sysmocom

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icE1usb User Manual

by Harald Welte

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

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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.

- Jan Luebbe, Stefan Schmidt, Daniel Willmann, Pablo Neira, Nico Golde, Kevin Redon, Ingo Albrecht, Alexander Huemer, Alexander Chemeris, Max Suraev, Tobias Engel, Jacob Erlbeck, Ivan Kluchnikov

May the source be with you!

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

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This version of the manual is endorsed by Harald Welte as the official version of the manual.

While the GFDL license (see Appendix A) permits anyone to create and distribute modified versions of this manual, such modified versions must remove the above endorsement.

2 Preface

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

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

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

2.1 FOSS lives by contribution!

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

If your organization is 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.

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

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Please see Appendix A for further information.

3 Introduction

3.1 Required Skills

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

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

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

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

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

Some of the useful skills we recommend are:

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

3.2 Getting assistance

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

If you don't have a support package / contract, you have the option of using the resources put together by the Osmocom community at 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 icE1usb Hardware

The icE1usb Hardware consists of a single circuit board (in an optional enclosure).

It's main building blocks are:

- an iCE40 FPGA
- Two E1 line interface (transformers, biasing networks and ESD protection) [1]
- a GPS receiver module with 1PPS output to the FPGA [2]

4.1 Schematics

As icE1usb is an OSHW (Open Source Hardware) project, the full schematics and design files are publicly available.

The design files in KiCAD formwa are available at https://git.osmocom.org/osmo-e1-hardware/tree/hardware/icE1usb

PDF rendered schematics are available at https://git.osmocom.org/osmo-e1-hardware/plain/hardware/icE1usb/r1.0/icE1usb.pdf

4.2 Connectors

4.2.1 X5A and X5B: E1 Interface Connectors

On one side of the PCB there are two RJ45 connectors next to each other.

Those are the two E1 line interfaces. The interfaces are of symmetric 120 Ohms type.

Assuming the board is oriented with the tab of the RJ45 connectors facing up:

- Interface 0 is on the right side
- Interface 1 is on the left side (next to the button)

The pin-out of the connectors can be swapped between TE and NT mode using the J4 and J5 jumper blocks on the circuit board.

A GSM BTS typically implements TE pin-out, while the icE1usb should then use NT mode pin-out if no cross-over cable is used.

Table 1: Pin-out of RJ45 E1 connectors

Pin	Function (TE)	Function (NT Mode)
1	Rx	Tx
2	Rx	Tx
3	not used	not used
4	Tx	Rx
5	Tx	Rx
7	not used	not used
8	not used	not used

Note
E1 cables use RJ45 like Ethernet, but Ethernet cables have a different pin-out. Particularly, you cannot use an Ethernet cross-over cable as an E1 cross-over!

[1] Only one E1 line supported by firmware so far
[2] GPS-DO supported by firmware yet

4.2.2 X4: USB Connector

The USB connector is a USB Type C connector. However, it only carries USB 1.1 full-speed signals. 5V DC power is also sourced from this connector.

4.2.3 X2: Serial Console Connector

The serial console is used for development and debugging. It uses an Osmocom-style 2.5mm stereo TRS jack.

The serial console uses 3.3V CMOS logic levels

The serial console uses a rate of 1000000 bps.

The pin-out is as follows:

- Tip: Tx output from PC (Rx input of icE1usb)
- Ring: Rx input of PC (Tx output of icE1usb)
- Shield: GND

A compatible cable can be sourced from the sysmocom web-shop at http://shop.sysmocom.de/.

4.2.4 X1: GPS Antenna Connector

The GPS antenna connector is a female SMA connector.

You can connect most standard active GPS antennas with built-in LNA.

icE1us provide phantom voltage.

The use of a GPS antenna is only required when you need a high precision clock reference for the 2.048 MHz E1 bit clock, e.g. to provide a clock reference to a cellular base station on the A-bis interface.

4.2.5 X3: GPIO / Extension Connector

This is a RJ45 connector adjacent to the USB connector.

It is currently unused and reserved for future use.

4.3 Pushbutton

This is a push-button next to the *E1 interface '1'*. It is recessed to protect against accidental use. You will need to use a paper clip, pen tip or other similar object to push it.

The button can be used to force booting into the DFU loader in order to recover from a broken firmware installation.

4.4 Multi-Color LED

Above the USB-C connector, there is a multi-color RGB LED.

This LED is used by the firmware to indicate a variety of status information. Pleas see the firmware documentation in [firmware].

5 icE1usb Gateware

The icE1usb *gateware* is where pretty much everything happens, from the E1 Line Interface Unit to the E1 Framer/Deframer, the picoRISCV soft-core running the as well as the USB device peripheral talking to the host PC.

As an OSHW project, all of it is available in source code format at https://git.osmocom.org/osmo-e1-hardware/tree/gateware/-icE1usb

Please use `git clone --recursive` when cloning the git repository so you get all of the sub-modules for the various soft-cores.

6 icE1usb Firmware

The icE1usb *firmware* is a small amount of bare-iron software running on the picoRISCV soft-core of the *gateware*.

It mainly consists of drivers for the no2e1 E1 Framer IP core and the no2usb USB Device IP core which are part of the gateware described in Section 5.

6.1 Firmware Upgrade (DFU)

icE1usb contains support for the USB DFU (Device Firmware Upgrade) standard.

As such, you can use any USB DFU compliant utility to upgrade the firmware of the icE1usb device.

DFU mode can be entered in two ways:

1. by performing a DFU detach from the normal application firmware (obviously that requires a [still] working firmware present on the device). To do so, please use `dfu-util -e`
2. by pushing the push-button (see Section 4.3) during power-up. Simply disconnect the USB cable, then push that button and keep it pushed while re-attaching the USB cable.

The icE1usb boot loader enumerates as VID:PID `1d50:6144`, while the normal application firmware enumerates as `1d50:6145`,

You can for example use `lsusb` to check the VID:PID:

```
$ lsusb -d 1d50:
Bus 001 Device 042: ID 1d50:6145❶ OpenMoko, Inc. icE1usb
$ sudo dfu-util -d 1d50:6145 -e ❷
...
$ lsusb -d 1d50:
Bus 001 Device 043: ID 1d50:6144❸ OpenMoko, Inc. icE1usb (DFU)
```

❶ initially the device is in normal runtime mode

❷ we use `dfu-util -e` to switch to DFU mode

❸ we can see, the device is now in DFU mode

6.1.1 Obtaining firmware upgrades

The latest firmware can be found at https://ftp.osmocom.org/binaries/icE1usb/firmware/latest/

The latest gateware can currently only be found at the personal developer directory of tnt at https://people.osmocom.org/tnt/e1/-icE1usb-202010-bd399e96.bin A more official download location for the gateware will be provided shortly.

6.1.2 Upgrading the FPGA gateware

Gateware files are called `icE1usb-*.bin`. (without *fw* in the name)

The gateware can be upgraded by accessing the DFU *altsetting 0* using `dfu-util` **`-a 0`**

Assuming you already are in DFU mode, you would typically use a command like `dfu-util -d 1d50:6144 -a 0 -D icE1usb-202010-bd3999e96.bin -R` to perform the upgrade.

Note

The `-R` will switch the device back to runtime mode after the upgrade. If you want to upgrade the firmware in the same session, skip the `-R` in the above command.

6.1.3 Upgrading the picoRISCV firmware

Firmware files are called `icE1usb-fw*.bin`.

The firmware can be upgraded by accessing the DFU *altsetting 1* using `dfu-util` **`-a 1`**

Assuming you already are in DFU mode, you would typically use a command like `dfu-util -d 1d50:6144 -a 1 -D fw_app-202011-4d9a04e2.bin -R` to perform the upgrade.

Typical output during upgrade of the firmware

```
$ sudo dfu-util -d 1d50:6144 -a 1 -D ./fw_app.bin -R
dfu-util 0.9

Copyright 2005-2009 Weston Schmidt, Harald Welte and OpenMoko Inc.
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This program is Free Software and has ABSOLUTELY NO WARRANTY
Please report bugs to http://sourceforge.net/p/dfu-util/tickets/

dfu-util: Invalid DFU suffix signature
dfu-util: A valid DFU suffix will be required in a future dfu-util release!!!
Opening DFU capable USB device...
ID 1d50:6144
Run-time device DFU version 0101
Claiming USB DFU Interface...
Setting Alternate Setting #1 ...
Determining device status: state = dfuIDLE, status = 0
dfuIDLE, continuing
DFU mode device DFU version 0101
Device returned transfer size 4096
Copying data from PC to DFU device
Download        [=========================] 100%        11256 bytes
Download done.
state(2) = dfuIDLE, status(0) = No error condition is present
Done!
Resetting USB to switch back to runtime mode
```

As the `-R` option was used, the device will reset and re-enumerate in the newly programmed firmware.

You can verify this as follows:

```
$ lsusb -d 1d50:
Bus 001 Device 042: ID 1d50:6145 OpenMoko, Inc. icE1usb
```


or alternatively:

```
$ dfu-util -l -d 1d50:
dfu-util 0.9

Copyright 2005-2009 Weston Schmidt, Harald Welte and OpenMoko Inc.
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Please report bugs to http://sourceforge.net/p/dfu-util/tickets/

Found Runtime: [1d50:6145] ver=0003, devnum=44, cfg=1, intf=1, path="1-2", alt=0, name="DFU ↩
     runtime", serial="dc697407e7881531"
```

6.2 Use of the E1 Interface LEDs

Each E1 interface has two LEDs integrated into the RJ45 connector. They are (starting to get) used by the firmware to indicate status information to the user.

Color	Pattern	Meaning
Green	Blinking (slow)	E1 Receiver attempting to align
Green	On	E1 Receiver fully aligned

6.3 Use of the Multi-Color RGB LED

FIXME: describe how it is used.

7 Host Software

Host Software is software running on the USB host computer to which the icE1usb is attached.

At the time of this writing, the only software implementing icE1usb support is `osmo-e1d`.

7.1 `osmo-e1d`

`osmo-e1d` utilizes `libusb` to talk to the icE1usb hardware and offers a unix domain socket based interface to application software.

Software such as `osmo-bsc` and `osmo-mgw` can interface `osmo-e1d` via the `libosmo-abis` support for `osmo-e1d`.

More information about `osmo-e1d` can be found at its homepage https://osmocom.org/projects/osmo-e1d/wiki

7.2 DAHDI driver

DAHDI (Digium Asterisk Hardware Driver Interface) is an extremely popular driver for a variety of POTS/PSTN and also TDM interface boards by originally Zaptel, later Digium and now most recently Sangoma.

DAHDI is supported by a wide range of open source PBX / softswitch software, including Asterisk, FreeSWITCH and yate.

There is an experimental DAHDI driver for the icE1usb available from the `laforge/icE1usb` branch of the https://github.com/-osmocom/dahdi-linux git repository.

When using that DAHDI Linux kernel driver, there is no need for osmo-e1d. The USB interface is directly managed inside the kernel.

7.3 Other software

you can interface 3rd party applications with osmo-e1d in the following ways:

- by adding support for `osmo-e1d`, e.g. via `libosmo-e1d` to the respective application
- by directly implementing the USB interface exposed by icE1usb in your software

Should you require any related development/porting services, please do not hesitate to reach out to sysmocom.

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