP_SYS_NICE+ep" /path/to/binary`, or allow the user running the program to set rtprio by adding a file */etc/security/limits.d/youruser_allow-rtprio.conf* with something like `youruser - rtprio 99`. See `man 7 sched` for more information on the topic.

## 8.2 CPU-Affinity Mask

Most operating systems allow for some sort of configuration on restricting the amount of CPUs a given process or thread can run on. The procedure is sometimes called as *cpu-pinning* since it allows to keep different processes pinned on a subset of CPUs to make sure the scheduler won't run two CPU-hungry processes on the same CPU.

The set of CPUs where each thread is allowed to run on is expressed by means of a bitmask in hexadecimal representation, where the right most bit relates to CPU 0, and the Nth most significant bit relates to CPU *N-1*. Setting the bit means the process is allowed to run on that CPU, while clearing it means the process is forbidden to run on that CPU.

Hence, for instance a cpu-affinity mask of *0x00* means the thread is not allowed on any CPU, which will cause the thread to stall until a new value is applied. A mask of *0x01* means the thread is only allowed to run on the 1st CPU (CPU 0). A mask of *0xff00* means CPUs 8-15 are allowed, while 0-7 are not.

For single-threaded processes (most of Osmocom are), it is usually enough to set this line in VTY config file as follows:

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

```
cpu-sched
 cpu-affinity self 0x01 ❶
```

❶ Allow main thread (the one managing the VTY) only on CPU 0

Or otherwise:

```
cpu-sched
 cpu-affinity all 0x01 ❶
```

❶ Allow all threads only on CPU 0

For multi-threaded processes, it may be desired to run some threads on a subset of CPUs while another subset may run on another one. In order to identify threads, one can either use the TID of the thread (each thread has its own PID in Linux), or its specific Thread Name in case it has been set by the application.

The related information on all threads available in the process can be listed through VTY. This allows identifying quickly the different threads, its current cpu-affinity mask, etc.

**Example: Get osmo-trx Thread list information from VTY**

```
OsmoTRX> show cpu-sched threads
Thread list for PID 338609:
 TID: 338609, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338610, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338611, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338629, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338630, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338631, NAME: 'osmo-trx-uhd', cpu-affinity: 0x3
 TID: 338634, NAME: 'UHDAsyncEvent', cpu-affinity: 0x3
 TID: 338635, NAME: 'TxLower', cpu-affinity: 0x3
 TID: 338636, NAME: 'RxLower', cpu-affinity: 0x3
 TID: 338637, NAME: 'RxUpper0', cpu-affinity: 0x3
 TID: 338638, NAME: 'TxUpper0', cpu-affinity: 0x3
 TID: 338639, NAME: 'RxUpper1', cpu-affinity: 0x3
 TID: 338640, NAME: 'TxUpper1', cpu-affinity: 0x3
```

At runtime, one can change the cpu-affinity mask for a given thread identifying it by either TID or name:

**Example: Set CPU-affinity from VTY telnet interface**

```
OsmoTRX> cpu-affinity TxLower 0x02 ❶
OsmoTRX> cpu-affinity TxLower 0x03 ❷
```

❶ Allow thread named *TxLower* (*338635*) only on CPU 1

❷ Allow with TID *338636* (*RxLower*) only on CPU 0 and 1

Since thread names are set dynamically by the process during startup or at a later point after creating the thread itself, One may need to specify in the config file that the mask must be applied by the thread itself once being configured rather than trying to apply it immediately. To specify so, the *delay* keyword is using when configuring in the VTY. If the *delay* keyword is not used, the VTY will report and error and fail at startup when trying to apply a cpu-affinity mask for a yet-to-be-created thread.

**Example: Set CPU-affinity from VTY config file**

```
cpu-sched
 cpu-affinity TxLower 0x01 delay ❶
```

❶ Allow thread named *TxLower* (*338635*) only on CPU 1. It will be applied by the thread itself when created.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

# 9 Glossary

**2FF**
2nd Generation Form Factor; the so-called plug-in SIM form factor

**3FF**
3rd Generation Form Factor; the so-called microSIM form factor

**3GPP**
3rd Generation Partnership Project

**4FF**
4th Generation Form Factor; the so-called nanoSIM form factor

**A Interface**
Interface between BTS and BSC, traditionally over E1 (*3GPP TS 48.008* [3gpp-ts-48-008])

**A3/A8**
Algorithm 3 and 8; Authentication and key generation algorithm in GSM and GPRS, typically COMP128v1/v2/v3 or MILENAGE are typically used

**A5**
Algorithm 5; Air-interface encryption of GSM; currently only A5/0 (no encryption), A5/1 and A5/3 are in use

**Abis Interface**
Interface between BTS and BSC, traditionally over E1 (*3GPP TS 48.058* [3gpp-ts-48-058] and *3GPP TS 52.021* [3gpp-ts-52-021])

**ACC**
Access Control Class; every BTS broadcasts a bit-mask of permitted ACC, and only subscribers with a SIM of matching ACC are permitted to use that BTS

**AGCH**
Access Grant Channel on Um interface; used to assign a dedicated channel in response to RACH request

**AGPL**
GNU Affero General Public License, a copyleft-style Free Software License

**AQPSK**
Adaptive QPSK, a modulation scheme used by VAMOS channels on Downlink

**ARFCN**
Absolute Radio Frequency Channel Number; specifies a tuple of uplink and downlink frequencies

**AUC**
Authentication Center; central database of authentication key material for each subscriber

**BCCH**
Broadcast Control Channel on Um interface; used to broadcast information about Cell and its neighbors

**BCC**
Base Station Color Code; short identifier of BTS, lower part of BSIC

**BTS**
Base Transceiver Station

**BSC**
Base Station Controller

**BSIC**
Base Station Identity Code; 16bit identifier of BTS within location area

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**BSSGP**
Base Station Subsystem Gateway Protocol (*3GPP TS 48.018* [3gpp-ts-48-018])

**BVCI**
BSSGP Virtual Circuit Identifier

**CBC**
Cell Broadcast Centre; central entity of Cell Broadcast service

**CBCH**
Cell Broadcast Channel; used to transmit Cell Broadcast SMS (SMS-CB)

**CBS**
Cell Broadcast Service

**CBSP**
Cell Broadcast Service Protocol (*3GPP TS 48.049* [3gpp-ts-48-049])

**CC**
Call Control; Part of the GSM Layer 3 Protocol

**CCCH**
Common Control Channel on Um interface; consists of RACH (uplink), BCCH, PCH, AGCH (all downlink)

**Cell**
A cell in a cellular network, served by a BTS

**CEPT**
Conférence européenne des administrations des postes et des télécommunications; European Conference of Postal and Telecommunications Administrations.

**CGI**
Cell Global Identifier comprised of MCC, MNC, LAC and BSIC

**CSFB**
Circiut-Switched Fall Back; Mechanism for switching from LTE/EUTRAN to UTRAN/GERAN when circuit-switched services such as voice telephony are required.

**dB**
deci-Bel; relative logarithmic unit

**dBm**
deci-Bel (milliwatt); unit of measurement for signal strength of radio signals

**DHCP**
Dynamic Host Configuration Protocol (*IETF RFC 2131* [ietf-rfc2131])

**downlink**
Direction of messages / signals from the network core towards the mobile phone

**DSCP**
Differentiated Services Code Point (*IETF RFC 2474* [ietf-rfc2474])

**DSP**
Digital Signal Processor

**dvnixload**
Tool to program UBL and the Bootloader on a sysmoBTS

**EDGE**
Enhanced Data rates for GPRS Evolution; Higher-speed improvement of GPRS; introduces 8PSK

**EGPRS**
Enhanced GPRS; the part of EDGE relating to GPRS services

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**EIR**
Equipment Identity Register; core network element that stores and manages IMEI numbers

**ESME**
External SMS Entity; an external application interfacing with a SMSC over SMPP

**ETSI**
European Telecommunications Standardization Institute

**FPGA**
Field Programmable Gate Array; programmable digital logic hardware

**Gb**
Interface between PCU and SGSN in GPRS/EDGE network; uses NS, BSSGP, LLC

**GERAN**
GPRS/EDGE Radio Access Network

**GGSN**
GPRS Gateway Support Node; gateway between GPRS and external (IP) network

**GMSK**
Gaussian Minimum Shift Keying; modulation used for GSM and GPRS

**GPL**
GNU General Public License, a copyleft-style Free Software License

**Gp**
Gp interface between SGSN and GGSN; uses GTP protocol

**GPRS**
General Packet Radio Service; the packet switched 2G technology

**GPS**
Global Positioning System; provides a highly accurate clock reference besides the global position

**GSM**
Global System for Mobile Communications. ETSI/3GPP Standard of a 2G digital cellular network

**GSMTAP**
GSM tap; pseudo standard for encapsulating GSM protocol layers over UDP/IP for analysis

**GSUP**
Generic Subscriber Update Protocol. Osmocom-specific alternative to TCAP/MAP

**GT**
Global Title; an address in SCCP

**GTP**
GPRS Tunnel Protocol; used between SGSN and GGSN

**HLR**
Home Location Register; central subscriber database of a GSM network

**HNB-GW**
Home NodeB Gateway. Entity between femtocells (Home NodeB) and CN in 3G/UMTS.

**HPLMN**
Home PLMN; the network that has issued the subscriber SIM and has his record in HLR

**IE**
Information Element

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**IMEI**
International Mobile Equipment Identity; unique 14-digit decimal number to globally identify a mobile device, optionally with a 15th checksum digit

**IMEISV**
IMEI software version; unique 14-digit decimal number to globally identify a mobile device (same as IMEI) plus two software version digits (total digits: 16)

**IMSI**
International Mobile Subscriber Identity; 15-digit unique identifier for the subscriber/SIM; starts with MCC/MNC of issuing operator

**IP**
Internet Protocol (*IETF RFC 791* [ietf-rfc791])

**IPA**
*ip.access GSM over IP* protocol; used to multiplex a single TCP connection

**Iu**
Interface in 3G/UMTS between RAN and CN

**IuCS**
Iu interface for circuit-switched domain. Used in 3G/UMTS between RAN and MSC

**IuPS**
Iu interface for packet-switched domain. Used in 3G/UMTS between RAN and SGSN

**LAC**
Location Area Code; 16bit identifier of Location Area within network

**LAPD**
Link Access Protocol, D-Channel (*ITU-T Q.921* [itu-t-q921])

**LAPDm**
Link Access Protocol Mobile (*3GPP TS 44.006* [3gpp-ts-44-006])

**LLC**
Logical Link Control; GPRS protocol between MS and SGSN (*3GPP TS 44.064* [3gpp-ts-44-064])

**Location Area**
Location Area; a geographic area containing multiple BTS

**LU**
Location Updating; can be of type IMSI-Attach or Periodic. Procedure that indicates a subscriber's physical presence in a given radio cell.

**M2PA**
MTP2 Peer-to-Peer Adaptation; a SIGTRAN Variant (*RFC 4165* [ietf-rfc4165])

**M2UA**
MTP2 User Adaptation; a SIGTRAN Variant (*RFC 3331* [ietf-rfc3331])

**M3UA**
MTP3 User Adaptation; a SIGTRAN Variant (*RFC 4666* [ietf-rfc4666])

**MCC**
Mobile Country Code; unique identifier of a country, e.g. 262 for Germany

**MFF**
Machine-to-Machine Form Factor; a SIM chip package that is soldered permanently onto M2M device circuit boards.

**MGW**
Media Gateway

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**MM**
Mobility Management; part of the GSM Layer 3 Protocol

**MNC**
Mobile Network Code; identifies network within a country; assigned by national regulator

**MNCC**
Mobile Network Call Control; Unix domain socket based Interface between MSC and external call control entity like osmo-sip-connector

**MNO**
Mobile Network Operator; operator with physical radio network under his MCC/MNC

**MO**
Mobile Originated. Direction from Mobile (MS/UE) to Network

**MS**
Mobile Station; a mobile phone / GSM Modem

**MSC**
Mobile Switching Center; network element in the circuit-switched core network

**MSC pool**
A number of redundant MSCs serving the same core network, which a BSC / RNC distributes load across; see also the "MSC Pooling" chapter in OsmoBSC's user manual [userman-osmobsc] and *3GPP TS 23.236* [3gpp-ts-23-236]

**MSISDN**
Mobile Subscriber ISDN Number; telephone number of the subscriber

**MT**
Mobile Terminated. Direction from Network to Mobile (MS/UE)

**MTP**
Message Transfer Part; SS7 signaling protocol (*ITU-T Q.701* [itu-t-q701])

**MVNO**
Mobile Virtual Network Operator; Operator without physical radio network

**NCC**
Network Color Code; assigned by national regulator

**NITB**
Network In The Box; combines functionality traditionally provided by BSC, MSC, VLR, HLR, SMSC functions; see OsmoNITB

**NRI**
Network Resource Indicator, typically 10 bits of a TMSI indicating which MSC of an MSC pool attached the subscriber; see also the "MSC Pooling" chapter in OsmoBSC's user manual [userman-osmobsc] and *3GPP TS 23.236* [3gpp-ts-23-236]

**NSEI**
NS Entity Identifier

**NVCI**
NS Virtual Circuit Identifier

**NWL**
Network Listen; ability of some BTS to receive downlink from other BTSs

**NS**
Network Service; protocol on Gb interface (*3GPP TS 48.016* [3gpp-ts-48-016])

**OCXO**
Oven Controlled Crystal Oscillator; very high precision oscillator, superior to a VCTCXO

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**OML**
Operation & Maintenance Link (ETSI/*3GPP TS 52.021* [3gpp-ts-52-021])

**OpenBSC**
Open Source implementation of GSM network elements, specifically OsmoBSC, OsmoNITB, OsmoSGSN

**OpenGGSN**
Open Source implementation of a GPRS Packet Control Unit

**OpenVPN**
Open-Source Virtual Private Network; software employed to establish encrypted private networks over untrusted public networks

**Osmocom**
Open Source MObile COMmunications; collaborative community for implementing communications protocols and systems, including GSM, GPRS, TETRA, DECT, GMR and others

**OsmoBSC**
Open Source implementation of a GSM Base Station Controller

**OsmoNITB**
Open Source implementation of a GSM Network In The Box, combines functionality traditionally provided by BSC, MSC, VLR, HLR, AUC, SMSC

**OsmoSGSN**
Open Source implementation of a Serving GPRS Support Node

**OsmoPCU**
Open Source implementation of a GPRS Packet Control Unit

**OTA**
Over-The-Air; Capability of operators to remotely reconfigure/reprogram ISM/USIM cards

**PC**
Point Code; an address in MTP

**PCH**
Paging Channel on downlink Um interface; used by network to page an MS

**PCP**
Priority Code Point (*IEEE 802.1Q* [?])

**PCU**
Packet Control Unit; used to manage Layer 2 of the GPRS radio interface

**PDCH**
Packet Data Channel on Um interface; used for GPRS/EDGE signalling + user data

**PIN**
Personal Identification Number; a number by which the user authenticates to a SIM/USIM or other smart card

**PLMN**
Public Land Mobile Network; specification language for a single GSM network

**PUK**
PIN Unblocking Code; used to unblock a blocked PIN (after too many wrong PIN attempts)

**RAC**
Routing Area Code; 16bit identifier for a Routing Area within a Location Area

**RACH**
Random Access Channel on uplink Um interface; used by MS to request establishment of a dedicated channel

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**RAM**
Remote Application Management; Ability to remotely manage (install, remove) Java Applications on SIM/USIM Card

**RF**
Radio Frequency

**RFM**
Remote File Management; Ability to remotely manage (write, read) files on a SIM/USIM card

**Roaming**
Procedure in which a subscriber of one network is using the radio network of another network, often in different countries; in some countries national roaming exists

**Routing Area**
Routing Area; GPRS specific sub-division of Location Area

**RR**
Radio Resources; Part of the GSM Layer 3 Protocol

**RSL**
Radio Signalling Link (*3GPP TS 48.058* [3gpp-ts-48-058])

**RTP**
Real-Time Transport Protocol (*IETF RFC 3550* [ietf-rfc3550]); Used to transport audio/video streams over UDP/IP

**SACCH**
Slow Associate Control Channel on Um interface; bundled to a TCH or SDCCH, used for signalling in parallel to active dedicated channel

**SCCP**
Signaling Connection Control Part; SS7 signaling protocol (*ITU-T Q.711* [itu-t-q711])

**SDCCH**
Slow Dedicated Control Channel on Um interface; used for signalling and SMS transport in GSM

**SDK**
Software Development Kit

**SGs**
Interface between MSC (GSM/UMTS) and MME (LTE/EPC) to facilitate CSFB and SMS.

**SGSN**
Serving GPRS Support Node; Core network element for packet-switched services in GSM and UMTS.

**SIGTRAN**
Signaling Transport over IP (*IETF RFC 2719* [ietf-rfc2719])

**SIM**
Subscriber Identity Module; small chip card storing subscriber identity

**Site**
A site is a location where one or more BTSs are installed, typically three BTSs for three sectors

**SMPP**
Short Message Peer-to-Peer; TCP based protocol to interface external entities with an SMSC

**SMSC**
Short Message Service Center; store-and-forward relay for short messages

**SS7**
Signaling System No. 7; Classic digital telephony signaling system

**SS**
Supplementary Services; query and set various service parameters between subscriber and core network (e.g. USSD, 3rd-party calls, hold/retrieve, advice-of-charge, call deflection)

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**SSH**
Secure Shell; *IETF RFC 4250* [ietf-rfc4251] to 4254

**SSN**
Sub-System Number; identifies a given SCCP Service such as MSC, HLR

**STP**
Signaling Transfer Point; A Router in SS7 Networks

**SUA**
SCCP User Adaptation; a SIGTRAN Variant (*RFC 3868* [ietf-rfc3868])

**syslog**
System logging service of UNIX-like operating systems

**System Information**
A set of downlink messages on the BCCH and SACCH of the Um interface describing properties of the cell and network

**TCH**
Traffic Channel; used for circuit-switched user traffic (mostly voice) in GSM

**TCP**
Transmission Control Protocol; (*IETF RFC 793* [ietf-rfc793])

**TFTP**
Trivial File Transfer Protocol; (*IETF RFC 1350* [ietf-rfc1350])

**TOS**
Type Of Service; bit-field in IPv4 header, now re-used as DSCP (*IETF RFC 791* [ietf-rfc791])

**TRX**
Transceiver; element of a BTS serving a single carrier

**TS**
Technical Specification

**u-Boot**
Boot loader used in various embedded systems

**UBI**
An MTD wear leveling system to deal with NAND flash in Linux

**UBL**
Initial bootloader loaded by the TI Davinci SoC

**UDP**
User Datagram Protocol (*IETF RFC 768* [ietf-rfc768])

**UICC**
Universal Integrated Chip Card; A smart card according to *ETSI TR 102 216* [etsi-tr102216]

**Um interface**
U mobile; Radio interface between MS and BTS

**uplink**
Direction of messages: Signals from the mobile phone towards the network

**USIM**
Universal Subscriber Identity Module; application running on a UICC to provide subscriber identity for UMTS and GSM networks

**USSD**
Unstructured Supplementary Service Data; textual dialog between subscriber and core network, e.g. **100 → Your extension is 1234*

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

**VAMOS**
Voice services over Adaptive Multi-user channels on One Slot; an optional extension for GSM specified in Release 9 of 3GPP GERAN specifications (*3GPP TS 48.018* [3gpp-ts-48-018]) allowing two independent UEs to transmit and receive simultaneously on traffic channels

**VCTCXO**
Voltage Controlled, Temperature Compensated Crystal Oscillator; a precision oscillator, superior to a classic crystal oscillator, but inferior to an OCXO

**VLAN**
Virtual LAN in the context of Ethernet (*IEEE 802.1Q* [ieee-802.1q])

**VLR**
Visitor Location Register; volatile storage of attached subscribers in the MSC

**VPLMN**
Visited PLMN; the network in which the subscriber is currently registered; may differ from HPLMN when on roaming

**VTY**
Virtual TeletYpe; a textual command-line interface for configuration and introspection, e.g. the OsmoBSC configuration file as well as its telnet link on port 4242

# A Osmocom TCP/UDP Port Numbers

The Osmocom GSM system utilizes a variety of TCP/IP based protocols. The table below provides a reference as to which port numbers are used by which protocol / interface.

Table 10: TCP/UDP port numbers

| L4 Protocol | Port Number | Purpose | Software |
|---|---|---|---|
| UDP | 1984 | Osmux | osmo-mgw, osmo-bts |
| UDP | 2427 | MGCP GW | osmo-bsc_mgcp, osmo-mgw |
| TCP | 2775 | SMPP (SMS interface for external programs) | osmo-nitb |
| TCP | 3002 | A-bis/IP OML | osmo-bts, osmo-bsc, osmo-nitb |
| TCP | 3003 | A-bis/IP RSL | osmo-bts, osmo-bsc, osmo-nitb |
| TCP | 4227 | telnet (VTY) | osmo-pcap-client |
| TCP | 4228 | telnet (VTY) | osmo-pcap-server |
| TCP | 4236 | Control Interface | osmo-trx |
| TCP | 4237 | telnet (VTY) | osmo-trx |
| TCP | 4238 | Control Interface | osmo-bts |
| TCP | 4239 | telnet (VTY) | osmo-stp |
| TCP | 4240 | telnet (VTY) | osmo-pcu |
| TCP | 4241 | telnet (VTY) | osmo-bts |
| TCP | 4242 | telnet (VTY) | osmo-nitb, osmo-bsc, cellmgr-ng |
| TCP | 4243 | telnet (VTY) | osmo-bsc_mgcp, osmo-mgw |
| TCP | 4244 | telnet (VTY) | osmo-bsc_nat |
| TCP | 4245 | telnet (VTY) | osmo-sgsn |
| TCP | 4246 | telnet (VTY) | osmo-gbproxy |
| TCP | 4247 | telnet (VTY) | OsmocomBB |
| TCP | 4249 | Control Interface | osmo-nitb, osmo-bsc |
| TCP | 4250 | Control Interface | osmo-bsc_nat |
| TCP | 4251 | Control Interface | osmo-sgsn |
| TCP | 4252 | telnet (VTY) | sysmobts-mgr |
| TCP | 4253 | telnet (VTY) | osmo-gtphub |
| TCP | 4254 | telnet (VTY) | osmo-msc |

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

Table 10: (continued)

| L4 Protocol | Port Number | Purpose | Software |
|---|---|---|---|
| TCP | 4255 | Control Interface | osmo-msc |
| TCP | 4256 | telnet (VTY) | osmo-sip-connector |
| TCP | 4257 | Control Interface | osmo-ggsn, ggsn (OpenGGSN) |
| TCP | 4258 | telnet (VTY) | osmo-hlr |
| TCP | 4259 | Control Interface | osmo-hlr |
| TCP | 4260 | telnet (VTY) | osmo-ggsn |
| TCP | 4261 | telnet (VTY) | osmo-hnbgw |
| TCP | 4262 | Control Interface | osmo-hnbgw |
| TCP | 4263 | Control Interface | osmo-gbproxy |
| TCP | 4264 | telnet (VTY) | osmo-cbc |
| TCP | 4265 | Control Interface | osmo-cbc |
| TCP | 4266 | D-GSM MS Lookup: mDNS serve | osmo-hlr |
| TCP | 4267 | Control Interface | osmo-mgw |
| TCP | 4268 | telnet (VTY) | osmo-uecups |
| SCTP | 4268 | UECUPS | osmo-uecups |
| TCP | 4269 | telnet (VTY) | osmo-e1d |
| TCP | 4270 | telnet (VTY) | osmo-isdntap |
| TCP | 4271 | telnet (VTY) | osmo-smlc |
| TCP | 4272 | Control Interface | osmo-smlc |
| TCP | 4273 | telnet (VTY) | osmo-hnodeb |
| TCP | 4274 | Control Interface | osmo-hnodeb |
| TCP | 4275 | telnet (VTY) | osmo-upf |
| TCP | 4276 | Control Interface | osmo-upf |
| TCP | 4277 | telnet (VTY) | osmo-pfcp-tool |
| TCP | 4278 | Control Interface | osmo-pfcp-tool |
| UDP | 4729 | GSMTAP | Almost every osmocom project |
| TCP | 5000 | A/IP | osmo-bsc, osmo-bsc_nat |
| UDP | 23000 | GPRS-NS over IP default port | osmo-pcu, osmo-sgsn, osmo-gbproxy |
| TCP | 48049 | BSC-CBC (CBSP) default port | osmo-bsc, osmo-cbc |

# B Bibliography / References

#### B.0.0.0.1 References


[1] [userman-ice1usb] Osmocom Project: icE1usb User Manual.

[2] [userman-ogt] Pau Espin: osmo-gsm-tester User Manual.

[3] [userman-remsim] Harald Welte: osmo-remsim User Manual.

[4] [osmobts-abis-spec] Neels Hofmeyr & Harald Welte. OsmoBTS Abis Protocol Specification. https://ftp.osmocom.org/docs/latest/osmobts-abis.pdf

[5] [userman-osmobsc] Osmocom Project: OsmoBSC User Manual. https://ftp.osmocom.org/docs/latest/osmobsc-usermanual.pdf

[6] [vty-ref-osmobsc] Osmocom Project: OsmoBSC VTY Reference Manual. https://ftp.osmocom.org/docs/-latest/osmobsc-vty-reference.pdf

[7] [userman-osmobts] Osmocom Project: OsmoBTS User Manual. https://ftp.osmocom.org/docs/latest/osmobts-usermanual.pdf


Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

[8] [vty-ref-osmobts] Osmocom Project: OsmoBTS VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmobts-trx-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmobts-sysmo-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmobts-lc15-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmobts-oc2g-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmobts-octphy-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmobts-virtual-vty-reference.pdf

[9] [userman-osmocbc] Osmocom Project: OsmoCBC User Manual. https://ftp.osmocom.org/docs/latest/osmocbc-usermanual.pdf

[10] [vty-ref-osmocbc] Osmocom Project: OsmoCBC VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmocbc-vty-reference.pdf

[11] [userman-osmogbproxy] Osmocom Project: OsmoGBProxy User Manual. https://ftp.osmocom.org/docs/latest/osmogbproxy-usermanual.pdf

[12] [vty-ref-osmogbproxy] Osmocom Project: OsmoGBPRoxy VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmogbproxy-vty-reference.pdf

[13] [userman-osmoggsn] Osmocom Project: OpenGGSN User Manual. https://ftp.osmocom.org/docs/latest/osmoggsn-usermanual.pdf

[14] [vty-ref-osmoggsn] Osmocom Project: OsmoGGSN VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmoggsn-vty-reference.pdf

[15] [userman-osmohlr] Osmocom Project: OsmoHLR User Manual. https://ftp.osmocom.org/docs/latest/osmohlr-usermanual.pdf

[16] [vty-ref-osmohlr] Osmocom Project: OsmoHLR VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmohlr-vty-reference.pdf

[17] [userman-osmohnbgw] Osmocom Project: OsmoHNBGW User Manual. https://ftp.osmocom.org/docs/latest/osmohnbgw-usermanual.pdf

[18] [vty-ref-osmohnbgw] Osmocom Project: OsmoHNBGW VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmohnbgw-vty-reference.pdf

[19] [userman-osmomgw] Osmocom Project: OsmoMGW User Manual. https://ftp.osmocom.org/docs/latest/osmomgw-usermanual.pdf

[20] [vty-ref-osmomgw] Osmocom Project: OsmoMGW VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmomgw-vty-reference.pdf

[21] [userman-osmomsc] Osmocom Project: OsmoMSC User Manual. https://ftp.osmocom.org/docs/latest/osmomsc-usermanual.pdf

[22] [vty-ref-osmomsc] Osmocom Project: OsmoMSC VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmomsc-vty-reference.pdf

[23] [userman-osmonitb] Osmocom Project: OsmoNITB User Manual. https://ftp.osmocom.org/docs/latest/osmonitb-usermanual.pdf

[24] [vty-ref-osmonitb] Osmocom Project: OsmoNITB VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmonitb-vty-reference.pdf

[25] [userman-osmopcu] Osmocom Project: OsmoPCU User Manual. https://ftp.osmocom.org/docs/latest/osmopcu-usermanual.pdf

[26] [vty-ref-osmopcu] Osmocom Project: OsmoPCU VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmopcu-vty-reference.pdf

[27] [userman-osmosgsn] Osmocom Project: OsmoSGSN User Manual. https://ftp.osmocom.org/docs/latest/osmosgsn-usermanual.pdf

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

[28] [vty-ref-osmosgsn] Osmocom Project: OsmoSGSN VTY Reference Manual. https://ftp.osmocom.org/docs/-latest/osmosgsn-vty-reference.pdf

[29] [userman-osmosipconnector] Osmocom Project: OsmoSIPconnector User Manual. https://ftp.osmocom.org/-docs/latest/osmosipconnector-usermanual.pdf

[30] [vty-ref-osmosipconnector] Osmocom Project: OsmoSIPconnector VTY Reference Manual. https://ftp.osmocom.org/docs/latest/osmosipconnector-vty-reference.pdf

[31] [userman-osmosmlc] Osmocom Project: OsmoSMLC User Manual. https://ftp.osmocom.org/docs/latest/-osmosmlc-usermanual.pdf

[32] [vty-ref-osmosmlc] Osmocom Project: OsmoSMLC VTY Reference Manual. https://ftp.osmocom.org/docs/-latest/osmosmlc-vty-reference.pdf

[33] [userman-osmostp] Osmocom Project: OsmoSTP User Manual. https://ftp.osmocom.org/docs/latest/osmostp-usermanual.pdf

[34] [vty-ref-osmostp] Osmocom Project: OsmoSTP VTY Reference Manual. https://ftp.osmocom.org/docs/latest/-osmostp-vty-reference.pdf

[35] [userman-osmotrx] Osmocom Project: OsmoTRX User Manual. https://ftp.osmocom.org/docs/latest/osmotrx-usermanual.pdf

[36] [vty-ref-osmotrx] Osmocom Project: OsmoTRX VTY Reference Manual. https://ftp.osmocom.org/docs/-latest/osmotrx-uhd-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmotrx-lms-vty-reference.pdf https://ftp.osmocom.org/docs/latest/osmotrx-ipc-vty-reference.pdf https://ftp.osmocom.org/docs/latest/-osmotrx-usrp1-vty-reference.pdf

[37] [3gpp-ts-23-041] 3GPP TS 23.041: Technical realization of Cell Broadcast Service (CBS)

[38] [3gpp-ts-23-048] 3GPP TS 23.048: Security mechanisms for the (U)SIM application toolkit; Stage 2 https://www.3gpp.org/DynaReport/23048.htm

[39] [3gpp-ts-23-236] 3GPP TS 23.236: Intra-domain connection of Radio Access Network (RAN) nodes to multiple Core Network (CN) nodes https://www.3gpp.org/DynaReport/23236.htm

[40] [3gpp-ts-24-007] 3GPP TS 24.007: Mobile radio interface signalling layer 3; General Aspects https://www.3gpp.org/DynaReport/24007.htm

[41] [3gpp-ts-24-008] 3GPP TS 24.008: Mobile radio interface Layer 3 specification; Core network protocols; Stage 3. https://www.3gpp.org/dynareport/24008.htm

[42] [3gpp-ts-31-101] 3GPP TS 31.101: UICC-terminal interface; Physical and logical characteristics https://www.3gpp.org/DynaReport/31101.htm

[43] [3gpp-ts-31-102] 3GPP TS 31.102: Characteristics of the Universal Subscriber Identity Module (USIM) application https://www.3gpp.org/DynaReport/31102.htm

[44] [3gpp-ts-31-103] 3GPP TS 31.103: Characteristics of the IMS Subscriber Identity Module (ISIM) application https://www.3gpp.org/DynaReport/31103.htm

[45] [3gpp-ts-31-111] 3GPP TS 31.111: Universal Subscriber Identity Module (USIM) Application Toolkit (USAT) https://www.3gpp.org/DynaReport/31111.htm

[46] [3gpp-ts-31-115] 3GPP TS 31.115: Secured packet structure for (Universal) Subscriber Identity Module (U)SIM Toolkit applications https://www.3gpp.org/DynaReport/31115.htm

[47] [3gpp-ts-31-116] 3GPP TS 31.116: Remote APDU Structure for (U)SIM Toolkit applications https://www.3gpp.org/DynaReport/31116.htm

[48] [3gpp-ts-35-205] 3GPP TS 35.205: 3G Security; Specification of the MILENAGE algorithm set: General

[49] [3gpp-ts-35-206] 3GPP TS 35.206: 3G Security; Specification of the MILENAGE algorithm set: Algorithm specification https://www.3gpp.org/DynaReport/35206.htm

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

[50] [3gpp-ts-44-006] 3GPP TS 44.006: Mobile Station - Base Station System (MS - BSS) interface; Data Link (DL) layer specification https://www.3gpp.org/DynaReport/44006.htm

[51] [3gpp-ts-44-018] 3GPP TS 44.018: Mobile radio interface layer 3 specification; Radio Resource Control (RRC) protocol https://www.3gpp.org/DynaReport/44018.htm

[52] [3gpp-ts-44-064] 3GPP TS 44.064: Mobile Station - Serving GPRS Support Node (MS-SGSN); Logical Link Control (LLC) Layer Specification https://www.3gpp.org/DynaReport/44064.htm

[53] [3gpp-ts-45-002] 3GPP TS 45.002: Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Multiplexing and multiple access on the radio path https://www.3gpp.org/DynaReport/45002.htm

[54] [3gpp-ts-48-008] 3GPP TS 48.008: Mobile Switching Centre - Base Station system (MSC-BSS) interface; Layer 3 specification https://www.3gpp.org/DynaReport/48008.htm

[55] [3gpp-ts-48-016] 3GPP TS 48.016: General Packet Radio Service (GPRS); Base Station System (BSS) - Serving GPRS Support Node (SGSN) interface; Network service https://www.3gpp.org/DynaReport/48016.htm

[56] [3gpp-ts-48-018] 3GPP TS 48.018: General Packet Radio Service (GPRS); Base Station System (BSS) - Serving GPRS Support Node (SGSN); BSS GPRS protocol (BSSGP) https://www.3gpp.org/DynaReport/48018.htm

[57] [3gpp-ts-48-049] 3GPP TS 48.049: Digital cellular communications system; Base Station Controller - Cell Broadcast Centre (BSC-CBC) interface specification; Cell Broadcast Service Protocol (CBSP) https://www.3gpp.org/DynaReport/48049.htm

[58] [3gpp-ts-48-056] 3GPP TS 48.056: Base Station Controller - Base Transceiver Station (BSC - BTS) interface; Layer 2 specification https://www.3gpp.org/DynaReport/48056.htm

[59] [3gpp-ts-48-058] 3GPP TS 48.058: Base Station Controller - Base Transceiver Station (BSC - BTS) Interface; Layer 3 specification https://www.3gpp.org/DynaReport/48058.htm

[60] [3gpp-ts-51-011] 3GPP TS 51.011: Specification of the Subscriber Identity Module - Mobile Equipment (SIM-ME) interface

[61] [3gpp-ts-51-014] 3GPP TS 51.014: Specification of the SIM Application Toolkit for the Subscriber Identity Module - Mobile Equipment (SIM - ME) interface https://www.3gpp.org/DynaReport/51014.htm

[62] [3gpp-ts-52-021] 3GPP TS 52.021: Network Management (NM) procedures and messages on the A-bis interface https://www.3gpp.org/DynaReport/52021.htm

[63] [etsi-tr102216] ETSI TR 102 216: Smart cards https://www.etsi.org/deliver/etsi_tr/102200_102299/102216/03.00.00_60/tr_102216v030000p.pdf

[64] [etsi-ts102221] ETSI TS 102 221: Smart Cards; UICC-Terminal interface; Physical and logical characteristics https://www.etsi.org/deliver/etsi_ts/102200_102299/102221/13.01.00_60/ts_102221v130100p.pdf

[65] [etsi-ts101220] ETSI TS 101 220: Smart Cards; ETSI numbering system for telecommunication application providers https://www.etsi.org/deliver/etsi_ts/101200_101299/101220/12.00.00_60/ts_101220v120000p.pdf

[66] [etsi-ts102671] ETSI TS 102 671: Smart Cards; Machine to Machine UICC; Physical and logical characteristics https://www.etsi.org/deliver/etsi_ts/102600_102699/102671/18.01.00_60/ts_102671v180100p.pdf

[67] [ieee-802.1q] IEEE 802.1Q: Bridges and Bridged Networks https://ieeexplore.ieee.org/document/6991462

[68] [ietf-rfc768] IETF RFC 768: User Datagram Protocol https://tools.ietf.org/html/rfc768

[69] [ietf-rfc791] IETF RFC 791: Internet Protocol https://tools.ietf.org/html/rfc791

[70] [ietf-rfc793] IETF RFC 793: Transmission Control Protocol https://tools.ietf.org/html/rfc793

[71] [ietf-rfc1035] IETF RFC 1035: Domain Names - Implementation and Specification https://tools.ietf.org/html/rfc1035

[72] [ietf-rfc1350] IETF RFC 1350: Trivial File Transfer Protocol https://tools.ietf.org/html/rfc1350

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

[73] [ietf-rfc2131] IETF RFC 2131: Dynamic Host Configuration Protocol https://tools.ietf.org/html/rfc2131

[74] [ietf-rfc2474] IETF RFC 2474: Definition of the Differentiated Services Field (DS Field) in the IPv44 and IPv6 Headers https://tools.ietf.org/html/rfc2474

[75] [ietf-rfc2719] IETF RFC 2719: Signal Transport over IP https://tools.ietf.org/html/rfc2719

[76] [ietf-rfc3331] IETF RFC 3331: Message Transfer Part 2 User Adaptation Layer https://tools.ietf.org/html/-rfc3331

[77] [ietf-rfc3550] IETF RFC 3550: RTP: A Transport protocol for Real-Time Applications https://tools.ietf.org/-html/rfc3550

[78] [ietf-rfc3596] IETF RFC 3596: DNS Extensions to Support IP Version 6 https://tools.ietf.org/html/rfc3596

[79] [ietf-rfc3868] IETF RFC 3868: SCCP User Adaptation Layer https://tools.ietf.org/html/rfc3868

[80] [ietf-rfc4165] IETF RFC 4165: Message Transfer Part 2 Peer-to-Peer Adaptation Layer https://tools.ietf.org/-html/rfc4165

[81] [ietf-rfc4251] IETF RFC 4251: The Secure Shell (SSH) Protocol Architecture https://tools.ietf.org/html/-rfc4251

[82] [ietf-rfc4666] IETF RFC 4666: Message Transfer Part 3 User Adaptation Layer https://tools.ietf.org/html/-rfc4666

[83] [ietf-rfc5771] IETF RFC 5771: IANA Guidelines for IPv4 Multicast Address Assignments https://tools.ietf.org/html/rfc5771

[84] [itu-t-q701] ITU-T Q.701: Functional Description of the Message Transfer Part (MTP) https://www.itu.int/rec/-T-REC-Q.701/en/

[85] [itu-t-q711] ITU-T Q.711: Functional Description of the Signalling Connection Control Part https://www.itu.int/rec/T-REC-Q.711/en/

[86] [itu-t-q713] ITU-T Q.713: Signalling connection control part formats and codes https://www.itu.int/rec/T-REC-Q.713/en/

[87] [itu-t-q714] ITU-T Q.714: Signalling connection control part procedures https://www.itu.int/rec/T-REC-Q.714/en/

[88] [itu-t-q921] ITU-T Q.921: ISDN user-network interface - Data link layer specification https://www.itu.int/rec/-T-REC-Q.921/en

[89] [smpp-34] SMPP Develoepers Forum. Short Message Peer-to-Peer Protocol Specification v3.4 https://docs.nimta.com/SMPP_v3_4_Issue1_2.pdf

[90] [gnu-agplv3] Free Software Foundation. GNU Affero General Public License. https://www.gnu.org/licenses/-agpl-3.0.en.html

[91] [freeswitch_pbx] FreeSWITCH SIP PBX https://freeswitch.org

[92] [tw-ts-001] TW-TS-001: Enhanced RTP transport of FR and EFR codec frames in an IP-based GSM RAN https://www.freecalypso.org/specs/tw-ts-001-v010100.txt

[93] [tw-ts-002] TW-TS-002: Enhanced RTP transport of HRv1 codec frames in an IP-based GSM RAN https://www.freecalypso.org/specs/tw-ts-002-v010100.txt

[94] [tw-ts-003] TW-TS-003: BSSMAP extension for selection of enhanced RTP transport formats https://www.freecalypso.org/specs/tw-ts-003-v010002.txt

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

# C GNU Free Documentation License

Version 1.3, 3 November 2008

Copyright © 2000, 2001, 2002, 2007, 2008 Free Software Foundation, Inc. http://fsf.org/

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

## C.1 PREAMBLE

The purpose of this License is to make a manual, textbook, or other functional and useful document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondarily, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

## C.2 APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The "Document", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "you". You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A "Modified Version" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "Secondary Section" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "Invariant Sections" are certain Secondary Section whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The "Cover Texts" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A "Transparent" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not Transparent is called "Opaque".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary

formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The "Title Page" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, Title Page means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

The "publisher" means any person or entity that distributes copies of the Document to the public.

A section "Entitled XYZ" means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as "Acknowledgements", "Dedications", "Endorsements", or "History".) To "Preserve the Title" of such a section when you modify the Document means that it remains a section "Entitled XYZ" according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

## C.3 VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section Section C.4.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

## C.4 COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

## C.5 MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

a. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.

b. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.

c. State on the Title Page the name of the publisher of the Modified Version, as the publisher.

d. Preserve all the copyright notices of the Document.

e. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.

f. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.

g. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.

h. Include an unaltered copy of this License.

i. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.

j. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.

k. For any section Entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.

l. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.

m. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version.

n. Do not retitle any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Sections.

o. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Section and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section Entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties—for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

## C.6 COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled "History" in the various original documents, forming one section Entitled "History"; likewise combine any sections Entitled "Acknowledgements", and any sections Entitled "Dedications". You must delete all sections Entitled "Endorsements".

## C.7 COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

## C.8 AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an "aggregate" if the copyright resulting from the compilation is not used to limit the legal rights of the compilation's users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document's Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

## C.9 TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled "Acknowledgements", "Dedications", or "History", the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

## C.10 TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense, or distribute it is void, and will automatically terminate your rights under this License.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, receipt of a copy of some or all of the same material does not give you any rights to use it.

## C.11 FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See http://www.gnu.org/copyleft/.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License "or any later version" applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation. If the Document specifies that a proxy can decide which future versions of this License can be used, that proxy's public statement of acceptance of a version permanently authorizes you to choose that version for the Document.

## C.12 RELICENSING

"Massive Multiauthor Collaboration Site" (or "MMC Site") means any World Wide Web server that publishes copyrightable works and also provides prominent facilities for anybody to edit those works. A public wiki that anybody can edit is an example of such a server. A "Massive Multiauthor Collaboration" (or "MMC") contained in the site means any set of copyrightable works thus published on the MMC site.

"CC-BY-SA" means the Creative Commons Attribution-Share Alike 3.0 license published by Creative Commons Corporation, a not-for-profit corporation with a principal place of business in San Francisco, California, as well as future copyleft versions of that license published by that same organization.

"Incorporate" means to publish or republish a Document, in whole or in part, as part of another Document.

An MMC is "eligible for relicensing" if it is licensed under this License, and if all works that were first published under this License somewhere other than this MMC, and subsequently incorporated in whole or in part into the MMC, (1) had no cover texts or invariant sections, and (2) were thus incorporated prior to November 1, 2008.

The operator of an MMC Site may republish an MMC contained in the site under CC-BY-SA on the same site at any time before August 1, 2009, provided the MMC is eligible for relicensing.

## C.13 ADDENDUM: How to use this License for your documents

To use this License in a document you have written, include a copy of the License in the document and put the following copyright and license notices just after the title page:

```
Copyright (c)  YEAR  YOUR NAME.
Permission is granted to copy, distribute and/or modify this document
under the terms of the GNU Free Documentation License, Version 1.3
or any later version published by the Free Software Foundation;
with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts.
A copy of the license is included in the section entitled ``GNU
Free Documentation License''.
```

If you have Invariant Sections, Front-Cover Texts and Back-Cover Texts, replace the "with…Texts." line with this:

```
with the Invariant Sections being LIST THEIR TITLES, with the
Front-Cover Texts being LIST, and with the Back-Cover Texts being LIST.
```

If you have Invariant Sections without Cover Texts, or some other combination of the three, merge those two alternatives to suit the situation.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.

Copyright © 2012-2017 sysmocom - s.f.m.c. GmbH 