

sysmocom

sysmocom - s.f.m.c. GmbH

sysmolSIM-SJA5 User Manual

by Harald Welte

Copyright © 2016-2024 sysmocom - s.f.m.c. GmbH

All rights reserved.

REVISION HISTORY			
NUMBER	DATE	DESCRIPTION	NAME
v0	May 2023	Initial version for SJA5 v0 samples	hw
v1	August 2023	Updated version for SJA5 v1 (CCC Event)	hw
v2	October 2023	Updated version for SJA5 v2 (first 10k sysmocom branded cards with 9FV chip)	hw
v3	May 2024	Mention that S17 SUCI-on-card supports only uncompressed format for Profile B	hw

Contents

1	Introduction	1
2	History	1
3	About SIM / USIM Cards	2
3.1	SIM Cards	2
3.2	USIM Cards	2
3.3	ISIM Cards	2
3.4	Authentication Algorithms	3
3.4.1	OP or OPc in USIM	3
3.4.2	Shared or application-specific keys	3
3.5	Interoperability SIM/USIM vs. Network vs Phone	4
3.5.1	SIM Card vs. Network Technology 2G/3G/4G/5G	4
3.5.2	SIM Card vs. Phone	4
3.6	Card Form Factors	4
3.6.1	2FF, 3FF, 4FF	5
3.6.2	MFF2	5
3.7	Identities	5
3.7.1	ICCID	5
3.7.2	IMSI	5
3.7.3	MSISDN	6
4	sysmoISIM-SJA5 specifications	6
4.1	Physical Specification	6
4.2	Logical Specification	7
4.2.1	ETSI/3GPP/GP Specification Compliance	7
4.3	Supported Features	8
4.3.1	Authentication Algorithms	8
4.3.2	PIN Data	8
4.3.3	Network Authentication	9
4.3.4	OTA Configuration	9
4.3.5	Subscriber Identities	9
4.4	Product Form-Factor Variants	9
4.5	Java API Packages	10
5	Smart Card Readers	10
5.1	Verifying your smart card reader + software stack	11
5.2	Verifying your smart card reader + software stack	11
5.3	Mechanical Card Adapters	12

6	Testing sysmocom SIM cards with utilities	12
6.1	osmo-auc-gen	13
6.1.1	SYNOPSIS	13
6.1.2	OPTIONS	13
6.1.3	Example	13
6.2	osmo-sim-auth.py	14
6.2.1	SYNOPSIS	14
6.2.2	OPTIONS	14
6.2.3	Example	15
6.2.4	Re-Synchronization	15
7	Provisioning of different identities or keys	15
7.1	pySim-prog.py	16
7.1.1	Example	16
7.1.2	Error Codes	16
7.2	sysmo-isim-tool	16
7.2.1	OPC value	17
7.2.2	Ki value	17
7.2.3	ICCID value	18
7.2.4	Authentication Algorithms	18
7.2.5	Milenage parameters (Ci/Ri)	18
7.2.6	Enable / Disable USIM Application	19
	USIM record in EF.DIR	19
	Disabling the USIM application	20
7.2.7	APDU trace	21
8	Disabling / Enabling SQN verification	21
8.1	pySim-shell.py	22
9	USIM cards and 5G	23
9.1	Disabling DF_5GS files and services	24
10	USIM/ISIM cards and IMS	25
10.1	Disabling the ISIM functionality	25
10.1.1	Deactivating IMS files + services from ADF.USIM	25
10.1.2	Locking the ISIM application	26
11	Java Card Features	26
11.1	Application List	26
11.2	Example Applet	27
11.3	Installation via 03.48 OTA	27
11.4	Installation via GlobalPlatform SCP02	27

12 OTA (Over The Air) 28

12.1 Transports 28

12.2 TAR (Toolkit Application Reference) 28

12.3 MSL (Minimum Security Level) 28

13 sysmoISIM-SJA5 changelog 28

13.1 Major new features in sysmoISIM-SJA5 vs sysmoISIM-SJA2 29

13.2 sysmoISIM-SJA5 v0 samples (May 2023) 29

13.2.1 Errata: Re-create larger EF.USIM_AUTH_KEY for TUAK support 29

13.3 sysmoISIM-SJA5 v1 (August 2023) 29

13.4 sysmoISIM-SJA5 v2 (October 2023) 30

14 Acknowledgements 30

15 Glossary 30

A Osmocom TCP/UDP Port Numbers 39

B Bibliography / References 40

References 40

1 Introduction

This manual describes the sysmoISIM-SJA5 state-of-the-art Java SIM/USIM/ISIM cards for authentication in cellular networks. The target audience are operators of cellular networks (large and small) who use the sysmoISIM-SJA5 in order to identify the subscribers to their network.

As an operator of a cellular network, having significant knowledge about SIM/USIM/ISIM card operation and configuration is a key aspect of running a secure and safe cellular network.

A specific emphasis is given to cellular networks running on the Osmocom CN1 and open5gs protocol stack, as this is what the sysmoISIM-SJA5 was specifically introduced for, and why sysmocom is selling it. However, there is nothing restricting the cards to use in networks based on Osmocom software.

Please note however, that unless you have a specific support contract with sysmocom on said configuration, sysmocom will not be able to help you with questions regarding the use of sysmoISIM-SJA5, particularly configurations not described in this manual.

2 History

When the Open Source GSM network-side protocol stack implementation OpenBSC started in 2009, it created a new opportunity for interested individuals and organizations to operate small-scale private or public, local or regional cellular networks without the dependency to the classic vendors of cellular technology.

If you want to run such a network without security, you can technically do that with pretty much any SIM card of any other operator (though their contract terms might not permit that legally).

Once you want to use cryptographic authentication and/or encryption in such networks, you need to issue your own SIM cards.

Traditional suppliers of SIM cards only sell to commercial public GSM operators and deal in quantities millions or at least hundreds of thousands. Individual SIM cards might be available for R&D and testing, but they are super expensive.

Also, cards from the classic suppliers are pre-provisioned to a given operator profile at manufacturing time, and do not provide the customer to re-program them later.

To solve the problem, sysmocom started to sell a series of SIM cards since 2011. Those cards are

- sold in small quantities
- provided with the card-individual pre-programmed identities and keys
- customer-reprogrammable, i.e. the sysmocom customer can change IMSI, MSISDN, ICCID and keys of the card as needed

For the first couple of years, the sysmoSIM-GR1 and later sysmoSIM-GR2 were sold. Those cards are not documented here as they have no longer been for sale for quite some time.

In 2014, sysmocom introduced the sysmoUSIM-SJS1. Contrary to its SIM-only predecessors, this card was the first sysmocom USIM, which prepared them for use in 3G networks, offering mutual authentication as part of UMTS AKA.

Furthermore, the sysmoUSIM-SJS1 was the first Java SIM card available from sysmocom, enabling the users to develop and run their own Java card applets, to use remote file management to update the SIM card files, etc.

In 2020, sysmocom introduced the sysmoISIM-SJA2. The migration to this new card model was mandated by end-of-life of both the chip and the operating system used in the sysmoUSIM-SJS1. The new sysmoISIM-SJA2 has is an almost feature-complete successor. In addition, it adds an ISIM (IMS/VoLTE) and HPSIM application.

In 2023, sysmocom introduced the sysmoISIM-SJA5. Like before, the migration to a new CardOS and chip was mandated by the end-of-life status of what was used in the previous sysmoISIM-SJA2. The new SJA5 product contains a card profile with GSM-R support and updated to all files of 3GPP Release 17.

All the above features make the cards ideal for the following user groups:

- users of small-scale local or regional cellular networks, whether GSM, GPRS, EDGE, UMTS, HSPA, LTE or 5G. This includes OpenBTS, OsmoBTS, OpenBSC, OsmoSGSN, YateBTS, srsLTE, nextepc, open5gs, free5gc and many other Free Software implementations, but also includes proprietary implementations such as Amarisoft

- researchers using small-scale private networks for security analysis of mobile phones
- researchers and developers interested in SIM card related security issues, particularly in terms of STK and OTA

3 About SIM / USIM Cards

The SIM (Subscriber Identity Module) contains the cryptographic identity of a subscriber in a cellular network.

3.1 SIM Cards

The GSM (2G) network first introduced the SIM and specified its properties in ETSI TS 11.11. Later 2G extensions like GPRS and EDGE/EGPRS used the same SIM to authenticate the subscriber to the network.

Next to the cryptographic subscriber identity, SIM cards can also store a variety of other configuration parameters as well as user data, such as:

- the operator name
- the MSISDN of the subscriber
- received and sent SMSs
- phone book data
- parameters related to SMS (SMSC, ...)
- the most recently used cell ARFCN
- the most recently negotiated TMSI and Kc

sysmocom has been selling various types of SIM cards over the years, specifically the sysmoSIM-GR1 and sysmoSIM-GR2 cards, in all the different form factors

3.2 USIM Cards

The UMTS (3G) networks introduced the *USIM Application* which runs on top of an ETSI UICC. The *USIM Application* covers the UMTS specific parts, while the ETSI UICC covers general aspects of chip cards, irrespective of their specific application.

A USIM implements the functions required by UMTS Authentication and Key Agreement. The particular differentiators compared to the SIM are:

- mutual authentication, i.e. the USIM also authenticates the network
- replay protection by introduction of a sequence number

Most USIMs also implement the SIM card protocol for backwards compatibility, so they can be used in older GSM-only phones.

3.3 ISIM Cards

The IMS (IP Multimedia System, required for VoLTE) introduced the *ISIM Application* which runs on top of an ETSI UICC, typically in parallel to the USIM Application.

While IMS/VoLTE can be operated on a legacy USIM without an ISIM application, many related parameters can only be configured with an on-card ISIM application.

NOTE

Many UE/phone manufacturers implement additional constraints/restrictions on when to enable IMS/VoLTE functionality. The presence of an ISIM application on the card may not be sufficient to unlocking VoLTE capabilities.

3.4 Authentication Algorithms

A GSM network can support any authentication algorithm, as long as that algorithm is implemented in the (U)SIM and the AUC. As those are both controlled by the home operator of the subscriber, the operator can freely choose any algorithm for authentication.

In practise, not every operator has both the cryptographic expertise and a market power significant enough to have SIM manufacturers implement their algorithm.

So a set of algorithms was designed by the GSMA, and subsequently used by many operators in their networks: the COMP128 family.

There are three version of COMP128: v1, v2 and v3. Only v3 is considered reasonably secure, while COMP128v1 has been publicly demonstrated to be broken already in 1997.

The sysmoISIM-SJA5 supports the full set of COMP128v1, COMP128v2 and COMP128v3 algorithms. In addition, it supports the XOR-2G algorithm (Annex 4 (A.4.1.2) of 3GPP TS 51.010-1) for testing purpose.

In USIMs, the situation is similar in that only the USIM and the AUC need to know the algorithm, and thus an operator can implement and deploy whatever they want.

However, in practice most networks seem to utilize the MILENAGE algorithm.

The sysmoISIM-SJA5 implements the MILENAGE and TUAK algorithms. In addition, the XOR-3G algorithm (3GPP TS 34.108) is supported for testing purpose.

3.4.1 OP or OPc in USIM

The OP value is the Operator Variant Algorithm Configuration field, which was included to provide separation between the functionality of the algorithms when used by different operators. It is left to each operator to select a value of OP.

The algorithm set is designed to be secure whether or not OP is publicly known; however, operators may see some advantage in keeping their value of OP secret as a secret OP is one more hurdle in an attacker's path.

The USIM can be configured to either store an OP value, or an OPc value. OPc is computed by XOR of OP and EK(OP).

So the operator and card-issuer has the choice to either:

- use one OP value all across his network, and store that value on each card, or
- pre-compute a card-specific OPc value, and store that individual OPc on each card

The latter choice (OPc on card) is generally considered more secure, as the reverse engineering of one OPc does not reveal any security parameters relevant beyond that single card.

The sysmoISIM-SJA5 supports storing either the card-individual OPc as well as the global OP value and thus gives maximum flexibility to the user.

For more details on OP and OPc as well as the rationale for preferring OPc storage on the card, see Section 5.1 of 3GPP TS 35.206 [3gpp-ts-35-206] as well as Section 8.3 of 3GPP TS 35.205 [3gpp-ts-35-205].

In case TUAK is used, those values are officially referred-to as TOP and TOPc, where TOP corresponds to OP and TOPC corresponds to TOPc.

Milenage OP/OPc is 128 bits in size, while TUAK TOP/TOPc is 256 bits in size.

3.4.2 Shared or application-specific keys

Card with multiple applications, such as the sysmoISIM-SJA5 containing SIM, USIM and ISIM applications can either

- use *shared keys* for all of those applications, meaning that one set of K and OP/OPc is used for authentication to any of those applications, or

- use *separate keys* for each of those applications. This would permit separate K and OP/OPc values for each application, e.g. different keys for authentication of USIM against the radio network and ISIM against the IMS network

In order to ensure more flexibility, sysmoISIM-SJA5 use *separate keys*.

In order to avoid frequent mis-configuration, `sysmo-isim-tool.sja5.py` as described in Section 7.2 will write the identical key to all of the applications. If you actually need separate keys, you would have to write the keys using custom software or modify the existing open source tools.

3.5 Interoperability SIM/USIM vs. Network vs Phone

There are several permutations between GERAN-only, GERAN/UTRAN or UTRAN-only phones, classic GSM SIM, USIM-only and combined USIM/SIM cards as well as the respective UTRAN/GERAN networks and the associated AUCs.

The following paragraphs are intended to shed some light on the respective interoperability.

3.5.1 SIM Card vs. Network Technology 2G/3G/4G/5G

Depending on operator configuration, a classic GSM SIM card may also be used on a UMTS UTRAN network. The authentication then is of course only one-way and not mutual. Also, the generated encryption and integrity keys are generated from the expanded shorter GSM keys, and thus considered less strong.

An USIM can always be used over a GSM/GERAN network. If the phone supports the USIM protocol, it will be able to use USIM AKA even over a GERAN network (if permitted/enabled by the network). If the phone only supports the classic SIM protocol, the SIM application on the card will be used.

LTE / EUTRAN always requires at least an USIM. Classic SIM are not sufficient for authentication on LTE/EUTRAN.

5G / NR also requires at least an USIM. However, certain additional features like SUCI require SIM card support. The sysmoISIM-SJA5 supports "SUCI calculation by ME" using ADF.USIM/EF.SUCI_Calc_Info as per 3GPP TS 31.102 Section 5.3.47.

only in its S17 chip variant, the sysmoISIM-SJA5 also supports "SUCI Calculation by USIM" as per section 5.3.48. If this is enabled (via service 125 of ADF.USIM/EF.UST), the related key material is stored in ADF.USIM/DF.SAIP/EF.SUCI_Calc_Info.

NOTE

The *SUCI Calculation by USIM* in the S17 chip variant **only supports the uncompressed format** for Protection scheme profile B!

3.5.2 SIM Card vs. Phone

A UMTS/UTRAN capable phone will first try to use the inserted SIM in USIM protocol. If that is not available, it will fall back to use the classic GSM SIM card protocol.

A GSM-only phone will inter-operate only with USIM cards which feature the backwards-compatible GSM SIM card protocol.

The sysmoISIM-SJA5 support both GSM as well as USIM mode, and are pre-provisioned in a way that both modes are available.

3.6 Card Form Factors

The original SIM cards for (portable, not hand-held!) GSM phones was credit-card sized.

3.6.1 2FF, 3FF, 4FF

Later on, the plug-in (2FF), micro (3FF) and nano (4FF) form-factors have been specified as the microelectronic integration progressed and phones became smaller and smaller.

All the above-mentioned form-factors are removable plastic cards with contacts and embedded SIM card chip.

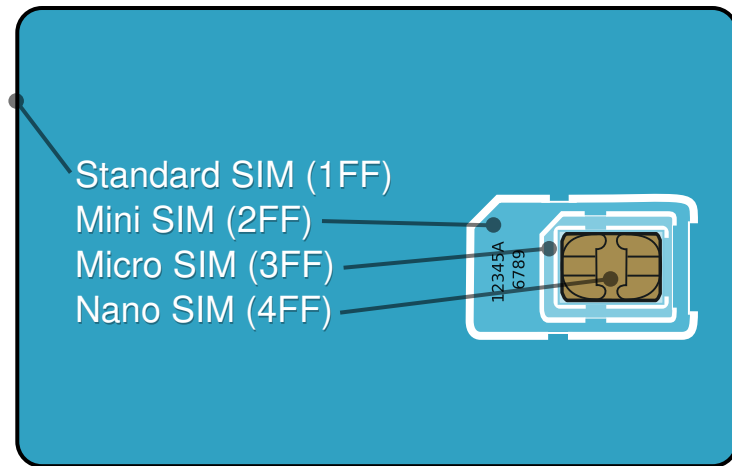


Figure 1: Card Form Factors by Cvdr based on Justin Ormont's work. CC BY-SA 3.0, via Wikimedia Commons

The sysmoISIM-SJA5 cards are made available in an "all-in-one" form-factor that covers the full credit-card size, 2FF, 3FF and 4FF form-factors in a single product.

3.6.2 MFF2

Furthermore, ETSI also specified the so called MFF2 form factor, which is a solder-type form-factor, meaning that the SIM is soldered to the circuit board like any other surface-mounted integrated circuit and hence no longer user swappable/removable.

The sysmoISIM-SJA5 is also available in MFF2 package.

3.7 Identities

There are several identities associated with the use of SIM cards.

3.7.1 ICCID

The ICCID (Integrated Circuit Card Identifier) is a [supposedly] globally unique serial number of chip cards. It is specified by ITU-T in ITU-T recommendation E.118. Its layout is based on ISO/IEC 7812.

It can be up to 22 digits long, including the Luhn check digit.

The ICCID is never transmitted over the radio interface and hence doesn't really play a relevant role in terms of operating a private cellular network.

3.7.2 IMSI

The IMSI (International Mobile Subscriber Identifier) is a [supposedly] globally unique number of the subscriber of 3GPP network technology. The number must be unique in public networks, but not necessarily so in private networks.

The first 5-6 digits of the IMSI are typically comprised by the MCC (Mobile Country Code) and MNC (Mobile Network Code).

The MCC specifies the country, and the MNC the card-issuing network within the country.

MNCs are assigned by the respective national telecommunications regulatory authority. The policies differ from country to country, but typically you have to be a licensed mobile network operator (with your own spectrum allocation) in order to receive a MCC allocation and hence be able to issue your own IMSIs within your MCC-MNC.

As sysmocom is not a telecom operator but just a R&D and equipment manufacturing company, we do not have our own MCC/IMSI allocations - neither can we get one.

The default IMSIs provisioned on the sysmoUSIM / sysmoISIM cards are within the MCC-MNC of

- **901-70** (until August 2021), where 901 is a trans-national country code, used for applications that span beyond one country but which are not of global scope. 901-70 used to be allocated but was abandoned/unused for a long time, which is why sysmocom started to use it as the default code on the sysmoUSIM / sysmoISIM products. Unfortunately, meanwhile ITU re-assigned 901-70 to an operator (Clementvale Baltic OY). This means there may be overlaps, and we strongly recommend to change the MCC-MNC and hence IMSI of the cards you use in your networks to a different one. It's best to follow the recommendations of the respective regulatory authority in your jurisdiction.
- **999-70** (from September 2021), where 999 is a newly-allocated trans-national MCC allocated by ITU for private cellular networks. The IMSI allocations within MNCs under MCC 999 are not coordinated or registered, so there is no guarantee that they are globally unique. However, sysmocom will not issue IMSIs multiple times, so if you use only sysmocom cards, you are guaranteed no duplicated within those cards.

3.7.3 MSISDN

The MSISDN (Mobile Subscriber ISDN Number) is the phone number allocated to a subscriber within the global numbering plan for telephony as per ITU-T recommendation E.164.

The MSISDN can optionally be stored on the SIM card, but in reality this is not required for operation of a cellular network: Only the core network elements (particularly the MSC or the IMS core) need to know which MSISDN can be reached behind which IMSI. The phone itself doesn't need to know its own MSISDN to receive or originate calls.

4 sysmoISIM-SJA5 specifications



Figure 2: sysmoISIM-SJA5

The sysmoISIM-SJA5 are Java SIM card with the following specifications and features:

4.1 Physical Specification

- Available mechanical form factor
 - 2FF + 3FF + 4FF seamless triple cut (either full-size or half-size plastic)

- MFF2 (solder-type) chip
- 480 kBytes flash memory
 - 100.000 write cycles
- Temperature Range: -25 to +85 Centigrade chip temperature

4.2 Logical Specification

4.2.1 ETSI/3GPP/GP Specification Compliance

The sysmoISIM-SJA5 adheres to the following specifications / spec versions:

- Combined SIM and USIM application
 - ETSI TS 102 221; [\[etsi-ts102221\]](#)
 - ETSI TS 102 225; [\[?\]](#)
 - 3GPP TS 51.011 (R17); [\[3gpp-ts-51-011\]](#)
 - 3GPP TS 31.101 (R17); [\[3gpp-ts-31-101\]](#)
 - 3GPP TS 31.102 (R17); [\[3gpp-ts-31-102\]](#)
 - 3GPP TS 31.103 (R17); [\[3gpp-ts-31-103\]](#)
- Java Card v3.0.4
 - SIM API (3GPP TS 43.019)
 - UICC API (ETSI TS 102 241)
 - UICC Remote File Update Event (ETSI TS 102 241)
 - USIM API (3GPP TS 31.130)
 - GlobalPlatform API
 - Connection API (ETSI TS 102 267)
 - Algorithms: DES/2DES/3DES, AES128/192/256, CRC16/32, SHA1/224/256, MD5, HMAC
- Global Platform v2.1.1 (SCP02, SCP80)
 - SCP81 Support (JavaCard v2.2)
- Sim Toolkit Support
 - 3GPP TS 51.014 (R4); [\[3gpp-ts-51-014\]](#)
 - 3GPP TS 31.111 (R6); [\[3gpp-ts-31-111\]](#)
- OTA (Over-The-Air) Support
- Remote File Management / Remote App Management
 - 3GPP TS 23.048 (R4); [\[3gpp-ts-23-048\]](#)
 - 3GPP TS 31.115 (R6); [\[3gpp-ts-31-115\]](#)
 - 3GPP TS 31.116 (R6); [\[3gpp-ts-31-116\]](#)

4.3 Supported Features

- Total number of logical channels: 4
- Maximum number of applets: 40
- Maximum number of user packages: 40
- Suspend and Resume
- BER-TLV files
- GBA network authentication
- EAP-SIM and EAP-AKA (no support for RFC5448 EAP-AKA')
- SUCI-computation-by-ME
- SUCI-computation-on-card: **Supported in S17 variant only**
- RAM (Remote Applet Management) + RFM (Remote File Management)
 - Proactive Commands
 - Expanded Format
 - Script chaining
 - Concatenated response
 - CAT-TP
 - HTTPS
 - TLS 1.0, 1.1 and 1.2

4.3.1 Authentication Algorithms

- 2G (GSM) Authentication
 - Supported: COMP128v1, COMP128v2, COMP128v3, MILENAGE, XOR-2G
 - Default 2G Authentication Algorithm: MILENAGE [\[3gpp-ts-35-206\]](#)
- 3G (UMTS AKA) Authentication, also used by 4G/5G/IMS
 - Default 3G Authentication Algorithm: MILENAGE [\[3gpp-ts-35-206\]](#)
 - Supported: MILENAGE, TUAK, XOR-3G

The algorithm can be changed when authenticated using ADM1 PIN.

4.3.2 PIN Data

Each card has card-unique PINs pre-provisioned.

Code	Enabled	Length	Max Attempts
PIN1	No	4 digits	3
PIN2	Yes	4 digits	3
ADM1	Yes	8 bytes	3
PUK1	Yes	8 bytes	10
PUK2	Yes	8 bytes	10

4.3.3 Network Authentication

The standard sysmoISIM-SJA5 are configured as follows when shipping:

- K (3G) == Ki (2G): card-individual 16 bytes
- OPc (3G): card-individual 16 bytes

A user authenticated via ADM1 pin can change this at any later point in time. In case of switching to TUAK, keep in mind the K value can be 16..32 bytes in length while the OPc value must be 32 bytes.

NOTE

The cards are provided with card-individual OPc value. Sometimes operators chose to have a globally shared OP value, and OPc computed from OP+K. This is **not** what sysmocom provides with the cards by default. See Section 3.4.1 for more details.

4.3.4 OTA Configuration

The following card-unique OTA keys are configured:

Code	Length	Key set
KIc	16 bytes	1, 2, 3
KID	16 bytes	1, 2, 3
KIK	16 bytes	1, 2, 3

4.3.5 Subscriber Identities

The following subscriber identities are pre-programmed into the sysmoISIM-SJA5, unless the customer has specified different provisioning data at time of purchase (or changed the values after purchase):

Identity	Value
IMSI	99970xxxxxxxxxx
ACC	equal distribution
ICCID	8988211xxxxxxxxxx
MSISDN	88211xxxxxx

4.4 Product Form-Factor Variants

The cards are sold by sysmocom in the following different product variants, depending on your needs.

SKU	Form-Factor	SUCI-on-card	Link to sysmocom webshop
sysmoISIM-SJA5-9FV	1FF + 2FF + 3FF + 4FF	no	https://shop.sysmocom.de/sysmoISIM-SJA5-SIM-USIM-ISIM-Card-10-pack-with-ADM-keys/sysmoISIM-SJA5-9FV-10p-adm
sysmoISIM-SJA5-S17	1FF + 2FF + 3FF + 4FF	yes	bulk / made-to-order only
sysmoISIM-SJA5-9FV-MFF2	MFF2	no	bulk / made-to-order only
sysmoISIM-SJA5-S17-MFF2	MFF2	yes	bulk / made-to-order only

4.5 Java API Packages

Package	Version	AID
java.lang	1.0	0xA0000000620001
javacard.framework	1.5	0xA0000000620101
javacard.security	1.5	0xA0000000620102
javacardx.crypto	1.5	0xA0000000620201
javacardx.framework.util	1.0	0xA000000062020801
javacardx.framework.util.intx	1.0	0xA00000006202080101
java.io	1.0	0xA0000000620002
java.rmi	1.0	0xA0000000620003
javacard.framework.service	1.0	0xA000000062010101
org.globalplatform	1.6	0xA00000015100
uicc.access	1.2	0xA0000000090005FFFFFFFFF8911000000
uicc.toolkit	1.12	0xA0000000090005FFFFFFFFF8912000000
uicc.system	1.2	0xA0000000090005FFFFFFFFF8913000000
uicc.suspendresume	1.0	0xA0000000090005FFFFFFFFF8917000000
uicc.access.fileadministration	1.0	0xA0000000090005FFFFFFFFF8911010000
uicc.usim.access	1.4	0xA0000000871005FFFFFFFFF891310000
uicc.usim.toolkit	1.9	0xA0000000871005FFFFFFFFF8913200000
uicc.usim.suci	1.0	0xA0000000871005FFFFFFFFF8913400000
sim.access	2.2	0xA0000000090003FFFFFFFFF8910710001
sim.toolkit	2.6	0xA0000000090003FFFFFFFFF8910710002
uicc.connection	2.0	0xA0000000090005FFFFFFFFF8915000000

5 Smart Card Readers

SIM/UICC/USIM/ISIM cards are smart cards compliant to the electrical parameters of ISO 7816-3, both in terms of voltage but also in terms of signal / timing. This is the same standard as used by many other smart cards, including all kinds of identification cards, debit/credit cards, cryptographic smart cards, etc.

In order to interface a SIM/UICC/USIM/ISIM to a computer, you thus need a smart card interface device (colloquially called "card reader") compliant to ISO 7816-3.

In order to support maximum compatibility with software programs, the reader should inter-operate with the pcsc-lite software stack on your GNU/Linux based operating system.

The easiest type of readers in recent years have proven to be USB attached smart card readers compliant to the USB CCID specification.

Compliance to USB CCID ensures that a variety of vendor-neutral/independent drivers will work on virtually any operating system.

sysmocom offers suitable USB CCID compliant card readers at <https://shop.sysmocom.de/SIM/Card-Readers-Writers/>



Figure 3: Omnikey CardMan 3121 USB CCID Smart Card Reader

5.1 Verifying your smart card reader + software stack

For details on how to configure your smart card reader / driver stack, please consult related documentation. In the case of USB CCID readers and `pcsc-lite`, any modern GNU/Linux distribution should have everything pre-configured without any manual intervention required.

In case of Ubuntu or Debian GNU/Linux, you only need to install the `pcscd` and `libccid` packages, e.g. using **`apt-get install pcscd libccid`**

5.2 Verifying your smart card reader + software stack

Every smart card returns a so-called ATR (Answer-To-Reset) as soon as it is first interrogated by the card reader.

You can use the **`pcsc_scan`** utility in order to read the status of your card reader and obtain the ATR of the currently-inserted card.

Example output of `pcsc_scan` with a `sysmoUSIM-SJS1` inserted

```
$ pcsc_scan
PC/SC device scanner
V 1.4.26 (c) 2001-2011, Ludovic Rousseau <ludovic.rousseau@free.fr>
Compiled with PC/SC lite version: 1.8.15
Using reader plug'n play mechanism
Scanning present readers...
0: Alcor Micro AU9560 00 00

Sat May 21 21:38:31 2016
Reader 0: Alcor Micro AU9560 00 00
  Card state: Card inserted,
  ATR: 3B 9F 96 80 1F C7 80 31 A0 73 BE 21 13 67 43 20 07 18 00 00 01 A5
ATR: 3B 9F 96 80 1F C7 80 31 A0 73 BE 21 13 67 43 20 07 18 00 00 01 A5
+ TS = 3B --> Direct Convention
+ T0 = 9F, Y(1): 1001, K: 15 (historical bytes)
  TA(1) = 96 --> Fi=512, Di=32, 16 cycles/ETU
    250000 bits/s at 4 MHz, fMax for Fi = 5 MHz => 312500 bits/s
  TD(1) = 80 --> Y(i+1) = 1000, Protocol T = 0
---
  TD(2) = 1F --> Y(i+1) = 0001, Protocol T = 15 - Global interface bytes following
---
```



```

TA(3) = C7 --> Clock stop: no preference - Class accepted by the card: (3G) A 5V B 3V C ←
1.8V
+ Historical bytes: 80 31 A0 73 BE 21 13 67 43 20 07 18 00 00 01
Category indicator byte: 80 (compact TLV data object)
Tag: 3, len: 1 (card service data byte)
Card service data byte: A0
- Application selection: by full DF name
- BER-TLV data objects available in EF.DIR
- EF.DIR and EF.ATR access services: by GET RECORD(s) command
- Card with MF
Tag: 7, len: 3 (card capabilities)
Selection methods: BE
- DF selection by full DF name
- DF selection by path
- DF selection by file identifier
- Implicit DF selection
- Short EF identifier supported
- Record number supported
Data coding byte: 21
- Behaviour of write functions: proprietary
- Value 'FF' for the first byte of BER-TLV tag fields: invalid
- Data unit in quartets: 2
Command chaining, length fields and logical channels: 13
- Logical channel number assignment: by the card
- Maximum number of logical channels: 4
Tag: 6, len: 7 (pre-issuing data)
Data: 43 20 07 18 00 00 01
+ TCK = A5 (correct checksum)

Possibly identified card (using /home/laforge/.cache/smartcard_list.txt):
3B 9F 96 80 1F C7 80 31 A0 73 BE 21 13 67 43 20 07 18 00 00 01 A5
sysmoUSIM-SJS1 (Telecommunication)
http://www.sysmocom.de/products/sysmousim-sjs1-sim-usim

```

5.3 Mechanical Card Adapters

Smart card readers most often only are available for insertion of full-size (credit-card sized) smart cards.

Thus, you may need a mechanical adapter that converts the physical size of your SIM card to the full-sized card as supported by the smart card reader. The adapter is not required, if your SIM is still in full size (credit card size), but generally required if the card is already broken out and now has the 2FF, 3FF or 4FF form-factor

sysmocom offers a suitable low-cost, reliable adapter at <https://shop.sysmocom.de/Professional-SIM-card-adapter-plug-in-micro-nano-SIM-to-full-size/sim-adapter-pcb>

We also sell a number of other adapters suitable for different use cases, for example for interfacing

- MFF2-packaged UICC / eUICC with a card reader (solder type)
- MFF2-packaged UICC / eUICC with a card reader (ZIF socket type)
- half-sized cards with card readers whose slot is deeper than the card
- Flex-PCB (FPC) adapters to use MFF2 or full-sized cards in 2FF/3FF/4FF slots

The full range of adapter products is available from <https://shop.sysmocom.de/SIM/Adapters/>

6 Testing sysmocom SIM cards with utilities

There are some utilities that can be used to test the sysmocom SIM cards cards.

6.1 osmo-auc-gen

The **osmo-auc-gen** utility can be used to generate authentication triplets (GSM) or quintuples (UMTS AKA) from the secret key. It replicates the core operation that usually happens in the AUC component of the cellular network.

In order to use the tool to generate authentication triplets / quintuples, you need

- the secret key data (K, OPc) associated with the respective card for which the triplets / quintuples are to be generated
- the authentication algorithm to be used
- the osmo-auc-gen utility, part of <https://gitea.osmocom.org/osmocom/libosmocore>

6.1.1 SYNOPSIS

osmo-auc-gen [-2|-3] [-a comp128v1|comp128v2|comp128v3|mileneage] -k *KEY* -o *OPC* [-r *RAND*] [-f *AMF*] [-s *SQN*] [-A *AUTS*]

6.1.2 OPTIONS

-2

Use 2G (GSM) Authentication

-3

Use 3G (UMTS) Authentication

-a comp128v1|comp128v2|comp128v3|mileneage

Specify the algorithm to use for computing the authentication data

-k KEY

Specify the secret key (Ki in case of GSM, K in case of UMTS) as 16 hex-encoded bytes

-o OPC

Specify the secret OPC value (in case of UMTS AKA) as 16 hex-encoded bytes

-r RAND

Optionally specify the random challenge as 16 hex-encoded bytes. If none is specified, a weak pseudo-random value is used. Don't use this in practise.

-f AMF

Optionally specify the AMF value for UMTS AKA

-s SQN

Specify the UMTS AKA sequence number as integer. 0 is used as default.

-A AUTS

Specify the UMTS AKA re-synchronization value AUTS, as received from the card

6.1.3 Example

The below example shows an **osmo-auc-gen** invocation using the given values for K, OPC and RAND.

```
$ osmo-auc-gen -3 -a mileneage -k 1D8B2562B992549F20D0F42113EAA6FB -o 398153093661279 ↵
    FB1FC74BE07059FEF -r 000102030405060708090a0b0c0d0e0f -s 101
osmo-auc-gen (C) 2011-2012 by Harald Welte
This is FREE SOFTWARE with ABSOLUTELY NO WARRANTY

RAND:  00 01 02 03 04 05 06 07 08 09 0a 0b 0c 0d 0e 0f
AUTN:  e6 0a b2 d3 64 48 00 00 b8 32 f8 98 3c bb 39 c6
```

```

IK:      d5 9c 8e 92 93 bc 73 5e 62 39 24 47 a1 e6 58 8a
CK:      a8 8a 03 ff f8 2a 8a 26 e3 ea 43 d8 28 65 a7 25
RES:     dc 22 4d a2 03 51 d4 d1
SRES:    df 73 99 73
Kc:      fc c5 ea f2 e2 15 06 d7

```

The resulting values have the following meaning:

Parameter	Gen	Transmitted to SIM	Meaning
RAND	2G+3G	X	The random challenge used. Transmitted to (U)SIM
AUTN	3G	X	The authentication nonce
IK	3G	-	Integrity Protection Key
CK	3G	-	Ciphering Key
RES	3G	-	Authentication result; compared by MSC/SGSN with value received from card
SRES	2G	-	Authentication result; compared by MSC/SGSN with value received from card
Kc	2G	-	Ciphering key for GSM A5 / GPRS GEA encryption

6.2 osmo-sim-auth.py

The **osmo-sim-auth.py** utility can be used to perform authentication against a SIM/USIM card located in a smart card reader attached to your computer. It performs the exact same set of operations against the SIM/USIM card as a mobile phone would as part of a cellular network.

This permits you to test the authentication functions of your card without the complexity of running an entire cellular network.

In order to use this tool, you need

- a smart card reader supported by the pcsc-lite software stack as described in Section 5.
- a sysmocom SIM card which you would like to test
- optionally a mechanical adapter that converts the physical size of your SIM card to that of the smart card reader. This is not required, if your SIM is still in full size (credit card size), but generally required if the card is already broken out and now has the 2FF, 3FF or 4FF form-factor
- an authentication challenge to test the card with. This can e.g. be created by a prior call to osmo-auc-gen.
- the osmo-sim-auth.py script from / <https://gitea.osmocom.org/sim-card/osmo-sim-auth>

6.2.1 SYNOPSIS

osmo-sim-auth.py [-h] -r *RAND* [-d] [-s|-a *AUTN*]

6.2.2 OPTIONS

-h, --help

Print help message

-r, --rand *RAND*

Specify the random challenge (RAND) to be sent to the card as 16 hex-encoded bytes

-a, --autn *AUTN*

Specify the Authentication Nonce (AUTN) to be sent to card as 16 hex-encoded bytes. Must be specified in case of UMTS AKA authentication.

-d, --debug

Enable debug output

-s, --sim

Enable GSM SIM authentication mode (default mode is USIM)

6.2.3 Example

Using the AUTN and RAND parameters from the previous example of `osmo-auc-gen`, we can run the following example against the real card:

```
./osmo-sim-auth.py -a e60ab2d364480000b832f8983cbb39c6 -r 000102030405060708090a0b0c0d0e0f
[+] UICC AID found:
found [AID 1] 3GPP || USIM || (255, 255) || (255, 255) || (137, 7, 9, 0, 0)
[+] USIM AID selection succeeded

Testing USIM card with IMSI 901700000011000

UMTS Authentication
RES:    dc224da20351d4d1
CK:     a88a03fff82a8a26e3ea43d82865a725
IK:     d59c8e9293bc735e62392447a1e6588a
Kc:     fcc5eaf2e21506d7

GSM Authentication
SRES:   dc4ca85d
Kc:     6efa00fbbd41dc00
```

As we can see, the computed values by the card correspond to those values computed by the network. Thus, the authentication procedure is a success.

6.2.4 Re-Synchronization

If the SQN value on card-side and network-side are not in sync, `osmo-sim-auth.py` will not return RES/SERS, but instead return an AUTS value for re-synchronization.

This value then needs to be passed to `osmo-auc-gen` (-A parameter), which will then compute the current SQN value.

A SQN value higher than the one determined by the AUTS procedure must be used as input to `osmo-auc-gen` to generate a new authentication quintuples (-s parameter). The SQN value has to be such one that at least causes a changes of bit 2⁵ or bit 6. Please refer to 3GPP TS 33.102 Release 11, annex C. 3.2, "Management of sequence numbers which are not time-based", where the following parameter values are suggested for reference: Length of IND in bits = 5, Length of the array: a = 32. The last one relates to verification of sequence numbers in the USIM. Minimum value that satisfies the requirements is a value that is achieved by applying incremental step of 32.

7 Provisioning of different identities or keys

If you have a variant of the card-individual ADM1 PIN of your sysmoISIM-SJA5 card, you can change any identity (IMSI, MSISDN) stored on the (U)SIM, as well as the private key data (K, OPC).

In order to do so, you will need:

- a smart card reader supported by the pcsc-lite software stack on Linux. We recommend the use of a USB CCID compliant card reader.
- a sysmoISIM-SJA5 card which you would like to modify
- optionally a mechanical adapter that converts the physical size of your SIM card to that of the smart card reader. This is not required, if your SIM is still in full size (credit card size), but generally required if the card is already broken out and now has the 2FF, 3FF or 4FF form-factor
- the ADM1 PIN for the card
- the `pySim-prog.py` and `pySim-shell.py` programs from <https://gitea.osmocom.org/sim-card/pysim>
- the `sysmo-usim-tool` program from <https://git.sysmocom.de/sysmocom/sysmo-usim-tool>

7.1 pySim-prog.py

7.1.1 Example

In the below example, we are changing the card's IMSI to 901710000011000 (it was 901700000011000 before), and specify a new set of K and OPC values.

Full example of re-programming the card using pysim

```
$ ./pySim-prog.py -p 0 -t sysmoISIM-SJA5 -a 32627241 -x 901 -y 71 -i 901710000011000 -s ↵
8988211000000110000 -o 398153093661279FB1FC74BE07059FEF -k 1 ↵
D8B2562B992549F20D0F42113EAA6FB
Insert card now (or CTRL-C to cancel)
Generated card parameters :
> Name      : Magic
> SMSP      : e1ffffffffffffffffffffffff0581005155f5ffffffffffff000000
> ICCID     : 8988211000000110000
> MCC/MNC   : 901/71
> IMSI      : 901710000011000
> Ki        : 1D8B2562B992549F20D0F42113EAA6FB
> OPC       : 398153093661279FB1FC74BE07059FEF
> ACC       : None

Programming ...
Done !
```

7.1.2 Error Codes

The following is a non-comprehensive list of error codes that you might encounter while attempting to program a SIM card. We only list the ones that are most likely to be encountered.

ValueError: Please provide a PIN-ADM as there is no default one

You didn't provide the ADM key at the command line

RuntimeError: SW match failed ! Expected 9000 and got 63c2.

You provided a wrong ADM key to the card.

RuntimeError: SW match failed ! Expected 9000 and got 6983.

The number of attempts to enter the ADM1 PIN was exceeded. At this point, there card cannot be recovered and you will never be able to authenticate using ADM1 PIN again. Still, the card can be used normally, you just cannot make any changes requiring ADM1.

For a more complete list of status and error codes, take a look at the relevant ETSI/3GPP specs or the following source file from the libosmocore project:

```
http://cgit.osmocom.org/libosmocore/tree/src/sim/card\_fs\_uicc.c
```

7.2 sysmo-isim-tool

In cases where fine-tuning of sysmoISIM parameters is needed, sysmo-isim-tool adds an extra level of inspection and control. The tool requires the ADM1 PIN for all operations. The ADM1 PIN is always specified with the option **-a** or **--adm1** as an 8 digit number.

When supplying the ADM1 PIN, some extra care has to be taken, since the card will irreversibly lock down when it receives up to three wrong authentication keys.

In order to prevent the user from accidentally damaging the card by messing up the authentication keys, sysmo-isim-tool checks the retry counter before each authentication attempt. If it finds a decreased counter, it will refuse to try another authentication attempt until the option **-f** (**--force**) added to the command line.

7.2.1 OPC value

With sysmo-isim-tool the OP/OPc value can be inspected and modified if necessary. Option **-o (--opc)** displays the OPC value and the OP flag. (0x00 for OP, 0x01 for OPc, see Section 3.4.1)

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -o
sysmoISIM-SJA5 parameterization tool
Copyright (c)2017 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
* Protocol: 1

Authenticating...
* Remaining attempts: 3
* Authenticating...
* Authentication successful
* Remaining attempts: 3

Reading OP/C value...
* Initializing...
* Reading...
* Current OPc setting:
  OP: 0x1
  OP/OPc: df3d7f95d27005a5441820a31a020bf6
```

EF.OPC can either hold an OPC or an OP value. The first byte denotes if the following 16 bytes are an OPC or OP value.

An OP value is programmed using option **-O (--set-op)**

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -O df3d7f95d27005a5441820a31a020bf6
```

An OPC value is programmed using the option **-C (--set-opc)**

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -C df3d7f95d27005a5441820a31a020bf6
```

7.2.2 Ki value

sysmo-isim-tool also provides access to EF.KI, which holds the precious network authentication key. In order to read out the KI (EF.KI), the option **-k (--ki)** can be used.

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -k
sysmoISIM-SJA5 parameterization tool
Copyright (c) 2023 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
* Protocol: 1

Authenticating...
* Remaining attempts: 3
* Authenticating...
* Authentication successful
* Remaining attempts: 3

Reading KI value...
* Initializing...
* Reading...
* Current KI setting:
  KI: 0123456789abcdef0123456789abcdef
```

Option **-K (--set-ki)** allows setting the Ki to a user defined value.

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -K 0123456789ABCDEF0123456789ABCDEF
```

7.2.3 ICCID value

The ICCID can not be changed on a sysmoISIM-SJA5 card.

If you require sysmoISIM-SJA5 cards with non-default ICCID values, please contact sysmocom for factory-programming them with the specific values you require.

7.2.4 Authentication Algorithms

It is also possible to modify the contents of EF.AUTH, which determines the authentication scheme that is used. Two schemes can be set up, one for 2G and one for 3G.

To inspect which authentication algorithms are currently in configured, the option **-t (--auth)** can be used as follows:

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -t
sysmoISIM-SJA5 parameterization tool
Copyright (c)2017 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
* Protocol: 1

Authenticating...
* Remaining attempts: 3
* Authenticating...
* Authentication successful
* Remaining attempts: 3

Reading Authentication parameters...
* Initializing...
* Reading...
* Current algorithm setting:
  2G: 0x3
  3G: 0x1
```

The authentication algorithm types are represented as two hex numbers. In the example above, COMP128v1 is configured for 2G and MILENAGE for 3G. See also Section 4.3.1 for a complete list with all authentication algorithms available.

Lets assume that the configuration has to be changed in order to use COMP128v2 for 2G and XOR 3G for 3G. To program the authentication parameters option **-T (--set-auth)** followed by the colon separated values for 2G and 3G is used. The command line would look like this:

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -T COMP128v1:XOR-3G
```

7.2.5 Milenage parameters (Ci/Ri)

The milenage authentication methods features a set of constants (C1, C2,C3,C4,C5,R1,R2,R3,R4,R5. To read the current configuration from the card, command line option **-l (--milenage)** can be used:

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -l
sysmoISIM-SJA5 parameterization tool
Copyright (c)2017 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
```

```

* Protocol: 1

Authenticating...
* Remaining attempts: 3
* Authenticating...
* Authentication successful
* Remaining attempts: 3

Reading Milenage parameters...
* Initalizing...
* Reading...
* Current Milenage Parameters in (EF.MLNGC):
C1: 00000000000000000000000000000000
C2: 00000000000000000000000000000001
C3: 00000000000000000000000000000002
C4: 00000000000000000000000000000004
C5: 00000000000000000000000000000008
R1: 0x40
R2: 0x0
R3: 0x20
R4: 0x40
R5: 0x60

```

In order to set a new milenage configuration. The option **-L (--set-milenage)** is used, followed by the concatenated values of C1, C2, C3, C4, C5, R1, R2, R3, R4 and R5. The parameters may be separated using a colon to increase human readability

The following example resets the milenage parameters to their factory default

```

./sysmo-isim-tool.sja5.py --adm1 55538407 -L \
00000000000000000000000000000000\
00000000000000000000000000000001\
00000000000000000000000000000002\
00000000000000000000000000000004\
00000000000000000000000000000008\
40:00:20:40:60

```

7.2.6 Enable / Disable USIM Application

By default, sysmoISIM-SJA5 acts as both a classic GSM SIM card as well as a USIM on UICC, using an USIM application in parallel to the SIM functionality. This means, that it's up to the phone to decide whether to talk to the card as USIM, or as classic SIM. Typically, modern (3G capable) phones will talk to the card as USIM, and only old, pre-3G phones will talk to it as SIM card.

Please note that the used/supported radio technology (GSM/GPRS/EGPRS vs. UMTS/HSPA/LTE/5G) has no direct relation to which method the phone will use to the smart card. You can very well have a classic GSM SIM card inside a UMTS capable phone while attaching to the UMTS radio network (UTRAN).

In some cases it may become necessary to disable the USIM application. This will basically turn the card into a classic GSM SIM card without any USIM capability.

There are two steps needed to disable the USIM application:

- removing it from the directory EF.DIR (done by pySim-shell or sysmo-isim-tool.sja5.py)
- locking the USIM card application (done via GlobalPlatformPro)

USIM record in EF.DIR

sysmo-isim-tool can add and remove the USIM application from EF.DIR. In order to remove the USIM entry, record No.1, which contains the USIM AID, will be overwritten with 0xFF. To add the USIM application again, **sysmo-isim-tool** restores the factory default to record No.1.

The current setting can be inspected using the command line switch **-m (--mode)**

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -m
sysmoISIM-SJA5 parameterization tool
Copyright (c)2017 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
* Protocol: 1

Authenticating...
* Remaining attempts: 3
* Authenticating...
* Authentication successful
* Remaining attempts: 3

Reading SIM-Mode...
* Initializing...
* Reading...
* Current status of Record No. 1 in EF.DIR:
61194f10a000000871002ffffffff890709000050055553696d31ffffffffffffffffffffffff
==> USIM application enabled
```

In the example above, the USIM application is still enabled. We can disable the USIM application using the command line switch **-c (--classic)**

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -c
```

In order to restore the USIM functionality again we can use option **-u (--usim)**

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -u
```

Disabling the USIM application

Removing the EF.DIR record alone may not be sufficient for all phones to stop using the card as a USIM. Some phones/modems might try to blindly select the USIM application, even though it is not listed in EF.DIR anymore.

In order to make it impossible to even select the USIM application, it can be locked via the GlobalPlatform SET STATUS command, which must be secured with the SCP02 protocol.

There is an open source tool available supporting this: GlobalPlatformPro available from <https://github.com/martinpaljak/-GlobalPlatformPro>

You can use the following command to lock the USIM application:

```
java -jar ./gp.jar --key-enc KIC1❶ --key-mac KID1 --key-dek KIK1 --lock-applet ↵
A0000000871002FFFFFFFF8907090000
```

- ❶ you must substitute the KIC1, KID1, and KIK1 parameters with the card-specific KIC1, KID1 and KIK1 key material for your specific card. Those values are provided by sysmocom together with the ADM1 PIN by e-mail to the person placing the order in the webshop.

Likewise, you can re-enable the USIM application using

```
java -jar ./gp.jar --key-enc KIC1❶ --key-mac KID1 --key-dek KIK1 --unlock-applet ↵
A0000000871002FFFFFFFF8907090000
```

- ❶ you must substitute the KIC1, KID1, and KIK1 parameters with the card-specific KIC1, KID1 and KIK1 key material for your specific card. Those values are provided by sysmocom together with the ADM1 PIN by e-mail to the person placing the order in the webshop.

7.2.7 APDU trace

In case of problems it may be helpful to trace the exact APDU commands which are exchanged with between card and reader. In order to do this, stop the pcscd daemon on your system and start it manually using **sudo pcscd -fa**. This will give you a log of the raw traffic between reader and card.

```
$ ./sysmo-isim-tool.sja5.py --adm1 55538407 -L \
sysmoISIM-SJA5 parameterization tool
Copyright (c)2017 Sysmocom s.f.m.c. GmbH

Initializing smartcard terminal...
* Terminal: OMNIKEY CardMan 4321 00 00
* Protocol: 1

Authenticating...
  Card transaction: APDU:0020000a00 ==> APDU:(no data) SW:63c3
* Remaining attempts: 3
* Authenticating...
  Card transaction: APDU:0020000a083535353338343037 ==> APDU:(no data) SW:9000
* Authentication successful
  Card transaction: APDU:0020000a00 ==> APDU:(no data) SW:63c3
* Remaining attempts: 3

Programming Milenage parameters...
* Initializing...
  Card transaction: APDU:00a4000c023f00 ==> APDU:(no data) SW:9000
* New Milenage Parameters for (EF.MLNGC):
  C1: 00000000000000000000000000000000
  C2: 00000000000000000000000000000001
  C3: 00000000000000000000000000000002
  C4: 00000000000000000000000000000004
  C5: 00000000000000000000000000000008
  R1: 0x40
  R2: 0x0
  R3: 0x20
  R4: 0x40
  R5: 0x60
  Card transaction: APDU:00a4000c027fcc ==> APDU:(no data) SW:9000
  Card transaction: APDU:00a4000c026f01 ==> APDU:(no data) SW:9000
* Programming...
  Card transaction: APDU:00d600001000000000000000000000000000000000000000000 ==> APDU:(no data) SW ←
:9000
  Card transaction: APDU:00d600101000000000000000000000000000000000000000001 ==> APDU:(no data) SW ←
:9000
  Card transaction: APDU:00d600201000000000000000000000000000000000000000002 ==> APDU:(no data) SW ←
:9000
  Card transaction: APDU:00d600301000000000000000000000000000000000000000004 ==> APDU:(no data) SW ←
:9000
  Card transaction: APDU:00d600401000000000000000000000000000000000000000008 ==> APDU:(no data) SW ←
:9000
  Card transaction: APDU:00d600500140 ==> APDU:(no data) SW:9000
  Card transaction: APDU:00d600510100 ==> APDU:(no data) SW:9000
  Card transaction: APDU:00d600520120 ==> APDU:(no data) SW:9000
  Card transaction: APDU:00d600530140 ==> APDU:(no data) SW:9000
  Card transaction: APDU:00d600540160 ==> APDU:(no data) SW:9000
```

8 Disabling / Enabling SQN verification

A USIM as specified by 3GPP performs a *SQN freshness check* at every authentication. This ensures that an attacker cannot re-play old authentication vectors.

When those 5G related files exist *and* they are activated, they need to contain valid data. sysmocom is not the operator of your 5G network, so as the SIM card manufacturer sysmocom has no idea what kind of parameters your specific network in its specific configuration supports. It is up to you as the network operator to ensure they contain configuration consistent with your network and its configuration.

The contents of each of those files is specified by [3gpp-ts-31-102] Section 4.4.11 *Contents of files at the DF_5GS level*. The commands for reading and writing (such as READ BINARY, READ RECORD, WRITE BINARY, WRITE RECORD) are fully specified in [etsi-ts102221].

9.1 Disabling DF_5GS files and services

If you prefer to not populate those files with configuration data consistent to your network, you can disable those files. To do so, you would have to:

1. disable the related services from EF.UST (Services no. 122 through no. 130)
2. if that's insufficient (some UE may ignore the EF.UST contents and "blindly" try to read a file), deactivate all of the files below relevant files using the DEACTIVATE FILE command as specified in [etsi-ts102221] Section 11.1.14.

sysmocom is selling SIM cards that are compliant with the relevant 3GPP, ETSI and ISO specifications. It is not selling any associated software.

You can use whatever software conforming to the above-mentioned 3GPP and ETSI standards to configure the cards.

The open source pySim-shell software implements support for [almost] all of the thousands of settings over hundreds of files that can be configured on SIM/USIM/ISIM cards. It is an open source collaborative project and not something that is part of the product you bought from sysmocom.

Irrespective of the above, sysmocom has been and continues to contribute many man-months of development resources to improve pySim capabilities. But it is a collaborative open source project, and anyone can, if they have a related requirement, submit patches to improve and extend it.

pySim-shell versions after May 2021 contain support for the to operations described above:

- the `deactivate_file` command to deactivate the currently selected file
- the `ust_service_deactivate` command to deactivate services from EF.UST.

Furthermore, from pySim gc89a1a9 (February 17, 2022) onwards, there is a script included at the `scripts/deactivate-5g.script`, which will perform deactivation of all 5G related EF.UST services and deactivation of all 5G related files.

Example pySim-shell command for deactivating 5G services and files

```
$ ./pySim-shell.py -p0 --script ./scripts/deactivate-5g.script
```

Note

The above command only works if you either edit the script to insert your card-individual ADM1 pin, or you store the ADM1 in a CSV file accessible to pySim (see the [verify_adm](#) section in the [pySim-shell documentation](#))

Should you later decide you need to re-enable some services and files, you can similarly use the `activate_file` and `ust_service_activate` commands to achieve the inverse operations.

If you're new to pySim-shell, the video recording of a recent Osmocom Developer Call available from https://people.osmocom.org/-tnt/osmodevcall/osmodevcall-20210409-laforge-pysim-shell_h264_420.mp4 may be useful.

10 USIM/ISIM cards and IMS

IMS, the IP Multimedia System is how circuit-switched calls like voice calls are implemented in 3GPP networks over modern cellular technologies like LTE/4G, NR/5G and WiFi.

IMS can work without any specific configuration or support from the SIM. In this mode, automatic provisioning and default parameters (such as deriving the IMPI from the IMSI) are used.

However, for advanced configuration, there are two ways of providing IMS related configuration on cards:

- via some additional files in `ADF.USIM`, or
- via a completely separate additional `ADF.ISIM` application

The two methods are exclusive of each other: If `ADF.ISIM` is present, the IMS related files in `ADF.USIM` must not be present.

The sysmoISIM-SJA5 contains an `ADF.ISIM` application and all files specified by 3GPP up to Release 17.

So if you want to use the sysmoISIM-SJA5 with IMS, you have two options: You can either ensure that the IMS related configuration on the card reflects your network side configuration, or you can disable the ISIM on the card and use the 3GPP default / fallback mechanism.

10.1 Disabling the ISIM functionality

If you prefer to not populate those IMS related files with configuration data consistent to your network, you can disable those files. To do so, you would have to:

1. disable the related services from `ADF.USIM/EF.UST`
2. deactivate the related files in `ADF.USIM`
3. remove the ISIM application from `EF.DIR`
4. lock the entire ISIM application to prevent it from being selected

sysmocom is selling SIM cards that are compliant with the relevant 3GPP, ETSI and ISO specifications. It is not selling any associated software.

You can use whatever software conforming to the above-mentioned 3GPP and ETSI standards to configure the cards.

10.1.1 Deactivating IMS files + services from `ADF.USIM`

The open source `pySim` software by no means implements support for all of the thousands of settings over hundreds of files that can be configured on SIM/USIM/ISIM cards. It is an open source collaborative project and not something that is part of the product you bought from sysmocom.

Irrespective of the above, sysmocom has been and continues to contribute many man-months of development resources to improve `pySim` capabilities. But it is a collaborative open source project, and anyone can, if they have a related requirement, submit patches to improve and extend it.

`pySim-shell` versions after May 2021 contain support for the to operations described above:

- the `deactivate_file` command to deactivate the currently selected file
- the `ust_service_deactivate` command to deactivate services from `EF.UST`.

Furthermore, from `pySim gc89a1a9` (February 21, 2022) onwards, there is a script included at the `scripts/deactivate-ims.scr` which will perform deactivation of all 5G related `EF.UST` services and deactivation of all IMS related files in `ADF.USIM`.

Example `pySim-shell` command for deactivating IMS services and files in `ADF.USIM`

```
$ ./pySim-shell.py -p0 --script ./scripts/deactivate-ims.script
```

It is expected that some commands will fail, for example if the related files did not exist. A non-existent file is like a deactivated file from the perspective of the phone or modem.

Should you later decide you need to re-enable some services and files, you can similarly use the `activate_file` and `ust_service_activate` commands to achieve the inverse operations.

If you're new to `pySim-shell`, the video recording of a recent Osmocom Developer Call available from https://people.osmocom.org/-tnt/osmodevcall/osmodevcall-20210409-laforge-pysim-shell_h264_420.mp4 may be useful.

10.1.2 Locking the ISIM application

Locking the ISIM application will make it inaccessible and it is no longer possible to select that application by the phone/modem. Like any on-card application, locking can be performed via the standard GlobalPlatform `SET STATUS` Command.

GlobalPlatform commands need to be cryptographically protected via the SCP02 protocol, using the key material provided together with the sysmoISIM-SJA5 card.

An open source tool implementing both SCP02 and the `SET STATUS` command is `GlobalPlatformPro`, which is available from <https://github.com/martinpaljak/GlobalPlatformPro>

You can use the following command to lock the ISIM application:

```
java -jar ./gp.jar --key-enc KIC1❶ --key-mac KID1 --key-dek KIK1 --lock-applet ↔  
A0000000871004FFFFFFFFF8907090000
```

- ❶ you must substitute the KIC1, KID1, and KIK1 parameters with the card-specific KIC1, KID1 and KIK1 key material for your specific card. Those values are provided by sysmocom together with the ADM1 key by e-mail to the person placing the order in the webshop.

Likewise, you can unlock the ISIM application using:

```
java -jar ./gp.jar --key-enc KIC1❶ --key-mac KID1 --key-dek KIK1 --unlock-applet ↔  
A0000000871004FFFFFFFFF8907090000
```

- ❶ you must substitute the KIC1, KID1, and KIK1 parameters with the card-specific KIC1, KID1 and KIK1 key material for your specific card. Those values are provided by sysmocom together with the ADM1 key by e-mail to the person placing the order in the webshop.

11 Java Card Features

The sysmoISIM-SJA5 is a Java Card (and Java SIM/USIM card) compliant to the specifications listed in Section 4.2.1

Note

In order to install and/or manage Java Card applets on your card, you need the card-individual KIC/KID/KIK key material.

11.1 Application List

Table 1: List of Java applications on sysmoISIM-SJA5 card

Application	AID
USIM	A0000000871002FFFFFFFFF8907090000
ISIM	A0000000871004FFFFFFFFF8907090000
HPSIM	A000000087ABCDFFFFFFFFF8907090000
Remote Application Management	53696D62614E2E52414D
SIM	A0000000090001FFFFFFFFF8900000000
Remote File Management	53696D62614E2E52464D
ARA-M	A00000015141434C00

The detailed coding/suffix of the PID / AID may change from card batch to card batch. In case of any questions, please refer to Annex E of [etsi-ts101220] for the AID prefixes applications have to start with or the PID values.

For more information on EF.DIR, see Section 13.1 of [etsi-ts102221].

11.2 Example Applet

There is an example "Hello World" applet provided in source code, you can find it at <https://gitea.osmocom.org/sim-card/hello-stk>. Please follow the instructions at <https://osmocom.org/projects/cellular-infrastructure/wiki/Shadysimpy> to install the hello world STK applet.

11.3 Installation via 03.48 OTA

This means the Java Applet will be installed OTA (Over The Air) via SMS messages.

There are open source tools provided at <https://gitea.osmocom.org/sim-card/sim-tools> which can be used to download the example applet (or other applets) onto the card.

The `shadysim.py` tool will format the Java Applet into small, SMS-sized chunks conformant to the TS 03.48 OTA messages, and then either

1. emulate a phone talking to a SIM card, informing the card about received OTA SMS, or
2. output the SMS as hexdumps so you can use them e.g. by typing into the OsmoMSC or OsmoNITB VTY of a private cellular network, or send them via SMPP or any other SMS delivery method you may have available.

11.4 Installation via GlobalPlatform SCP02

If you have the SIM card in a local card reader attached to your computer, you don't have to use the OTA SMS method as implemented by the sim-tools above.

Instead, you can use the GlobalPlatform / JavaCard SCP02 method of installing applets. This method is completely unrelated to SIM cards or 3GPP.

One commonly used Open Source program for this is the GlobalPlatformPro tool available from <https://github.com/martinpaljak/-GlobalPlatformPro>

The keys received with the sysmoISIM-SJA5 have to be used like this:

Table 2: Key mapping for GlobalPlatformPro

sysmoISIM key	GlobalPlatformPro argument
KIC1	--key-enc
KID1	--key-mac
KIK1	--key-dek

12 OTA (Over The Air)

Using OTA, the operator can communicate from a backend system (so-called "OTA platform") with software on the SIM card itself.

The OTA protocol / framework was first described in GSM TS 03.48, later.

12.1 Transports

OTA can happen over a number of different transports * SMS * SMSCB (Cell Broadcast) * USSD * BIP * CAT-TP * HTTPS

SMS is by far the most common mechanism for OTA access to SIM cards, including the sysmoISIM-SJA2.

12.2 TAR (Toolkit Application Reference)

Individual applications on the card can be identified by their TAR (Toolkit Application Reference) value.

The following table lists the TAR values for the sysmoISIM-SJA2 and sysmoISIM-SJA5:

Table 3: List of TAR and MSL for sysmoISIM-SJA2 and sysmoISIM-SJA5 card

Application	TAR	MSL
RAM (Remote Application Management)	00000	0x06
SIM RFM (Remote File Management)	B00010	0x06
USIM RFM (Remote File Management)	B00011	0x06
ISIM RFM (Remote File Management)	B00020	0x06
HPSIM RFM (Remote File Management)	B00021	0x06

12.3 MSL (Minimum Security Level)

The MSL (Minimum Security Level) defines which of the OTA security features are minimally mandatory for the card to accept an OTA command.

See the above table for the MSL values of the individual OTA applications on the card.

A MSL of 0x06 (sysmoISIM-SJA2 and sysmoISIM-SJA5 default value) indicates that both integrity protection and encryption shall be used. Counter based replay protection is possible, but not mandatory.

13 sysmoISIM-SJA5 changelog

This chapter documents the changes to the sysmoISIM-SJA5 product over time.

13.1 Major new features in sysmoISIM-SJA5 vs sysmoISIM-SJA2

- TUAK authentication algorithm
- SUCI computation on card (if used on chip with sufficiently fast EC crypto)
- XOR-2G support algorithm support
- XOR-3G test algorithm support
- EAP-SIM + EAP-AKA support
- HTTPS / TLS 1.2 support (for OTA)
- AES128/192/256 for OTA security
- Suspend/Resume support
- OTA Script chaining
- RFM APDU response data larger than 256 bytes

13.2 sysmoISIM-SJA5 v0 samples (May 2023)

- Initial version of sysmoISIM-SJA5 product
- Files as of 3GPP Release 17
 - new files in DF.5GS: EF.5GSEDRX, EF.5GNSWO_CONF, #F.MCHPPLMN, EF.KAUSF_DERIVATION
 - new DFs: ADF.USIM/DF.SNSP, ADF.USIM/DF.5G-ProSe (with respective EFs)
 - new EF: ADF.USIM/EF.eAKA
- Support for SUCI-on-Card via ADF.USIM/DF.SAIP/EF.SUCI_CalcInfo
- Enlarge DF.EIRENE/EF.FN + EF.FC to match sizes of commercial GSM-R SIM

13.2.1 Errata: Re-create larger EF.USIM_AUTH_KEY for TUAK support

```
pySIM-shell (MF)> select ADF.USIM
pySIM-shell (MF/ADF.USIM)> verify_adm 11111111
pySIM-shell (MF/ADF.USIM)> delete_file EF.USIM_AUTH_KEY --force-delete
pySIM-shell (MF/ADF.USIM)> apdu ↔
    e0e00000246222820241218302af208a01058c07fb1aff1a1a1a1a800200438800a506d00130d20100
SW: 9000
```

13.3 sysmoISIM-SJA5 v1 (August 2023)

- Shrink {DF.GSM/ADF.USIM}/EF.{VGCS,VBS} size from 400 to 200 bytes
 - 200 bytes is maximum as per 3GPP specs; avoids compatibility problems with UEs
- Enlarge ADF.{USIM,ISIM,HPSIM}/EF.USIM_AUTH_KEY from 33 to 67 bytes
 - This is required for TUAK algorithm configuration
- Enlarge ADF.USIM/DF.5GS/EF.SUCI_Calc_Info from 100 to 200 bytes
 - This is required for storage of multiple uncompressed network public keys

- Populate ADF.USIM/DF.5GS/EF.Routing_Indicator with 0
 - This is a more reasonable default than the previous invalid content ffffffff
- Indicate SUSPEND/RESUME support in EF.UMPC
- Populate ADF.USIM/DF.[5GS,SAIP]/EF.SUCI_Calc_Info with empty list of protection schemes
 - This is a more reasonable default than the previous invalid content of all-ff

13.4 sysmoISIM-SJA5 v2 (October 2023)

- Change PIN + PUK defaults from per-card random to static PIN=0000 PUK=12345678
 - most users have PIN disabled anyway. Random PIN/PUK can be set by users.
- Deactivate EF.UST service 126 (DF.5GS/EF.UAC_AIC presence)
- disable priority + mission-critical services in DF.5GS/EF.UAC_AIC

14 Acknowledgements

sysmocom would like to thank a number of individuals in the context of improving the availability of freely available programmable SIM cards and related tools

- **Sylvain Munaut** for developing the original `pySim` tool
- **Philipp Maier** for developing the `sysmo-usim-tool`
- **Benoit Michau** for the python `card` abstraction library
- **Kevin Redon** for `Osmocom SIMtrace`
- **Eric Butler** and **Karl Koscher** of `shadytel` for their hello world Java cardlet and the `sim-tools` for OTA installation
- **Supreeth Herle** for all of his research on the role of SIM cards in VoLTE/IMS, CarrierPrivileges and many related contributions to `pySim`
- **Bertrand Martel** for his open source implementation `ARA-M` applet, which we also pre-install on the sysmoISIM-SJA2
- **Martin Paljak** for his work on `GlobalPlatformPro`

15 Glossary

2FF

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

3FF

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

3GPP

3rd Generation Partnership Project

4FF

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

A Interface

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

A3/A8

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

A5

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

Abis Interface

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

ACC

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

AGCH

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

AGPL

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

AQPSK

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

ARFCN

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

AUC

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

BCCH

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

BCC

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

BTS

Base Transceiver Station

BSC

Base Station Controller

BSIC

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

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 (milliwatt); unit of measurement for signal strength of radio signals

DHCP

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

downlink

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

DSCP

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

DSP

Digital Signal Processor

dnvixload

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

GT

Global Title; an address in SCCP

GTP

GPRS Tunnel Protocol; used between SGSN and GGSN

HLR

Home Location Register; central subscriber database of a GSM network

HNB-GW

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

HPLMN

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

IE

Information Element

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* [\[itu-t-q711\]](#))

SDCCH

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

SDK

Software Development Kit

SGs

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

SGSN

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

SIGTRAN

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

SIM

Subscriber Identity Module; small chip card storing subscriber identity

Site

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

SMPP

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

SMSC

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

SS7

Signaling System No. 7; Classic digital telephony signaling system

SS

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

SSH

Secure Shell; *IETF RFC 4250* [\[ietf-rfc4251\]](#) to 4254

SSN

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

STP

Signaling Transfer Point; A Router in SS7 Networks

SUA

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

syslog

System logging service of UNIX-like operating systems

System Information

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

TCH

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

TCP

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

TFTP

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

TOS

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

TRX

Transceiver; element of a BTS serving a single carrier

TS

Technical Specification

u-Boot

Boot loader used in various embedded systems

UBI

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

UBL

Initial bootloader loaded by the TI Davinci SoC

UDP

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

UICC

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

Um interface

U mobile; Radio interface between MS and BTS

uplink

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

USIM

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

USSD

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

VAMOS

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

VCTCXO

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

VLAN

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

VLR

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

VPLMN

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

VTY

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

A Osmocom TCP/UDP Port Numbers

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

Table 4: TCP/UDP port numbers

L4 Protocol	Port Number	Purpose	Software
UDP	1984	Osmux	osmo-mgw, osmo-bts
UDP	2427	MGCP GW	osmo-bsc_mgcp, osmo-mgw
TCP	2775	SMPP (SMS interface for external programs)	osmo-nitb
TCP	3002	A-bis/IP OML	osmo-bts, osmo-bsc, osmo-nitb
TCP	3003	A-bis/IP RSL	osmo-bts, osmo-bsc, osmo-nitb
TCP	4227	telnet (VTY)	osmo-pcap-client
TCP	4228	telnet (VTY)	osmo-pcap-server
TCP	4236	Control Interface	osmo-trx
TCP	4237	telnet (VTY)	osmo-trx
TCP	4238	Control Interface	osmo-bts
TCP	4239	telnet (VTY)	osmo-stp
TCP	4240	telnet (VTY)	osmo-pcu
TCP	4241	telnet (VTY)	osmo-bts
TCP	4242	telnet (VTY)	osmo-nitb, osmo-bsc, cellmgr-ng
TCP	4243	telnet (VTY)	osmo-bsc_mgcp, osmo-mgw
TCP	4244	telnet (VTY)	osmo-bsc_nat
TCP	4245	telnet (VTY)	osmo-sgsn
TCP	4246	telnet (VTY)	osmo-gbproxy
TCP	4247	telnet (VTY)	OsmocomBB
TCP	4249	Control Interface	osmo-nitb, osmo-bsc
TCP	4250	Control Interface	osmo-bsc_nat
TCP	4251	Control Interface	osmo-sgsn
TCP	4252	telnet (VTY)	sysmobts-mgr
TCP	4253	telnet (VTY)	osmo-gtphub
TCP	4254	telnet (VTY)	osmo-msc
TCP	4255	Control Interface	osmo-msc
TCP	4256	telnet (VTY)	osmo-sip-connector
TCP	4257	Control Interface	osmo-ggsn, ggsn (OpenGGSN)
TCP	4258	telnet (VTY)	osmo-hlr
TCP	4259	Control Interface	osmo-hlr
TCP	4260	telnet (VTY)	osmo-ggsn
TCP	4261	telnet (VTY)	osmo-hnbgw
TCP	4262	Control Interface	osmo-hnbgw
TCP	4263	Control Interface	osmo-gbproxy
TCP	4264	telnet (VTY)	osmo-cbc
TCP	4265	Control Interface	osmo-cbc
TCP	4266	D-GSM MS Lookup: mDNS serve	osmo-hlr
TCP	4267	Control Interface	osmo-mgw
TCP	4268	telnet (VTY)	osmo-uecups
SCTP	4268	UECUPS	osmo-uecups
TCP	4269	telnet (VTY)	osmo-e1d

Table 4: (continued)

L4 Protocol	Port Number	Purpose	Software
TCP	4270	telnet (VTY)	osmo-isdn tap
TCP	4271	telnet (VTY)	osmo-smlc
TCP	4272	Control Interface	osmo-smlc
TCP	4273	telnet (VTY)	osmo-hnodeb
TCP	4274	Control Interface	osmo-hnodeb
TCP	4275	telnet (VTY)	osmo-upf
TCP	4276	Control Interface	osmo-upf
TCP	4277	telnet (VTY)	osmo-pfcp-tool
TCP	4278	Control Interface	osmo-pfcp-tool
UDP	4729	GSMTAP	Almost every osmocom project
TCP	5000	A/IP	osmo-bsc, osmo-bsc_nat
UDP	23000	GPRS-NS over IP default port	osmo-pcu, osmo-sgsn, osmo-gbproxy
TCP	48049	BSC-CBC (CBSP) default port	osmo-bsc, osmo-cbc

B Bibliography / References

References

- [1] [userman-ice1usb] Osmocom Project: icE1usb User Manual.
- [2] [userman-ogt] Pau Espin: osmo-gsm-tester User Manual.
- [3] [userman-remsim] Harald Welte: osmo-remsim User Manual.
- [4] [osmobts-abis-spec] Neels Hofmeyr & Harald Welte. OsmoBTS Abis Protocol Specification. <https://ftp.osmocom.org/docs/latest/osmobts-abis.pdf>
- [5] [userman-osmobsc] Osmocom Project: OsmoBSC User Manual. <https://ftp.osmocom.org/docs/latest/osmobsc-usermanual.pdf>
- [6] [vty-ref-osmobsc] Osmocom Project: OsmoBSC VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmobsc-vty-reference.pdf>
- [7] [userman-osmobts] Osmocom Project: OsmoBTS User Manual. <https://ftp.osmocom.org/docs/latest/osmobts-usermanual.pdf>
- [8] [vty-ref-osmobts] Osmocom Project: OsmoBTS VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmobts-trx-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmobts-sysmo-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmobts-lc15-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmobts-oc2g-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmobts-octphy-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmobts-virtual-vty-reference.pdf>
- [9] [userman-osmocbc] Osmocom Project: OsmoCBC User Manual. <https://ftp.osmocom.org/docs/latest/osmocbc-usermanual.pdf>
- [10] [vty-ref-osmocbc] Osmocom Project: OsmoCBC VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmocbc-vty-reference.pdf>
- [11] [userman-osmogbproxy] Osmocom Project: OsmoGBProxy User Manual. <https://ftp.osmocom.org/docs/latest/osmogbproxy-usermanual.pdf>
- [12] [vty-ref-osmogbproxy] Osmocom Project: OsmoGBPRoxy VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmogbproxy-vty-reference.pdf>

- [13] [userman-osmoggsn] Osmocom Project: OpenGGSN User Manual. <https://ftp.osmocom.org/docs/latest/-osmoggsn-usermanual.pdf>
- [14] [vty-ref-osmoggsn] Osmocom Project: OsmoGGSN VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmoggsn-vty-reference.pdf>
- [15] [userman-osmohlr] Osmocom Project: OsmoHLR User Manual. <https://ftp.osmocom.org/docs/latest/osmohlr-usermanual.pdf>
- [16] [vty-ref-osmohlr] Osmocom Project: OsmoHLR VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/-osmohlr-vty-reference.pdf>
- [17] [userman-osmohnbgw] Osmocom Project: OsmoHNBGW User Manual. <https://ftp.osmocom.org/docs/latest/-osmohnbgw-usermanual.pdf>
- [18] [vty-ref-osmohnbgw] Osmocom Project: OsmoHNBGW VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmohnbgw-vty-reference.pdf>
- [19] [userman-osmomgw] Osmocom Project: OsmoMGW User Manual. <https://ftp.osmocom.org/docs/latest/-osmomgw-usermanual.pdf>
- [20] [vty-ref-osmomgw] Osmocom Project: OsmoMGW VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmomgw-vty-reference.pdf>
- [21] [userman-osmomsc] Osmocom Project: OsmoMSC User Manual. <https://ftp.osmocom.org/docs/latest/-osmomsc-usermanual.pdf>
- [22] [vty-ref-osmomsc] Osmocom Project: OsmoMSC VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmomsc-vty-reference.pdf>
- [23] [userman-osmonitb] Osmocom Project: OsmoNITB User Manual. <https://ftp.osmocom.org/docs/latest/-osmonitb-usermanual.pdf>
- [24] [vty-ref-osmonitb] Osmocom Project: OsmoNITB VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmonitb-vty-reference.pdf>
- [25] [userman-osmopcu] Osmocom Project: OsmoPCU User Manual. <https://ftp.osmocom.org/docs/latest/-osmopcu-usermanual.pdf>
- [26] [vty-ref-osmopcu] Osmocom Project: OsmoPCU VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmopcu-vty-reference.pdf>
- [27] [userman-osmosgsn] Osmocom Project: OsmoSGSN User Manual. <https://ftp.osmocom.org/docs/latest/-osmosgsn-usermanual.pdf>
- [28] [vty-ref-osmosgsn] Osmocom Project: OsmoSGSN VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmosgsn-vty-reference.pdf>
- [29] [userman-osmosipconnector] Osmocom Project: OsmoSIPconnector User Manual. <https://ftp.osmocom.org/docs/latest/osmosipconnector-usermanual.pdf>
- [30] [vty-ref-osmosipconnector] Osmocom Project: OsmoSIPconnector VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmosipconnector-vty-reference.pdf>
- [31] [userman-osmosmlc] Osmocom Project: OsmoSMLC User Manual. <https://ftp.osmocom.org/docs/latest/-osmosmlc-usermanual.pdf>
- [32] [vty-ref-osmosmlc] Osmocom Project: OsmoSMLC VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmosmlc-vty-reference.pdf>
- [33] [userman-osmostp] Osmocom Project: OsmoSTP User Manual. <https://ftp.osmocom.org/docs/latest/osmostp-usermanual.pdf>
- [34] [vty-ref-osmostp] Osmocom Project: OsmoSTP VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/-osmostp-vty-reference.pdf>

- [35] [userman-osmotrx] Osmocom Project: OsmoTRX User Manual. <https://ftp.osmocom.org/docs/latest/osmotrx-usermanual.pdf>
- [36] [vty-ref-osmotrx] Osmocom Project: OsmoTRX VTY Reference Manual. <https://ftp.osmocom.org/docs/latest/osmotrx-uhd-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmotrx-lms-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmotrx-ipc-vty-reference.pdf> <https://ftp.osmocom.org/docs/latest/osmotrx-usrp1-vty-reference.pdf>
- [37] [3gpp-ts-23-041] 3GPP TS 23.041: Technical realization of Cell Broadcast Service (CBS)
- [38] [3gpp-ts-23-048] 3GPP TS 23.048: Security mechanisms for the (U)SIM application toolkit; Stage 2 <https://www.3gpp.org/DynaReport/23048.htm>
- [39] [3gpp-ts-23-236] 3GPP TS 23.236: Intra-domain connection of Radio Access Network (RAN) nodes to multiple Core Network (CN) nodes <https://www.3gpp.org/DynaReport/23236.htm>
- [40] [3gpp-ts-24-007] 3GPP TS 24.007: Mobile radio interface signalling layer 3; General Aspects <https://www.3gpp.org/DynaReport/24007.htm>
- [41] [3gpp-ts-24-008] 3GPP TS 24.008: Mobile radio interface Layer 3 specification; Core network protocols; Stage 3. <https://www.3gpp.org/dynareport/24008.htm>
- [42] [3gpp-ts-31-101] 3GPP TS 31.101: UICC-terminal interface; Physical and logical characteristics <https://www.3gpp.org/DynaReport/31101.htm>
- [43] [3gpp-ts-31-102] 3GPP TS 31.102: Characteristics of the Universal Subscriber Identity Module (USIM) application <https://www.3gpp.org/DynaReport/31102.htm>
- [44] [3gpp-ts-31-103] 3GPP TS 31.103: Characteristics of the IMS Subscriber Identity Module (ISIM) application <https://www.3gpp.org/DynaReport/31103.htm>
- [45] [3gpp-ts-31-111] 3GPP TS 31.111: Universal Subscriber Identity Module (USIM) Application Toolkit (USAT) <https://www.3gpp.org/DynaReport/31111.htm>
- [46] [3gpp-ts-31-115] 3GPP TS 31.115: Secured packet structure for (Universal) Subscriber Identity Module (U)SIM Toolkit applications <https://www.3gpp.org/DynaReport/31115.htm>
- [47] [3gpp-ts-31-116] 3GPP TS 31.116: Remote APDU Structure for (U)SIM Toolkit applications <https://www.3gpp.org/DynaReport/31116.htm>
- [48] [3gpp-ts-35-205] 3GPP TS 35.205: 3G Security; Specification of the MILENAGE algorithm set: General
- [49] [3gpp-ts-35-206] 3GPP TS 35.206: 3G Security; Specification of the MILENAGE algorithm set: Algorithm specification <https://www.3gpp.org/DynaReport/35206.htm>
- [50] [3gpp-ts-44-006] 3GPP TS 44.006: Mobile Station - Base Station System (MS - BSS) interface; Data Link (DL) layer specification <https://www.3gpp.org/DynaReport/44006.htm>
- [51] [3gpp-ts-44-018] 3GPP TS 44.018: Mobile radio interface layer 3 specification; Radio Resource Control (RRC) protocol <https://www.3gpp.org/DynaReport/44018.htm>
- [52] [3gpp-ts-44-064] 3GPP TS 44.064: Mobile Station - Serving GPRS Support Node (MS-SGSN); Logical Link Control (LLC) Layer Specification <https://www.3gpp.org/DynaReport/44064.htm>
- [53] [3gpp-ts-45-002] 3GPP TS 45.002: Digital cellular telecommunications system (Phase 2+) (GSM); GSM/EDGE Multiplexing and multiple access on the radio path <https://www.3gpp.org/DynaReport/45002.htm>
- [54] [3gpp-ts-48-008] 3GPP TS 48.008: Mobile Switching Centre - Base Station system (MSC-BSS) interface; Layer 3 specification <https://www.3gpp.org/DynaReport/48008.htm>
- [55] [3gpp-ts-48-016] 3GPP TS 48.016: General Packet Radio Service (GPRS); Base Station System (BSS) - Serving GPRS Support Node (SGSN) interface; Network service <https://www.3gpp.org/DynaReport/48016.htm>
- [56] [3gpp-ts-48-018] 3GPP TS 48.018: General Packet Radio Service (GPRS); Base Station System (BSS) - Serving GPRS Support Node (SGSN); BSS GPRS protocol (BSSGP) <https://www.3gpp.org/DynaReport/48018.htm>

- [57] [3gpp-ts-48-049] 3GPP TS 48.049: Digital cellular communications system; Base Station Controller - Cell Broadcast Centre (BSC-CBC) interface specification; Cell Broadcast Service Protocol (CBSP) <https://www.3gpp.org/DynaReport/48049.htm>
- [58] [3gpp-ts-48-056] 3GPP TS 48.056: Base Station Controller - Base Transceiver Station (BSC - BTS) interface; Layer 2 specification <https://www.3gpp.org/DynaReport/48056.htm>
- [59] [3gpp-ts-48-058] 3GPP TS 48.058: Base Station Controller - Base Transceiver Station (BSC - BTS) Interface; Layer 3 specification <https://www.3gpp.org/DynaReport/48058.htm>
- [60] [3gpp-ts-51-011] 3GPP TS 51.011: Specification of the Subscriber Identity Module - Mobile Equipment (SIM-ME) interface
- [61] [3gpp-ts-51-014] 3GPP TS 51.014: Specification of the SIM Application Toolkit for the Subscriber Identity Module - Mobile Equipment (SIM - ME) interface <https://www.3gpp.org/DynaReport/51014.htm>
- [62] [3gpp-ts-52-021] 3GPP TS 52.021: Network Management (NM) procedures and messages on the A-bis interface <https://www.3gpp.org/DynaReport/52021.htm>
- [63] [etsi-tr102216] ETSI TR 102 216: Smart cards https://www.etsi.org/deliver/etsi_tr/102200_102299/102216/-03.00.00_60/tr_102216v030000p.pdf
- [64] [etsi-ts102221] ETSI TS 102 221: Smart Cards; UICC-Terminal interface; Physical and logical characteristics https://www.etsi.org/deliver/etsi_ts/102200_102299/102221/13.01.00_60/ts_102221v130100p.pdf
- [65] [etsi-ts101220] ETSI TS 101 220: Smart Cards; ETSI numbering system for telecommunication application providers https://www.etsi.org/deliver/etsi_ts/101200_101299/101220/12.00.00_60/ts_101220v120000p.pdf
- [66] [ieee-802.1q] IEEE 802.1Q: Bridges and Bridged Networks <https://ieeexplore.ieee.org/document/6991462>
- [67] [ietf-rfc768] IETF RFC 768: User Datagram Protocol <https://tools.ietf.org/html/rfc768>
- [68] [ietf-rfc791] IETF RFC 791: Internet Protocol <https://tools.ietf.org/html/rfc791>
- [69] [ietf-rfc793] IETF RFC 793: Transmission Control Protocol <https://tools.ietf.org/html/rfc793>
- [70] [ietf-rfc1035] IETF RFC 1035: Domain Names - Implementation and Specification <https://tools.ietf.org/html/rfc1035>
- [71] [ietf-rfc1350] IETF RFC 1350: Trivial File Transfer Protocol <https://tools.ietf.org/html/rfc1350>
- [72] [ietf-rfc2131] IETF RFC 2131: Dynamic Host Configuration Protocol <https://tools.ietf.org/html/rfc2131>
- [73] [ietf-rfc2474] IETF RFC 2474: Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers <https://tools.ietf.org/html/rfc2474>
- [74] [ietf-rfc2719] IETF RFC 2719: Signal Transport over IP <https://tools.ietf.org/html/rfc2719>
- [75] [ietf-rfc3331] IETF RFC 3331: Message Transfer Part 2 User Adaptation Layer <https://tools.ietf.org/html/rfc3331>
- [76] [ietf-rfc3550] IETF RFC 3550: RTP: A Transport protocol for Real-Time Applications <https://tools.ietf.org/html/rfc3550>
- [77] [ietf-rfc3596] IETF RFC 3596: DNS Extensions to Support IP Version 6 <https://tools.ietf.org/html/rfc3596>
- [78] [ietf-rfc3868] IETF RFC 3868: SCCP User Adaptation Layer <https://tools.ietf.org/html/rfc3868>
- [79] [ietf-rfc4165] IETF RFC 4165: Message Transfer Part 2 Peer-to-Peer Adaptation Layer <https://tools.ietf.org/html/rfc4165>
- [80] [ietf-rfc4251] IETF RFC 4251: The Secure Shell (SSH) Protocol Architecture <https://tools.ietf.org/html/rfc4251>
- [81] [ietf-rfc4666] IETF RFC 4666: Message Transfer Part 3 User Adaptation Layer <https://tools.ietf.org/html/rfc4666>

- [82] [ietf-rfc5771] IETF RFC 5771: IANA Guidelines for IPv4 Multicast Address Assignments <https://tools.ietf.org/html/rfc5771>
- [83] [itu-t-q701] ITU-T Q.701: Functional Description of the Message Transfer Part (MTP) <https://www.itu.int/rec/-T-REC-Q.701/en/>
- [84] [itu-t-q711] ITU-T Q.711: Functional Description of the Signalling Connection Control Part <https://www.itu.int/rec/T-REC-Q.711/en/>
- [85] [itu-t-q713] ITU-T Q.713: Signalling connection control part formats and codes <https://www.itu.int/rec/T-REC-Q.713/en/>
- [86] [itu-t-q714] ITU-T Q.714: Signalling connection control part procedures <https://www.itu.int/rec/T-REC-Q.714/en/>
- [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>
- [88] [smpp-34] SMPP Develoepers Forum. Short Message Peer-to-Peer Protocol Specification v3.4 https://docs.nimta.com/SMPP_v3_4_Issue1_2.pdf
- [89] [gnu-agplv3] Free Software Foundation. GNU Affero General Public License. <https://www.gnu.org/licenses/-agpl-3.0.en.html>
- [90] [freeswitch_pbx] FreeSWITCH SIP PBX <https://freeswitch.org>