sysmocom

sysmocom - s.f.m.c. GmbH

OsmoGGSN User Manual

by Harald Welte

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

<table>
<thead>
<tr>
<th>NUMBER</th>
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<td>August 2017</td>
<td>Initial version.</td>
<td>HW</td>
</tr>
</tbody>
</table>
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 Overview ............................................. 4
  4.1 About OsmoGGSN ........................................... 4
  4.2 Software Components ....................................... 5
    4.2.1 GTP Implementation (libgtp) ................................ 5
    4.2.2 sgsnemu ................................................. 5
    4.2.3 osmo-ggsn ............................................... 5
    4.2.4 systemd service file .................................... 5
    4.2.5 init script ............................................. 5
  4.3 Limitations ............................................. 5
    4.3.1 GSM 09.60 (GTPv0) ..................................... 5
    4.3.2 3GPP 29.060 (GTPv1) .................................... 6

5 Running OsmoGGSN .................................... 7
  5.1 SYNOPSIS ............................................. 7
  5.2 OPTIONS ............................................... 7
  5.3 Routing ............................................... 7
  5.4 Multiple instances ....................................... 8
  5.5 GTP-U kernel module ..................................... 8
6 The Osmocom VTY Interface

6.1 Accessing the telnet VTY

6.2 VTY Nodes

6.3 Interactive help

6.3.1 The question-mark (?) command

6.3.2 TAB completion

6.3.3 The list command

6.3.4 The attribute system

6.3.5 The expert mode

7 libosmocore Logging System

7.1 Log categories

7.2 Log levels

7.3 Log printing options

7.4 Log filters

7.5 Log targets

7.5.1 Logging to the VTY

7.5.2 Logging to the ring buffer

7.5.3 Logging via gsmtap

7.5.4 Logging to a file

7.5.5 Logging to syslog

7.5.6 Logging to systemd-journal

7.5.7 Logging to stderr

8 Configuring OsmoGGSN

8.1 Configuring a virtual GGSN instance

8.1.1 Creating/Editing a GGSN instance

8.1.2 Configuring a GGSN instance

8.1.3 Deleting a GGSN instance

8.1.4 Taking a GGSN instance out of shutdown

8.1.5 Shutting a GGSN instance down

8.2 Configuring an Access Point Name

8.2.1 Creating/Editing an APN

8.2.2 Configuring an APN

8.2.3 Deleting an APN

8.2.4 Taking an APN out of shutdown

8.2.5 Shutting an APN down

8.3 Configuring for running without root privileges

8.3.1 Manual TUN device creation / configuration

8.3.2 systemd based TUN device creation+configuration

8.3.3 Config Changes
1 Foreword

Digital cellular networks based on the GSM specification were designed in the late 1980ies and first deployed in the early 1990ies 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.

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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 benefitting 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, work-arounds
- 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.
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.

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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.
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, backhaul 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 http://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.

4 Overview

4.1 About OsmoGGSN

OsmoGGSN is a Free / Open Source Software implementation of the GPRS GGSN (Gateway GPRS support node) element in side the packet switched core network of 2G and 3G cellular networks.

The GGSN function is the tunnel endpoint on the core network side, from where the external (IP) packet data network
4.2 Software Components

4.2.1 GTP Implementation (libgtp)

The OsmoGGSN source code includes a shared library implementation of the GTP protocol used on the GGSN-SGSN interface. This library and associated header files are installed system-wide and are available to other programs/applications.

In fact, libgtp is what the OsmoSGSN also uses for its use of GTP.

4.2.2 sgsnemu

In order to test OsmoGGSN without running a SGSN and other elements of a cellular network, there is a small command-line utility called sgsnemu which is able to simulate the customary operations of a SGSN towards the GGSN, such as a PDP Context Activation.

sgsnemu can even be used for testing against other GGSNs, as the GTP protocol is standardized across implementations.

4.2.3 osmo-ggsn

osmo-ggsn is the actual name of the OsmoGGSN executable program. It implements the GGSN functionality. All parameters are set using the configuration file, by default located in ./osmo-ggsn.cfg

4.2.4 systemd service file

In contrib/osmo-ggsn.service you can find a sample service file for OsmoGGSN which can be used with systemd.

4.2.5 init script

In contrib/osmo-ggsn.init you can find a sample init script to be used on systems with classic init process.

4.3 Limitations

OsmoGGSN supports both GTP0 (GSM 09.60) and GTP1 (3GPP 29.060). In the following tables the support of each individual message type is detailed. The numbers before each feature indicates the relevant section in the standard.

4.3.1 GSM 09.60 (GTPv0)

<table>
<thead>
<tr>
<th>Feature</th>
<th>gtpplib</th>
<th>osmo-ggsn</th>
<th>sgsnemu</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4 Path Management Messages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4.1 Echo Request</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.4.2 Echo Response</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.4.3 Version Not Supported</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.5 Tunnel Management Messages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5.1 Create PDP Context Request</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.5.2 Create PDP Context Response</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.5.3 Update PDP Context Request</td>
<td>Supported</td>
<td>Supported</td>
<td>Not</td>
<td></td>
</tr>
<tr>
<td>7.5.4 Update PDP Context Response</td>
<td>Supported</td>
<td>Supported</td>
<td>Not</td>
<td></td>
</tr>
<tr>
<td>7.5.5 Delete PDP Context Request</td>
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<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.5.6 Delete PDP Context Response</td>
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</tr>
<tr>
<td>7.5.7 Create AA PDP Context Request</td>
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</tr>
<tr>
<td>7.5.8 Create AA PDP Response</td>
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<td>Unsupported</td>
<td>Unsupported</td>
<td></td>
</tr>
<tr>
<td>7.5.9 Delete AA PDP Context Request</td>
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<tr>
<td>7.5.10 Delete AA PDP Context Response</td>
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<td>sgsnemu</td>
<td>notes</td>
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<td>--------</td>
<td>-----------</td>
<td>---------</td>
<td>------------------------</td>
</tr>
<tr>
<td>7.5.11 Error Indication</td>
<td>Supported</td>
<td>Supported</td>
<td>Supported</td>
<td></td>
</tr>
<tr>
<td>7.5.12 PDU Notification Request</td>
<td>Unsupported</td>
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<tr>
<td>7.5.13 PDU Notification Response</td>
<td>Unsupported</td>
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<td>Unsupported</td>
<td></td>
</tr>
<tr>
<td>7.5.14 PDU Notification Reject Request</td>
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<td></td>
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<tr>
<td>7.5.15 PDU Notification Reject Response</td>
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### 7.6 Location Management Messages

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<th>sgsnemu</th>
<th>notes</th>
</tr>
</thead>
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</tr>
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### 7.5 Mobility Management Messages

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<table>
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<td>7.2.2 Echo Response</td>
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<tr>
<td>7.2.3 Versio Not Supported</td>
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<td>7.2.4 Extension Headers Notification</td>
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### 7.3 Tunnel Management Messages

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<th>sgsnemu</th>
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<tr>
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<td>Supported</td>
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<td>7.3.6 Delete PDP Context Response</td>
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<tr>
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<td>7.3.10 PDU Notification Reject Request</td>
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</tbody>
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### 7.4 Location Management Messages

<table>
<thead>
<tr>
<th>Feature</th>
<th>gtplib</th>
<th>osmo-ggsn</th>
<th>sgsnemu</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4.1 Send Routeing Information for GPRS Request</td>
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<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.4.4 Failure Report Response</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.4.5 Note MS GPRS Present Request</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.4.6 Note MS GPRS Present Response</td>
<td>Unsupported</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td></td>
</tr>
</tbody>
</table>

### 7.5 Mobility Management Messages

<table>
<thead>
<tr>
<th>Feature</th>
<th>gtplib</th>
<th>osmo-ggsn</th>
<th>sgsnemu</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5.1 Identification Request</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.2 Identification Response</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.3 SGSN Context Request</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.4 SGSN Context Response</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.5 SGSN Context Acknowledge</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.6 Forward Relocation Request</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.7 Forward Relocation Response</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>7.5.8 Forward Relocation Complete</td>
<td>Unsupported</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
</tr>
</tbody>
</table>
### Notes

1) The "Secondary PDP Context Activation Procedure" is not supported.

## 5 Running OsmoGGSN

The OsmoGGSN executable (`osmo-ggsn`) offers the following command-line arguments:

### 5.1 SYNOPSIS

`osmo-ggsn [-h-V] [-D] [-c CONFIGFILE]`

### 5.2 OPTIONS

- `-h, --help`
  Print a short help message about the supported options

- `-V, --version`
  Print the compile-time version number of the program

- `-D, --daemonize`
  Fork the process as a daemon into background.

- `-c, --config-file CONFIGFILE`
  Specify the file and path name of the configuration file to be used. If none is specified, use `osmo-ggsn.cfg` in the current working directory.

### 5.3 Routing

Operating the OpenGGSN tun device naturally creates a network setup with multiple interfaces. Consider:

- Typical Linux setups prevent forwarding of packets between separate interfaces by default. To let subscribers reach the internet uplink from the tun device, it may be required to enable IP forwarding.

- Having a locally defined address range assigned to the tun device requires either sensible routing for this address range, or that masquerading is enabled to allow your single uplink IP address to "proxy" for the tun.

These are decisions to be made on a network administration level.

In a trivial case where you have a single box serving GPRS to few subscribers on an arbitrary IP address range not known in the larger network, the easiest way to enable GPRS uplink would be to enable IP forwarding and masquerading.

To manually enable IPv4 forwarding and masquerading ad-hoc, you can do:

```
sh -c "echo 1 > /proc/sys/net/ipv4/ip_forward"
iptables -t nat -A POSTROUTING -o '*' -j MASQUERADE
```

(You may want to replace `*` with the network device name, like `-o eth0`)

There are various ways to enable these settings persistently, please refer to your distribution’s documentation — e.g. look for `@net.ipv4.ip_forward=1` in `@/etc/sysctl.d/@`, and [https://wiki.debian.org/iptables](https://wiki.debian.org/iptables) for masquerading.
5.4 Multiple instances

Running multiple instances of osmo-ggsn is possible if all GGSN instances are binding to different local IP addresses and all other interfaces (VTY, OML) are separated using the appropriate configuration options. The IP based interfaces are binding to local host by default. In order to separate the processes, the user has to bind those services to specific but different IP addresses.

The VTY and the control interface can be bound to IP addresses from the loopback address range.

Example: Binding VTY and control interface to a specific ip-address

```
line vty
bind 127.0.0.2
ctrl
bind 127.0.0.2
```

Also make sure to place each instance’s GTP bind on a separate IP address (GTP uses a port number that is fixed in the GTP specifications, so it will not be possible to pick differing ports on the same IP address), like:

```
ggsn ggsn0
gtp bind-ip 127.0.0.2
```

5.5 GTP-U kernel module

**Warning**
As of writing, the kernel module does not support IPv6.

OsmoGGSN has support to use the Linux kernel GTP-U tunnel driver to accelerate the data/user plane while still implementing the control plane (GTP-C) in userspace in OsmoGGSN. The kernel module is included in Linux 4.7.0 and higher. Notably the Debian GNU/Linux distribution has it enabled by default.

In order to use this feature, make sure that your Linux kernel was configured to support it (CONFIG_GTP=m or =y). Furthermore, osmo-ggsn must have been built with ./configure argument --enable-gtp-linux (which requires libgtpnl to be installed).

Load the kernel module with:

```
$ sudo modprobe gtp
```

Then start OsmoGGSN with a configuration file that uses gtpu-mode kernel-gtp.

A full example configuration is in osmo-ggsn-kernel-gtp.cfg.

```
$ sudo osmo-ggsn -c /usr/share/doc/osmo-ggsn/examples/osmo-ggsn-kernel-gtp.cfg
```

Example: APN with kernel-gtp

```
ggsn ggsn0
gtp state-dir /tmp
gtp bind-ip 127.0.0.2
apn internet
gtpu-mode kernel-gtp
tun-device tun4
type-support v4
ip prefix dynamic 172.16.222.0/24
ip dns 0 8.8.8.8
ip dns 1 8.8.4.4
ip ifconfig 172.16.222.0/24
no shutdown
```
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.

**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>
<thead>
<tr>
<th>Pattern</th>
<th>Example</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.B.C.D</td>
<td>127.0.0.1</td>
<td>An IPv4 address</td>
</tr>
<tr>
<td>A.B.C.D/M</td>
<td>192.168.1.0/24</td>
<td>An IPv4 address and mask</td>
</tr>
<tr>
<td>X:X::X:X</td>
<td>::1</td>
<td>An IPv6 address</td>
</tr>
<tr>
<td>X:X::X:X/M</td>
<td>::1/128</td>
<td>An IPv6 address and mask</td>
</tr>
<tr>
<td>TEXT</td>
<td>example01</td>
<td>A single string without any spaces, tabs</td>
</tr>
<tr>
<td>.TEXT</td>
<td>Some information</td>
<td>A line of text</td>
</tr>
<tr>
<td>(OptionA</td>
<td>OptionB</td>
<td>OptionC)</td>
</tr>
<tr>
<td>&lt;0-10&gt;</td>
<td>5</td>
<td>A number from a range</td>
</tr>
</tbody>
</table>
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.

- **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> ?
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
```

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 ?
version    Displays program version
online-help Online help
history    Display the session command history
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
cconnection Subscriber Connections
transaction Transactions
statistics Display network statistics
sms-queue  Display SMSqueue statistics
smpp       SMPP Interface
```

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> s
show   sms   subscriber
```

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
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
```

Type <tab> here.

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
delete
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> sccpp addressbook
show cs7 instance <0-15> sccpp users
show cs7 instance <0-15> sccpp ssn <-0-65535>
show cs7 instance <0-15> sccpp connections
show cs7 instance <0-15> sccpp 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|ms|mmgcp|ho|db|ctrl|smpp|ranap|vlr|uics|bssap|←
    sgs|lglobal|llapd|linp|lmux|lmi|lmib|lms|lctrl|lgtp|lstats|lgsup|loap|lss7|lsccp|lsua ←
    lm3ua|lmgcp|ljibuf|lspro} (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 ascidoc 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
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 NETWORK config node:

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

<table>
<thead>
<tr>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>OsmoMSC(config-net)# list</td>
</tr>
<tr>
<td>help</td>
</tr>
<tr>
<td>list</td>
</tr>
<tr>
<td>write terminal</td>
</tr>
<tr>
<td>write file</td>
</tr>
<tr>
<td>write memory</td>
</tr>
<tr>
<td>write</td>
</tr>
<tr>
<td>show running-config</td>
</tr>
</tbody>
</table>
exit
end
network country code <1-999>
mobile network code <0-999>
short name NAME
long name NAME
ercryption 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 implements 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

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)
This command has no attributes assigned.

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

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

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
OsmoBSC# list with-flags
^ bts <0-255> (activate-all-lchan|deactivate-all-lchan)
^ bts <0-255> trx <0-255> (activate-all-lchan|deactivate-all-lchan)
```
This command enables the expert mode.

This is a hidden command (only shown in the expert mode).

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),
- 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 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**
  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.

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

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

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

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

- **log print file**
  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.

**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

When debugging complex issues it’s handy to be able to reconstruct exact chain of events. This is enabled by using GSMTAP log output where frames sent/received over the air are interspersed with the log lines. It also simplifies the bug handling as users don’t have to provide separate .pcap and .log files anymore - everything will be inside self-contained packet dump.

It’s configured as follows:
OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log gsmtap 192.168.2.3
OsmoBSC(config-log) #

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.

![Wireshark with logs delivered over GSMTAP](image)

Note: the logs are also duplicated to stderr when GSMTAP logging is configured because stderr is the default log target which is initialized automatically. To decrease stderr logging to absolute minimum, you can configure it as follows:

OsmoBSC> enable
OsmoBSC# configure terminal
OsmoBSC(config)# log stderr
OsmoBSC(config-log)# logging level force-all fatal

### 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
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**

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:

```
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.

**Note**

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.

### 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.


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 systemd (https://gerrit.osmocom.org/c/libosmocore/+/22651).

You can configure systemd based logging in two ways:

Example: systemd-journal target with offloaded rendering

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

- raw logging handler, rendering offloaded to systemd.

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.

```bash
# 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

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

- Generic logging handler, rendering is done by libosmocore.
- Disable timestamping, systemd will timestamp every message anyway.
- 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`.

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:
8 Configuring OsmoGGSN

All configuration of OsmoGGSN is performed using the VTY. For more general information on the VTY interface, see Section 6.

8.1 Configuring a virtual GGSN instance

OsmoGGSN can run multiple GGSN instances inside one program/process. Each GGSN instance binds to its own transport-layer GTP IP address and has its own set of APNs and associated IP address pools + tun/gtp devices.

In most usage cases, you will only have a single GGSN instance inside your configuration file, like in below example:

**Example: Single GGSN configuration section**

```
gsn ggsn0
  gtp state-dir /tmp
  gtp bind-ip 127.0.0.6
  apn internet
  gtpu-mode tun
  tun-device tun4
  type-support v4
  ip prefix dynamic 176.16.222.0/24
  ip dns 0 192.168.100.1
  ip dns 1 8.8.8.8
  ip ifconfig 176.16.222.0/24
  no shutdown
```

8.1.1 Creating/Editing a GGSN instance

Creating/Editing a GGSN instance can be done by the following sequence of VTY commands:

```
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# ggsn ggsn0
OsmoGGSN(config-ggsn)#
```

1. Change into privileged mode
2. Enter the interactive configuration mode
3. Create or edit the GGSN instance ggsn0. The name can be any ASCII string, its significance is only to the local user.
4. Your prompt is now in the ggsn config node, where you can configure the properties of this GGSN instance.

**NOTE**

After creating a new GGSN instance, it is in shutdown mode. See Section 8.2.4 to take it out of shutdown, but make sure to configure it fully before taking it out of shutdown.
8.1.2 Configuring a GGSN instance

The following two mandatory configuration statements have to be given for every GGSN instance:

```
OsmoGGSN(config-ggsn)# gtp state-dir /var/lib/ggsn/ggsn0
OsmoGGSN(config-ggsn)# gtp bind-ip 127.0.0.6
```

1. Store the GSN restart state in the specified directory
2. Bind the GGSN instance to the specified local IPv4 address

There are some further configuration statements that can be used at the GGSN node, some examples are given below. For a full list, see the *OsmoGGSN VTY reference manual* [vty-ref-osmoggsn].

```
OsmoGGSN(config-ggsn)# default-apn foobar
```

1. Configure a default APN to be used if the user-requested APN is not found. The named APN must previously be configured

8.1.3 Deleting a GGSN instance

A GGSN instance can be removed like this

**Example: Deleting a GGSN instance**

```
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# no ggsn ggsn0
```

1. Change into privileged mode
2. Enter the interactive configuration mode
3. Delete the GGSN instance

8.1.4 Taking a GGSN instance out of shutdown

**Example: Taking a GGSN instance out of shutdown**

```
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# ggsn ggsn0
OsmoGGSN(config-ggsn)# no shutdown ggsn
```

1. Change into privileged mode
2. Enter the interactive configuration mode
3. Enter the config node of the GGSN instance ggsn0
4. Take the GGSN instance out of shutdown
8.1.5 Shutting a GGSN instance down

If you would like to take a GGSN instance out of service, you can put it into shutdown mode. This will make the entire GGSN unavailable to user traffic and permit you to e.g. reconfigure it before taking it out of shutdown again.

**Example: Shutting down a GGSN instance**

<table>
<thead>
<tr>
<th>Command Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>enable</code></td>
<td>Change into privileged mode</td>
</tr>
<tr>
<td><code>configure terminal</code></td>
<td>Enter the interactive configuration mode</td>
</tr>
<tr>
<td><code>ggsn ggsn0</code></td>
<td>Enter the config node of the GGSN instance ggsn0</td>
</tr>
<tr>
<td><code>shutdown ggsn</code></td>
<td>Shut down the GGSN instance</td>
</tr>
</tbody>
</table>

8.2 Configuring an Access Point Name

An Access Point Name (APN) represents a connection to an external packet data network, such as the public Internet or private corporate networks.

APNs are selected by terminals (MS/UE) when establishing PDP contexts.

Each OsmoGGSN GGSN instance can have any number of APNs configured. Each APN is identified by a string name.

8.2.1 Creating/Editing an APN

**Example: Creating a new APN**

<table>
<thead>
<tr>
<th>Command Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>enable</code></td>
<td>Change into privileged mode</td>
</tr>
<tr>
<td><code>configure terminal</code></td>
<td>Enter the interactive configuration mode</td>
</tr>
<tr>
<td><code>ggsn ggsn0</code></td>
<td>Enter the config node of the GGSN instance ggsn0</td>
</tr>
<tr>
<td><code>apn internet</code></td>
<td>Create or Edit an APN called internet</td>
</tr>
</tbody>
</table>

**NOTE**
The newly-create APN is created in **shutdown** mode. See Section 8.2.4 to take it out of shutdown.
8.2.2 Configuring an APN

Example: Configuring an APN

```bash
OsmoGGSN(config-ggsn-apn)# gtpu-mode tun
OsmoGGSN(config-ggsn-apn)# type-support v4
OsmoGGSN(config-ggsn-apn)# ip prefix dynamic 176.16.222.0/24
OsmoGGSN(config-ggsn-apn)# ip dns 0 192.168.100.1
OsmoGGSN(config-ggsn-apn)# ip dns 1 8.8.8.8
OsmoGGSN(config-ggsn-apn)# ip ifconfig 176.16.222.0/24
```

1. Use the userspace GTP-U handling using a TUN device
2. Support (only) IPv4 Addresses
3. Specify the pool of dynamic IPv4 addresses to be allocated to PDP contexts
4. Specify the primary DNS server to be provided using IPCP/PCO
5. Specify the secondary DNS server to be provided using IPCP/PCO
6. Request OsmoGGSN to configure the `tun4` device network/netmask

**NOTE**

If you use the optional `ip ifconfig` command to set the network device address/mask, OsmoGGSN must run with root or `CAP_NET_ADMIN` support. It might be better to configure related tun devices at system startup and run OsmoGGSN as non-privileged user. See Section 8.3 for more details.

8.2.3 Deleting an APN

An APN configuration can be removed like this

Example: Deleting an APN

```bash
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# ggsn ggsn0
OsmoGGSN(config-ggsn)# no apn internet
```

1. Change into privileged mode
2. Enter the interactive configuration mode
3. Enter the config node of the GGSN instance `ggsn0`
4. Delete the APN `internet`

8.2.4 Taking an APN out of shutdown

In order to bring a deactived APN in `shutdown` state into active operation, use the `no shutdown` command at the APN node as explained in the following example:

Example: Taking an APN out of shutdown

```bash
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# ggsn ggsn0
OsmoGGSN(config-ggsn)# apn internet
OsmoGGSN(config-ggsn-apn)# no shutdown
```
Change into privileged mode

Enter the interactive configuration mode

Enter the config node of the GGSN instance ggsn0

Enter the config node of the APN internet

Take the APN out of shutdown

### 8.2.5 Shutting an APN down

If you would like to take an APN instance out of service, you can put it into shutdown mode. This will make the APN unavailable to user traffic and permit you to e.g. reconfigure it before taking it out of shutdown again.

**Example: Shutting down an APN**

```
OsmoGGSN> enable
OsmoGGSN# configure terminal
OsmoGGSN(config)# ggsn ggsn0
OsmoGGSN(config-ggsn)# apn internet
OsmoGGSN(config-ggsn-apn)# shutdown
```

Change into privileged mode

Enter the interactive configuration mode

Enter the config node of the GGSN instance ggsn0

Enter the config node of the APN internet

Shut down the APN

### 8.3 Configuring for running without root privileges

It’s possible to run OsmoGGSN without root privileges if the tun devices are already configured. The interface creation + configuration must then happen before osmo-ggsn starting up. This can be achieved by means such as

- a custom shell script run as root before starting osmo-ggsn (e.g. as init script)
- systemd .netdev and .network files, if your system is using systemd-networkd (see networkctl status).

#### 8.3.1 Manual TUN device creation / configuration

If you chose to go for custom shell/init scripts, you may use the `ip` program which is the standard tool for network interface configuration on Linux, part of the `iproute2` package. In order to create a tun device, you must call it like this:

**Example: iproute2 command to create a tun device**

```
# ip tuntap add dev apn0 mode tun user username group groupname
```

Where `username` and `groupname` correspond to the User and Group that will have ownership over the device, i.e. the privileges which you intend to run osmo-ggsn under, and `apn0` will be the name of the network device created. After creating the interface, you can configure its addresses using standard means like `ip addr add` or your distribution-specific utilities/tools to match the `ip prefix dynamic config` item, and activate the link, for example:

```
# ip addr add 192.168.7.1/24 dev apn0
# ip link set apn0 up
```
8.3.2 systemd based TUN device creation+configuration

If you want to have systemd take care of creating and configuring a tun device for you, you can use the below example config files.

Example: device config via systemd-networkd using apn0.netdev

```
[NetDev]
Name=apn0
Kind=tun

[Tun]
User=username
Group=username
```

1. The network interface name of the newly-created device
2. The username under which you will run OsmoGGSN
3. The group name under which you will run OsmoGGSN

Example: network settings via systemd-networkd using ggsn.network

```
[Match]
Name=apn0

[Network]
Address=192.168.7.1/24
IPMasquerade=yes
```

1. The network device name, which must match the one in the apn0.netdev unit file above
2. The local IP address configured on the device
3. Requesting systemd to configure IP masquerading for this interface. Depending on your needs, You may not want this if you have proper end-to-end routing set up, and want to have transparent inbound IP access to your GPRS-attached devices.

8.3.3 Config Changes

With the tun device pre-configured in one of the ways outlined above, the main changes in your osmo-ggsn.cfg file are:

- remove ip ifconfig directive,
- make sure that no shutdown is present in the apn section as well as no shutdown ggsn in the ggsn section.

Example: using externally configured tun device apn0 as non-root

```
ggsn ggsn0
gtp state-dir /tmp
gtp bind-ip 127.0.0.6
apn internet
gtpu-mode tun
tun-device apn0
type-support v4
ip prefix dynamic 192.168.7.0/24
ip dns 0 192.168.100.1
ip dns 1 8.8.8.8
no shutdown
default-apn internet
no shutdown ggsn
```
9 Osmocom Control Interface

The VTY interface as described in Section 6 is aimed at human interaction with the respective Osmocom program. Other programs should not use the VTY interface to interact with the Osmocom software, as parsing the textual representation is cumbersome, inefficient, and will break every time the formatting is changed by the Osmocom developers. Instead, the Control Interface was introduced as a programmatic interface that can be used to interact with the respective program.

9.1 Control Interface Protocol

The control interface protocol is a mixture of binary framing with text based payload. The protocol for the control interface is wrapped inside the IPA multiplex header with the stream identifier set to IPAC_PROTO_OSMO (0xEE).

![IPA header for control protocol](image)

Figure 2: IPA header for control protocol

Inside the IPA header is a single byte of extension header with protocol ID 0x00 which indicates the control interface.

![IPA extension header for control protocol](image)

Figure 3: IPA extension header for control protocol

After the concatenation of the two above headers, the plain-text payload message starts. The format of that plain text is illustrated for each operation in the respective message sequence chart in the chapters below.

The fields specified below follow the following meaning:

<id>

A numeric identifier, uniquely identifying this particular operation. Value 0 is not allowed unless it’s a TRAP message. It will be echoed back in any response to a particular request.
<var>
The name of the variable / field affected by the GET / SET / TRAP operation. Which variables/fields are available is
dependent on the specific application under control.
</var>

<val>
The value of the variable / field
</val>

<reason>
A text formatted, human-readable reason why the operation resulted in an error.
</reason>

9.1.1 GET operation

The GET operation is performed by an external application to get a certain value from inside the Osmocom application.

Client

GET <id> <var>

GET REPLY <id> <var> <val>

Control Interface

Figure 4: Control Interface GET operation (successful outcome)

Client

GET <id> <var>

ERROR <id> <reason>

Control Interface

Figure 5: Control Interface GET operation (unsuccessful outcome)

9.1.2 SET operation

The SET operation is performed by an external application to set a value inside the Osmocom application.

Client

SET <id> <var> <val>

SET REPLY <id> <var> <val>

Control Interface

Figure 6: Control Interface SET operation (successful outcome)

Client

SET <id> <var> <val>

ERROR <id> <reason>

Control Interface

Figure 7: Control Interface SET operation (unsuccessful outcome)
9.1.3 TRAP operation

The program can at any time issue a trap. The term is used in the spirit of SNMP.

![Control Interface TRAP operation](image)

9.2 Common variables

There are several variables which are common to all the programs using control interface. They are described in the following table.

<table>
<thead>
<tr>
<th>Name</th>
<th>Access</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>counter.*</td>
<td>RO</td>
<td>Get counter value.</td>
<td></td>
</tr>
<tr>
<td>rate_ctr.*</td>
<td>RO</td>
<td>Get list of rate counter groups.</td>
<td></td>
</tr>
<tr>
<td>rate_ctr.IN.GN.GI.name</td>
<td>RO</td>
<td>Get value for interval IN of rate counter name which belong to group named GN with index GI.</td>
<td></td>
</tr>
</tbody>
</table>

Those read-only variables allow to get value of arbitrary counter using its name.

For example "rate_ctr.per_hour.bsc.0.handover:timeout" is the number of handover timeouts per hour.

Of course for that to work the program in question have to register corresponding counter names and groups using libosmocore functions.

In the example above, "bsc" is the rate counter group name and "0" is its index. It is possible to obtain all the rate counters in a given group by requesting "rate_ctr.per_sec.bsc.*" variable.

The list of available groups can be obtained by requesting "rate_ctr.*" variable.

The rate counter group name have to be prefixed with interval specification which can be any of "per_sec", "per_min", "per_hour", "per_day" or "abs" for absolute value.

The old-style counters available via "counter.*" variables are superseded by "rate_ctr.abs" so its use is discouraged. There might still be some applications not yet converted to rate_ctr.

9.3 Control Interface python examples

In the osmo-python-tests repository, there is an example python script called scripts/osmo_ctrl.py which implements the Osmocom control interface protocol.

You can use this tool either stand-alone to perform control interface operations against an Osmocom program, or you can use it as a reference for developing your own python software talking to the control interface.

Another implementation is in scripts/osmo_rate_ctr2csv.py which will retrieve performance counters for a given Osmocom program and output it in csv format. This can be used to periodically (using systemd timer for example) retrieve data to build KPI and evaluate how it changes over time.
Internally it uses "rate_ctr.*" variable described in Section 9.2 to get the list of counter groups and than request all the counters in each group. Applications interested in individual metrics can request it directly using rate_ctr2csv.py as an example.

9.3.1 Getting rate counters

Example: Use rate_ctr2csv.py to get rate counters from OsmoBSC

```bash
$ ./scripts/osmo_rate_ctr2csv.py --header
Connecting to localhost:4249...
Getting rate counter groups info...
"group","counter","absolute","second","minute","hour","day"
e1inp.0","hdlc:abort","0","0","0","0","0"
e1inp.0","hdlc:bad_fcs","0","0","0","0","0"
e1inp.0","hdlc:overrun","0","0","0","0","0"
e1inp.0","alarm","0","0","0","0","0"
e1inp.0","removed","0","0","0","0","0"
bsc.0","chreq:total","0","0","0","0","0"
bsc.0","chreq:no_channel","0","0","0","0","0"
msc.0","call:active","0","0","0","0","0"
msc.0","call:complete","0","0","0","0","0"
msc.0","call:incomplete","0","0","0","0","0"
```

Completed: 44 counters from 3 groups received.

9.3.2 Setting a value

Example: Use osmo_ctrl.py to set the short network name of OsmoBSC

```bash
$ ./osmo_ctrl.py -d localhost -s short-name 32C3
Got message: SET_REPLY 1 short-name 32C3
```

9.3.3 Getting a value

Example: Use osmo_ctrl.py to get the mnc of OsmoBSC

```bash
$ ./osmo_ctrl.py -d localhost -g mnc
Got message: GET_REPLY 1 mnc 262
```

9.3.4 Listening for traps

You can use osmo_ctrl.py to listen for traps the following way:

Example: Using osmo_ctrl.py to listen for traps:

```bash
$ ./osmo_ctrl.py -d localhost -m
```

- the command will not return and wait for any TRAP messages to arrive

10 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.
10.1 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
```

Configure process to use SCHED RR policy with real time priority 1

10.2 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:

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

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

Or otherwise:

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

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
```

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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
OsmoTRX> cpu-affinity TxLower 0x03
```

- Allow thread named `TxLower` (338635) only on CPU 1
- 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
```

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

11 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](https://www.3gpp.org/ftp/Specs/html-info/48008.htm))

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](https://www.3gpp.org/ftp/Specs/html-info/48058.htm) and [3GPP TS 52.021](https://www.3gpp.org/ftp/Specs/html-info/52021.htm))
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

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
Circuit-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 (milliwait); unit of measurement for signal strength of radio signals

DHCP
Dynamic Host Configuration Protocol ([IETF RFC 2131](https://datatracker.ietf.org/doc/rfc2131/))

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

DSCP
Differentiated Services Code Point ([IETF RFC 2474](https://datatracker.ietf.org/doc/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

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 User 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

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

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

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

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](https://www.itu.int/rec/T-REC-Q.711))

SDCH
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](https://tools.ietf.org/html/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)

SSH
Secure Shell; [IETF RFC 4250](https://tools.ietf.org/html/rfc4250) 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](https://tools.ietf.org/html/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](https://tools.ietf.org/html/rfc793))

TFTP
Trivial File Transfer Protocol; ([IETF RFC 1350](https://tools.ietf.org/html/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

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
# 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 3: TCP/UDP port numbers

<table>
<thead>
<tr>
<th>L4 Protocol</th>
<th>Port Number</th>
<th>Purpose</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDP</td>
<td>2427</td>
<td>MGCP GW</td>
<td>osmo-bsc_mgcp, osmo-mgw</td>
</tr>
<tr>
<td>TCP</td>
<td>2775</td>
<td>SMPP (SMS interface for external programs)</td>
<td>osmo-nitb</td>
</tr>
<tr>
<td>TCP</td>
<td>3002</td>
<td>A-bis/IP OML</td>
<td>osmo-bts, osmo-bsc, osmo-nitb</td>
</tr>
<tr>
<td>TCP</td>
<td>3003</td>
<td>A-bis/IP RSL</td>
<td>osmo-bts, osmo-bsc, osmo-nitb</td>
</tr>
<tr>
<td>TCP</td>
<td>4227</td>
<td>telnet (VTY)</td>
<td>osmo-pcap-client</td>
</tr>
<tr>
<td>TCP</td>
<td>4228</td>
<td>telnet (VTY)</td>
<td>osmo-pcap-server</td>
</tr>
<tr>
<td>TCP</td>
<td>4236</td>
<td>Control Interface</td>
<td>osmo-trx</td>
</tr>
<tr>
<td>TCP</td>
<td>4237</td>
<td>telnet (VTY)</td>
<td>osmo-trx</td>
</tr>
<tr>
<td>TCP</td>
<td>4238</td>
<td>Control Interface</td>
<td>osmo-bts</td>
</tr>
<tr>
<td>TCP</td>
<td>4239</td>
<td>telnet (VTY)</td>
<td>osmo-stp</td>
</tr>
<tr>
<td>TCP</td>
<td>4240</td>
<td>telnet (VTY)</td>
<td>osmo-pcu</td>
</tr>
<tr>
<td>TCP</td>
<td>4241</td>
<td>telnet (VTY)</td>
<td>osmo-bts</td>
</tr>
<tr>
<td>TCP</td>
<td>4242</td>
<td>telnet (VTY)</td>
<td>osmo-nitb, osmo-bsc, cellmgr-ng</td>
</tr>
<tr>
<td>TCP</td>
<td>4243</td>
<td>telnet (VTY)</td>
<td>osmo-bsc_mgcp, osmo-mgw</td>
</tr>
<tr>
<td>TCP</td>
<td>4244</td>
<td>telnet (VTY)</td>
<td>osmo-bsc_nat</td>
</tr>
<tr>
<td>TCP</td>
<td>4245</td>
<td>telnet (VTY)</td>
<td>osmo-sgsn</td>
</tr>
<tr>
<td>TCP</td>
<td>4246</td>
<td>telnet (VTY)</td>
<td>osmo-gbproxy</td>
</tr>
<tr>
<td>TCP</td>
<td>4247</td>
<td>telnet (VTY)</td>
<td>OsmocomBB</td>
</tr>
<tr>
<td>TCP</td>
<td>4249</td>
<td>Control Interface</td>
<td>osmo-nitb, osmo-bsc</td>
</tr>
<tr>
<td>TCP</td>
<td>4250</td>
<td>Control Interface</td>
<td>osmo-bsc_nat</td>
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<td>TCP</td>
<td>4251</td>
<td>Control Interface</td>
<td>osmo-sgsn</td>
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<td>TCP</td>
<td>4252</td>
<td>telnet (VTY)</td>
<td>sysmobts-mgr</td>
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<td>TCP</td>
<td>4253</td>
<td>telnet (VTY)</td>
<td>osmo-gtphub</td>
</tr>
<tr>
<td>TCP</td>
<td>4254</td>
<td>telnet (VTY)</td>
<td>osmo-msc</td>
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<td>TCP</td>
<td>4255</td>
<td>Control Interface</td>
<td>osmo-msc</td>
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<td>TCP</td>
<td>4256</td>
<td>telnet (VTY)</td>
<td>osmo-sip-connector</td>
</tr>
<tr>
<td>TCP</td>
<td>4257</td>
<td>Control Interface</td>
<td>osmo-ggsn, ggsn (OpenGGSN)</td>
</tr>
<tr>
<td>TCP</td>
<td>4258</td>
<td>telnet (VTY)</td>
<td>osmo-hlr</td>
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<tr>
<td>TCP</td>
<td>4259</td>
<td>Control Interface</td>
<td>osmo-hlr</td>
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<td>TCP</td>
<td>4260</td>
<td>telnet (VTY)</td>
<td>osmo-ggsn</td>
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<td>TCP</td>
<td>4261</td>
<td>telnet (VTY)</td>
<td>osmo-hnbgw</td>
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<tr>
<td>TCP</td>
<td>4262</td>
<td>Control Interface</td>
<td>osmo-hnbgw</td>
</tr>
<tr>
<td>TCP</td>
<td>4263</td>
<td>Control Interface</td>
<td>osmo-gbproxy</td>
</tr>
<tr>
<td>TCP</td>
<td>4264</td>
<td>telnet (VTY)</td>
<td>osmo-cbc</td>
</tr>
<tr>
<td>TCP</td>
<td>4265</td>
<td>Control Interface</td>
<td>osmo-cbc</td>
</tr>
<tr>
<td>TCP</td>
<td>4266</td>
<td>D-GSM MS Lookup: mDNS serve</td>
<td>osmo-hlr</td>
</tr>
<tr>
<td>TCP</td>
<td>4267</td>
<td>Control Interface</td>
<td>osmo-mgw</td>
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<tr>
<td>TCP</td>
<td>4268</td>
<td>telnet (VTY)</td>
<td>osmo-uecups</td>
</tr>
<tr>
<td>SCTP</td>
<td>4268</td>
<td>UECUPS</td>
<td>osmo-uecups</td>
</tr>
<tr>
<td>TCP</td>
<td>4269</td>
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<tr>
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<td>telnet (VTY)</td>
<td>osmo-hnodeb</td>
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<td>osmo-upf</td>
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### Table 3: (continued)

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<th>L4 Protocol</th>
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<th>Software</th>
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<td>UDP</td>
<td>4729</td>
<td>GSMTAP</td>
<td>Almost every osmocom project</td>
</tr>
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<td>TCP</td>
<td>5000</td>
<td>A/IP</td>
<td>osmo-bsc, osmo-bsc_nat</td>
</tr>
<tr>
<td>UDP</td>
<td>23000</td>
<td>GPRS-NS over IP default port</td>
<td>osmo-pcu, osmo-sgsn, osmo-gbproxy</td>
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<tr>
<td>TCP</td>
<td>48049</td>
<td>BSC-CBC (CBS) default port</td>
<td>osmo-bsc, osmo-cbc</td>
</tr>
</tbody>
</table>

### B Bibliography / References

#### B.0.0.1 References

[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

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


https://www.3gpp.org/DynaReport/35206.htm

[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


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


[87] [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


[90] [freeswitch_pb] FreeSWITCH SIP PBX https://freeswitch.org

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