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| 3GPP TR 33.845 V0.5.0 (2020-10) | |
| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Service Aspects;  Study on storage and transport of 5GC security parameters for ARPF authentication (Release 16) | |
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For definitive guidance on drafting 3GPP TSs and TRs, see [3GPP TS 21.801](http://www.3gpp.org/DynaReport/21801.htm) supplemented by the 3GPP web page <http://www.3gpp.org/specifications-groups/delegates-corner/writing-a-new-spec>.

Ensure all blue guidance text is removed before submitting the TS/TR to the TSG for approval.

# Foreword

This clause is mandatory; do not alter the text in any way other than to choose between "Specification" and "Report".

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In drafting the TS/TR, pay particular attention to the use of modal auxiliary verbs! TRs shall not contain any normative provisions.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# Introduction

In Release 15, the ability to store various security parameters are standardised for the ARPF and the UDR. However, the security of this storage and the security related to transporting security parameters from the UDR to the UDM/ARPF are not defined.

This document provides the background and lists potential solutions for identified key issues.

# 1 Scope

The present document details the following:

- The security assumptions relating to security communication in 5G.

- The security assumptions related to protecting subscriber privacy.

- The home network parameters that are relevant to securing the communication in 5G and protecting subscriber privacy.

- Key Issues, threats and requirements relevant to securing the communication in 5G and protecting subscriber privacy.

- Solutions that potentially resolve the key issues described.

The present document does not describe the storage of security parameters in the UE or the serving network or the transportation of secure information between the home network and the serving network.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 33.501: "Security Architecture and Procedures for 5G System".

[3] 3GPP TS 35.205: "Specification of the MILENAGE algorithm set: An example algorithm set for the 3GPP authentication and key generation functions f1, f1\*, f2, f3, f4, f5 and f5\*; Document 1: General".

[4] 3GPP TS 35.231: "Specification of the Tuak algorithm set: A second example algorithm set for the 3GPP authentication and key generation functions f1, f1\*, f2, f3, f4, f5 and f5\*; Document 1: Algorithm specification ".

[5] 3GPP TS 23.632: "User Data Interworking, Coexistence and Migration".

[6] 3GPP TS 33.401: "3GPP System Architecture Evolution (SAE); Security architecture".

[7] 3GPP TS 33.402: "3GPP System Architecture Evolution (SAE); Security aspects of non-3GPP accesses".

[8] 3GPP TS 33.203: "3G security; Access security for IP-based services".

[9] 3GPP TS 33.220: "3G security; Generic Authentication Architecture (GAA); Generic Bootstrapping Architecture (GBA)".

[10] 3GPP TS 23.501: "System Architecture for the 5G System; Stage 2"

[11] 3GPP TS 29.505: "5G System; Usage of the Unified Data Repository services for Subscription Data".

[12] 3GPP TS 29.500: "5G System; Technical Realization of Service Based Architecture".

[13] 3GPP TS 23.502: "Procedures for the 5G System; Stage 2

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

Editor's Note: 'authentication subscription data' and 'subscription data' need to be defined.

For the purposes of the present document, the terms given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

Definition format (Normal)

**<defined term>:** <definition>.

**example:** text used to clarify abstract rules by applying them literally.

## 3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

Abbreviation format (EW)

<ACRONYM> <Explanation>

# 4 Security assumptions relating to communication security in 5G

## 4.1 Overview

As defined in TS 33.501 [2], the UDM plays a key role in primary authentication and the privacy feature by supporting the ARPF and SIDF functionality.

The ARPF and SIDF functionality requires the use of certain security parameters. The security parameters used for the ARPF functionality (authentication subscription data) are specified in clause 5.1. When UDM makes use of the UDR to manage subscription data, part of the security parameters required by the ARPF and SIDF may be stored in UDR as described in clause 4.2.

## 4.2 Models for ARPF and UDR setup

### 4.2.1 Model #A: Security parameters stored only in the ARPF

The model where security parameters for the execution of primary authentication are stored only at the ARPF corresponds to a stateful UDM/ARPF deployment model where UDR is not used.

### 4.2.2 Model #B: Security parameters stored only in the UDR

The model where all security parameters for the execution of primary authentication are only stored at the UDR.

Editor's Note: It is FFS on how to formulate this clause.

### 4.2.3 Model #C: Security parameters stored both in the ARPF and the UDR

This is a stateless UDM/ARPF deployment model.

The model where the security parameters for the execution of primary authentication common across subscribers within PLMN are stored in the ARPF and the security requirements specific to individual subscribers are stored in the UDR corresponds to a stateless UDM/ARPF deployment model.

TS 29.505 [11] specifies the usage of the Unified Data Repository, Nudr, services for subscription data. This specification provides the resource definition and data model for subscription data used over the Nudr Service Based Interface.

Editor's Note: The text below needs to be put into a suitable section

When it comes to the definition of resources related to subscription authentication material, TS 29.505 [11] defines the *AuthenticationSubscription* data type supporting primary authentication as follows:

Table 4.2.3-1: TS 29.505 [11], Table 5.4.2.2-1: Definition of type AuthenticationSubscription

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Attribute name* | *Data type* | *P* | *Cardinality* | *Description* |
| *authenticationMethod* | *AuthMethod* | *M* | *1* | *String containing the Authentication Method ( "5G\_AKA" , "EAP\_AKA\_PRIME, "EAP\_TLS"...)."* |
| *encPermanentKey* | *string* | *C* | *0..1* | *The encrypted value (hexstring) of the permanent authentication key (K) (see 3GPP TS 33.501 [9]).*  *It shall be present if the authentication method is "5G\_AKA" or "EAP\_AKA\_PRIME".* |
| *protectionParameterId* | *string* | *C* | *0..1* | *Identifies a parameter set securely stored in the UDM(ARPF) that can be used to decrypt the encPermanentKey (and encOpcKey or encTopcKey if present). Values and their meaning are HPLMN-operator specific.*  *It shall be present if the authentication method is "5G\_AKA" or "EAP\_AKA\_PRIME".* |
| *sequenceNumber* | *SequenceNumber* | *C* | *0..1* | *String containing the SQN as defined in 3GPP TS 33.102 [10].*  *It shall be present if the authentication method is "5G\_AKA" or "EAP\_AKA\_PRIME".* |
| *authenticationManagementField* | *string* | *C* | *0..1* | *Hexstring containing the Authentication management field as defined in 3GPP TS 33.501 [9].*  *It shall be present if the authentication method is "5G\_AKA" or "EAP\_AKA\_PRIME".*  *Pattern: '^[A-Fa-f0-9]{4}$'* |
| *algorithmId* | *string* | *C* | *0..1* | *Identifies a parameter set securely stored in the UDM(ARPF) that provides details on the algorithm and parameters used to generate authentication vectors. Values and their meaning are HPLMN-operator specific.*  *It shall be present if the authentication method is "5G\_AKA" or "EAP\_AKA\_PRIME".* |
| *encOpcKey* | *string* | *O* | *0..1* | *Hexstring of the encrypted OPC Key.*  *Presence indicates that the provided value (decrypted) shall be used instead of the value derived from OP and K.* |
| *encTopcKey* | *string* | *O* | *0..1* | *Hexstring of the encrypted TOPC Key.*  *Presence indicates that the provided value (decrypted) shall be used instead of the value derived from TOP and K.* |

As shown, the *AuthenticationSubscription* data type includes only the security parameters defined at individual subscriber’s basis required for the execution of AKA such as:

- Long term Key(s), including *encPermanentKey* and optionally *encOpcKey/encTopcKey*.

- Sequence Number, SQN (*sequenceNumber*).

- Authentication Management Field, AMF (*authenticationManagementField*).

- The identifier of the authentication algorithm (*algorithmId*).

The *algorithmId* attribute does not contain all the related information but it rather contains a string which refers to a parameter set securely stored in the UDM/ARPF. The *algorithmId* attribute identifies the authentication algorithm as well as other related parameters associated to the authentication algorithm which do not need to be specific for individual subscriber’s (e.g. settings for the constants *c* and/or *r* for MILENAGE) are referred to in the *AuthenticationSubscription* data resource by the *algorithmId* attribute.

The definition of the *AuthenticationSubscription* data type allows for the use of proprietary authentication algorithms and SQN schemes by the choice of ENUMERATED and/or string values for relevant information elements within the *AuthenticationSubscription* data type and making use if required of the API extensibility mechanisms defined in TS 29.500 [12] for any JSON object of any API.

Finally, based on implementation-specific means, it is possible that the storage of the *AuthenticationSubscription* resources within a UDR NF instance is managed in specific storage resources within the UDR NF instance. This can allow that the security parameters defined within the *AuthenticationSubscription* data type could be isolated from the rest of storage resources used for storing other subscription profile information within the UDR NF instance as described in TS 29.500 [12] and TS 29.505 [11].

## 4.3 Primary Authentication

3GPP TS 33.501 [2] defines primary authentication to enable mutual authentication between the UE and the network. It uses the pre-shared long-term Key which is bind to a unique SUPI to authenticate each other. The long-term Key is stored in the USIM and the ARPF of home network separately. The ARPF shall process the K only in its secure environment, the ARPF is a service offered by UDM.

Two methods including EAP-AKA' and 5G-AKA are defined for primary authentication, which method is used for mutual authentication is determined by the ARPF/UDM. The authentication methods are stored in the ARPF. The other security parameters (e.g. SQN, AMF) in addition to the K required for the primary authentication are also held by the ARPF.

During the registration procedure, the AMF determines to trigger the primary authentication on–demand for the UE. If the primary authentication is required, the AMF requests it from the AUSF. Upon request from the AMF, the AUSF shall execute authentication of the UE. In the primary authentication procedure, the ARPF is required for key storage, authentication methods storage, and key derivation.

## 4.4 Secondary Authentication

3GPP TS 33.501 [2] defines secondary authentication for a DN to authenticate and/or authorize a UE to access the DN. The EAP framework based authentication is introduced for secondary authentication between the UE and the DN-AAA server in the DN.

During the PDU session establishment procedure, the SMF (in non-roaming and Home Routed roaming cases, the H-SMF; in LBO case, the V-SMF) determines whether the secondary authentication is required via exchanging with UDM. If secondary authentication is required, the SMF shall trigger EAP authentication procedure. The UE and the DN AAA server exchange EAP message for secondary authentication. On the network side, the credential of the UE for secondary authentication is stored in DN-AAA.

## In the secondary authentication procedure, the ARPF is not involved.4.5 Privacy

3GPP TS 33.501 [2] defines a mechanism for subscription identifier privacy over-the-air. It uses the SUCI which is a privacy preserving identifier generated at the UE and containing the concealed SUPI, using a Home Network Public Key securely provisioned in the USIM and in control of the home network.

The Home Network Private Key used for subscriber privacy is protected from physical attacks in the UDM: TS 33.501 section 6.2.2.1, specifies that "*the ARPF holds the home network private key that is used by the SIDF to deconceal the SUCI and reconstruct the SUPI*".

In the network side, the SIDF (Subscription Identifier De-concealing Function) is responsible for de-concealment of the SUCI using a Home Network Private Key. The SIDF is a service offered by UDM and holds the Home Network Public Key Identifier(s) for the private/public key pair(s) used for subscriber privacy.

# 5 Parameters relevant to securing 5G communication

## 5.1 Overview

Authentication subscription data is data that:

- is needed for the generation of authentication vectors in the UDM/ARPF (as described in 3GPP TS 33.501 [2]); and

- is stored in the 5G core network.

NOTE 1: Other data related to authentication, but that does not need to be stored in the 5G core network is not authentication subscription data.

For AKA-based authentication, the authentication subscription data consists of:

- the long term key K;

- the sequence number SQN;

- (optionally) the authentication management field AMF;

NOTE 2: it is an operator policy whether the authentication management field AMF is stored or generated; therefore it is optionally included in the set of authentication subscription data.

- additional parameters depending on the authentication algorithm used (e.g. OP or OPc if MILENAGE (cf. 3GPP TS 35.205 [3]) is used, TOP or TOPc if TUAK (cf. 3GPP TS 35.231 [4]) is used, other parameters for proprietary algorithms);

- the authentication method used;

- the authentication algorithm used (e.g. MILENAGE, TUAK, proprietary algorithm).

Authentication subscription data may be specific per SUPI (e.g. long term key K, sequence number SQN, MILENAGE parameter OPc, TUAK parameter TOPc), or it may be generic (e.g. MILENAGE parameter OP, TUAK parameter TOP).

Editor’s note: it is FFS which part of the authentication subscription data needs to be secured during storage and transfer (if transferred).

Editor’s note: it is FFS whether or not to distinguish multiple levels of security (extremely high, high, medium) for the securing of stored and/or transferred data.

## 5.2 Milenage AKA authentication

To enable Milenage authentication algorithm, the following parameters are needed:

- OP (the operator variant algorithm configuration field);

- OPc (value derived from OP and K);

- c1,c2,c3,c4,c5 (value XORed onto intermediate variables);

- r1,r2,r3,r4,r5 (value used to define amounts by which intermediate variables are cyclically rotated);

## 5.3 TUAK AKA authentication

To enable TUKA authentication algorithm, the following parameters are needed:

- TOP (the operator variant algorithm configuration field);

- TOPc (value derived from TOP and K);

- ALGONAME (value specified as the ASCII representation of the string "TUAK1.0");

-

- the length of K (K is a 128-bit or 256-bit subscriber key that is an input to the functions *f1*, *f1\**, *f2*, *f3*, *f4*, *f5* and *f5\**);

- the length of MAC-A (MAC-A is a 64-bit, 128-bit or 256-bit network authentication code that is the output of the function *f1*);

- the length of MAC-S (MAC-S is a 64-bit, 128-bit or 256-bit resynchronization authentication code that is the output of the function *f1\**);

- the length of RES (RES is a 32-bit, 64-bit, 128-bit or 256-bit signed response that is the output of the function *f2*);

- the length of CK (CK is a 128-bit or 256-bit confidentiality key that is the output of the function *f3*);

- the length of IK (IK is a 128-bit or 256-bit integrity key that is the output of the function *f4*);

## 5.4 EAP methods for authentication

Editor's Note: Content to be added to this section

## 5.5 Proprietary authentication algorithms

Editor's Note: Content to be added to this section

## 5.6 AMF related parameters

To enable AKA-based authentication, the following AMF related parameters are needed: SUCI or SUPI;

The serving network name;

## 5.7 Counter related parameters

To enable AKA-based authentication, the following counter related parameters are needed:

- sqnScheme (scheme for generation of Sequence Numbers);

- sqn (value containing the SEQ part of SQN, and the IND part which is filled with 0's. When the sqnScheme is "TIME\_BASED", the SEQ part is the DIF value.);

- lastIndexes (a map of integer values map(integer), where the integer is the last used value of IND);

- indLength (number of bits of the IND part of SQN);

# 6. Key Issues

6.1 Key Issue #1: Separation of authentication subscription data from subscription data

6.1.1 Key issue details

The Unified Data Repository (UDR) is located in the same PLMN as the NF service consumers are storing or retrieving data from UDR using Nudr services. Data stored in the UDR are subscription data, authentication subscription data, policy data, structured data for exposure, and application data (see 3GPP TS 29.505).

Nudr is an intra-PLMN interface and allows NF consumers to use its service to retrieve, create, update, subscribe for change notifications, unsubscribe for change notifications and delete data stored in the UDR, based on the set of data applicable to the consumer.

6.1.2 Security threats

UDR can be accessed by several NFs. If authentication subscription data is accessible in the same branche of the data model as subscription data, also other NFs than UDM may be able to access those data.

6.1.3 Potential security requirements

Sensitive data such as authentication subscription data should be compartmentalized from subscription data.

For authentication subscription data, which are sensitive data, the access shall be limited to UDM only.

## 6.2 Key Issue #2: protection of long-term key during storage in UDR

### 6.2.1 Key issue details

In case the long-term key, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF, is stored in the UDR separate from the UDM/ARPF, then this key needs to be protected. This key issue addresses this need.

### 6.2.2 Security threats

If the stored long-term key can be modified in the UDR, this can cause a DOS attack by invalidating regular authentication subscription data.

If the stored long-term key is obtained, then it can be used to access previously recorded communications.

If the stored long-term key retrieved from a subscriber's authentication subscription data can be copied to another subscriber's authentication subscription data, then this can result in stealing network access from the first subscriber.

### 6.2.3 Potential security requirements

The long-term key in the UDR shall be protected against retrieval by unauthorized network elements and by unauthorized persons.

The long-term key shall be protected against unauthorized modification after storage in the UDR.

It shall be prevented that the long-term key is copied from one subscriber's authentication subscription data to another subscriber's authentication subscription data.

## 6.3 Key Issue #3: protection of long-term key during transfer out of UDR

### 6.3.1 Key issue details

In case the long-term key, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF, is transferred out of the UDR to the UDM/ARPF, then this key needs to be protected during its transfer. This key issue addresses this need.

### 6.3.2 Security threats

If the long-term key can be modified during transfer out of the UDR to the UDM/ARPF, this can cause a DOS attack by generating invalid authentication vectors in the UDM/ARPF.

If the long-term key is obtained during transfer out of the UDR, then it can be used to access previously recorded communications.

### 6.3.3 Potential security requirements

The long-term key shall be protected during transfer out of the UDR against eavesdropping by unauthorized network elements and by unauthorized persons.

The long-term key shall be protected against modification during transfer out of the UDR.

## 6.4 Key Issue #4: protection of Milenage OPc value during storage in UDR

### 6.4.1 Key issue details

In case the Milenage OPc value, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF – in case Milenage [3] is used – is stored in the UDR separate from the UDM/ARPF, then this value needs to be protected. This key issue addresses this need.

### 6.4.2 Security threats

OPc values are one of the sensitive data items needed to populate USIMs. If OPc values are obtained by unauthorized network elements or by unauthorized persons, this increases the risk of unauthorized USIM creation.

If the stored OPc value can be modified in the UDR, this can cause a DOS attack by invalidating regular authentication subscription data.

### 6.4.3 Potential security requirements

The OPc value shall be protected against retrieval by unauthorized network elements and by unauthorized persons.

The OPc value shall be protected against unauthorized modification during storage in the UDR.

## 6.5 Key Issue #5: protection of Milenage OPc value during transfer out of UDR

### 6.5.1 Key issue details

In case the Milenage OPc value, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF – in case Milenage [3] is used – is transferred out of the UDR to the UDM/ARPF, then this value needs to be protected. This key issue addresses this need.

### 6.5.2 Security threats

OPc values are one of the sensitive data items needed to populate USIMs. If OPc values are obtained by unauthorized network elements or by unauthorized persons, this increases the risk of unauthorized USIM creation.

If the stored OPc value can be modified during transfer out of the UDR, this can cause a DOS attack by invalidating regular authentication subscription data.

### 6.5.3 Potential security requirements

The OPc value shall be protected during transfer out of the UDR against eavesdropping by unauthorized network elements and by unauthorized persons.

The OPc value shall be protected against modification during transfer out of the UDR.

## 6.6 Key Issue #6: protection of Milenage OP value during storage in UDR

### 6.6.1 Key issue details

In case the Milenage OP value, which can be used to generate the OPc value that is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF – in case Milenage [3] is used – is stored in the UDR separate from the UDM/ARPF, then this value needs to be protected. This key issue addresses this need.

### 6.6.2 Security threats

If the OP value can be obtained by an unauthorized network element or an unauthorized person, it can be used – in combination with long-term keys – to create subscriber specific Milenage OPc values. These OPc values are one of the data items needed to populate USIMs.

If the stored OP value can be modified in the UDR, this can cause a DOS attack by invalidating regular authentication subscription data.

### 6.6.3 Potential security requirements

If the OP value is stored in the UDR, then the OP value shall be protected against retrieval by unauthorized network elements and by unauthorized persons.

If the OP value is stored in the UDR, then the OP value shall be protected against unauthorized modification after storage in the UDR.

## 6.7 Key Issue #7: protection of Milenage OP value during transfer out of UDR

### 6.7.1 Key issue details

In case the Milenage OP value, which can be used to generate the OPc value that is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF – in case Milenage [3] is used – is transferred out of the UDR to the UDM/ARPF, then this value needs to be protected. This key issue addresses this need.

### 6.7.2 Security threats

If the OP value can be obtained by an unauthorized network element or an unauthorized person, it can be used – in combination with long-term keys – to create subscriber specific Milenage OPc values. These OPc values are one of the data items needed to populate USIMs.

If the stored OP value can be modified in the UDR, this can cause a DOS attack by invalidating regular authentication subscription data.

### 6.7.3 Potential security requirements

If the OP value is stored in the UDR, then the OP value shall be protected during transfer out of the UDR against eavesdropping by unauthorized network elements and by unauthorized persons.

If the OP value is stored in the UDR, then the OP value shall be protected against modification during transfer out of the UDR.

## 6.8 Key Issue #8: protection of sequence number SQNHE during storage in UDR

### 6.8.1 Key issue details

In case the sequence number SQNHE, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF is stored in the UDR separate from the UDM/ARPF, then this sequence number needs to be protected. This key issue addresses this need.

### 6.8.2 Security threats

If the SQNHE can be obtained by an unauthorized network element or an unauthorized person, it can be used to identify and track a subscriber.

### 6.8.3 Potential security requirements

The SQNHE shall be protected against retrieval by unauthorized network elements and by unauthorized persons.

## 6.9 Key Issue #9: protection of sequence number SQNHE during transfer out of UDR

### 6.9.1 Key issue details

In case the sequence number SQNHE, which is part of the authentication subscription data needed to generate authentication vectors in the UDM/ARPF is transferred out the UDR to the UDM/ARPF, then this sequence number needs to be protected. This key issue addresses this need.

### 6.9.2 Security threats

If the SQNHE can be obtained by an unauthorized network element or an unauthorized person, it can be used to identify and track a subscriber.

### 6.9.3 Potential security requirements

The SQNHE shall be protected during transfer out of the UDR against eavesdropping by unauthorized network elements and by unauthorized persons.

## 6.x Key Issue #<X>: <Issue Title>

### 6.x.1 Key issue details

### 6.x.2 Security threats

### 6.x.3 Potential security requirements

# 7 Solutions

## 7.1 Solution 1: Authorization and Isolation of Authentication Data using existing techniques.

### 7.1.1 Introduction

This solution addresses key issue 1 on "Separation of authentication subscription data from subscription data".

The solution proposes the use of a UDR dedicated for subscription data and further isolation of the authentication data within this UDR based on internal implementation techniques.

This solution is based on capabilities defined or planned to already to be defined in 3GPP TSs and does not require any additional specification work.

### 7.1.2 Solution details

As defined in 3GPP TS 23.501 [10] the UDR is located in the same PLMN as the NF service consumers storing in and retrieving data from it using Nudr. This is, Nudr is an intra-PLMN interface.

The only NF service consumers that are defined to use UDR as per 3GPP TS 23.502 [13] are UDM (for subscription data), PCF (for policy subscription data), NEF (for exposure and application data) and NRF/SCP (for NF Group ID mapping data). It is possible however that multiple UDRs are deployed in the network, each of which can accommodate different data sets or subsets, (e.g. subscription data, subscription policy data, data for exposure, application data) and/or serve different sets of NFs. This is, it is possible to deploy a UDR dedicated to store subscription data used and accessed only by UDM. In this case, the UDR profile stored in the NRF can indicate that ONLY UDM NFs are authorized to discover UDR instances storing subscription data (i.e. NF consumers other than UDM will not be able to discover UDR instances handling subscription data nor authentication subscription data).

Even in the case where the same UDR is deployed to support storage of data for multiple NF consumers (e.g. UDM, PCF and NEF), UDR can authorize the access of specific data resources for specific operations (e.g. read, modify) on a per NF type basis using the OAuth 2.0 based Authorization Framework defined in 3GPP 33.501 [2] for Release 16.

The OAuth 2.0 based authorization framework defined in 3GPP 33.501 [2] is being enhanced in Release 16 to support the generation and validation of authorization tokens including authorization not only at service level but also to service operation and resource level. This allows the possibility to generate OAuth 2.0 tokens to retrieve *AuthenticationSubscription* data ONLY to UDM NF type of service consumers.

Finally, based on implementation-specific means, it is possible that the storage of the *AuthenticationSubscription* data resources within a UDR NF instance are managed in specific storage resources within the UDR NF instance as described in 3GPP TS 29.500 [12] and 3GPP TS 29.505 [11]. This can allow that the security parameters defined within the *AuthenticationSubscription* data type could be isolated from the rest of storage resources used for storing other subscription profile information within the UDR NF instance not only from a traffic reference point (i.e. via Nudr) but also from Provisioning and OAM interfaces.

### 7.1.3 Evaluation

## 7.2 Solution 2: Protection of LTK access over Nudr.

### 7.2.1 Introduction

This solution addresses key issue 2 on "protection of long-term key during storage in UDR ".

The solution describes how the long-term key in the UDR can be protected against modification by any network function and retrieval by unauthorized network elements over Nudr using the OAuth 2.0 based authorization framework defined in 3GPP TS 33.501 [2] in Release 16.

This solution is based on capabilities defined or planned to already to be defined in 3GPP TSs and does not require any additional specification work.

### 7.2.2 Solution details

The OAuth 2.0 based authorization framework defined in 3GPP 33.501 [2] is being enhanced in Release 16 to support the generation and validation of authorization tokens including authorization not only at service level but also to service operation and resource level. This allows the possibility to generate OAuth 2.0 tokens to retrieve *AuthenticationSubscription* data ONLY to UDM/ARPF NF type of service consumers.

UDR will in any case prevent the modification of LTK within the *AuthenticationSubscription* data resource by the UDM/ARPF over Nudr as defined in 3GPP TS 29.505 [11]:

*Table 5.2.1-1 provides an overview of the resources and applicable HTTP methods.*

*Table 5.2.1-1: Resources and methods overview*

|  |  |  |  |
| --- | --- | --- | --- |
| *Resource name* | *Resource URI* | *HTTP method* | *Description* |
| *AuthenticationSubscription* | */subscription-data/{ueId}/authentication-data/authentication-subscription* | *GET* | *Retrieve a UE's authentication subscription data* |
| *PATCH* | *Update a UE's authentication subscription data*  *Updates shall be limited to the* ***sequenceNumber*** *attribute. Attempts to patch any other attribute shall be rejected by the UDR.* |

The long-term key should be additionally provisioned and stored encrypted in UDR. This solution does not cover security requirements (e.g. encryption algorithms) for this.

Editor’s note: evaluation of this solution shall also consider the completeness of this solution against all threats to accessing the long term key.

### 7.2.3 Evaluation

## 7.3 Solution 3: Protection of LTK over Nudr

### 7.3.1 Introduction

This solution addresses key issue 3 on "protection of long-term key during transfer out of UDR".

The solution is based on storing the long-term key encrypted in UDR and transferring it also encrypted over Nudr. As any other SBA reference point, Nudr is additionally protected using TLS as defined in 3GPP TS 33.501 [2].

This solution is based on capabilities defined or planned to already to be defined in 3GPP TSs and does not require any additional specification work.

### 7.3.2 Solution details

The OAuth 2.0 based authorization framework defined in 3GPP 33.501 [2] is being enhanced in Release 16 to allows the possibility to generate OAuth 2.0 tokens to retrieve *AuthenticationSubscription* data ONLY to UDM/ARPF NF type of service consumers.

This solution proposes that the protection of the long-term key while provided to the UDM/ARPF over Nudr is two-fold:

* In the first place, the long-term key is provisioned and stored in UDR in encrypted form. This solution does not cover actual mechanisms to perform such encryption (e.g. encryption algorithms, key length, etc …).
* Secondly, as any other SBA reference point, the Nudr is protected using TLS as defined in 3GPP TS 33.501 [2].

These two protection levels make impossible for any intermediate actor to eavesdrop or modify the long-term key while in transit over Nudr.

### 7.3.3 Evaluation

This solution addresses the requirements of the KI by protecting the transfer of the long-term key between the UDR and the UDM/ARPF in three ways:

- transporting the long-term key in encrypted form during its transfer from UDR to UDM/APRF, and

- additionally, protecting the transfer of the long-term key over Nudr based on secure encrypted transport mechanisms (such as HTTPS).

- the OAuth tokens allow for the long-term key to only be retrieved by the UDM/ARPF

This solution requires that the UDM/ARPF stores the decryption key. The storage of the decryption key at the UDM/ARPF is subject to the same security requirements as if the ARPF would store the long-term keys. That is, the decryption key shall be protected from physical attacks and shall never leave the secure environment of the UDM/ARPF unprotected. This required security of the decryption key can be achieved as it is done in pre-5G networks (e.g. by using a Hardware Security Module in the UDM/ARPF). It may be desirable to export a protected copy of the decryption key to a backup location, to aid recovery if necessary.

## 7.4 Solution #4: Encrypted storage of the long-term key in the UDR

### 7.4.1 Introduction

This solution addresses key issue #2 on "protection of long-term key during storage in UDR".

In order to protect the long-term key during storage in the UDR, the long-term key is provisioned and stored in encrypted form in the UDR. During primary authentication, the UDM/ARPF retrieves the authentication subscription data for the UE which includes the encrypted long-term key as provisioned and stored in UDR. That is, the long-term key is never provided by the UDR in clear text and there is no need for the UDR to decrypt the long-term key.

At generation of a long-term key an encryption key is used that is shared with the UDM/ARPF where it is decrypted during primary authentication. The generation of a long-term key can be performed in the network of an operator or it can be performed at the facility where USIMs are being provisioned.

### 7.4.2 Solution details

The long-term key is provisioned and stored in encrypted form if stored in the UDR. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

Editor's note: whether or not provisioning to ARPF or UDR is in 3GPP scope is FFS.

### 7.4.3 Evaluation

This solution addresses the requirements of the KI by protecting the long-term key in one way:

- provisioning and storing the long-term key in encrypted in the UDR to UDM/APRF

This solution requires that the UDM/ARPF stores the decryption key. The storage of the decryption key at the UDM/ARPF is subject to the same security requirements as if the ARPF would store the long-term keys. That is, the decryption key shall be protected from physical attacks and shall never leave the secure environment of the UDM/ARPF unprotected. This required security of the decryption key can be achieved as it is done in pre-5G networks (e.g. by using a Hardware Security Module in the UDM/ARPF). It may be desirable to export a protected copy of the decryption key to a backup location, to aid recovery if necessary.

## 7.5 Solution #5: Encrypted transfer of the long-term key between UDR and UDM/ARPF

### 7.5.1 Introduction

This solution addresses key issue #3 on "protection of long-term key during transfer out of UDR".

As described in 3GPP TS 33.501 [2], clause 5.8.1, the long-term key used for authentication and security association setup purposes shall be protected from physical attacks and shall never leave the secure environment of the UDM/ARPF unprotected. If stored in the UDR, the long-term key is always transported in encrypted form during its transfer from UDR to UDM/ARPF.

### 7.5.2 Solution details

The long-term key is transferred in encrypted form between UDR and UDM/ARPF. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

The transfer of the encrypted long-term key over the Nudr interface is protected at transport level using the security mechanisms defined in 3GPP TS 33.501 [2], clause 13.1, as any other SBA interface.

During transfer, a key identifier is associated to the encrypted long-term key to enable identification of the decryption key in the UDM/ARPF.

NOTE: The implementation of how to identify the decryption key is out of scope of 3GPP.

### 7.5.3 Evaluation

This solution addresses the requirements of the KI by protecting the transfer of the long-term key between the UDR and the UDM/ARPF in two ways:

- transporting the long-term key in encrypted form during its transfer from UDR to UDM/APRF, and

- additionally, protecting the transfer of the long-term key over Nudr based on secure encrypted transport mechanisms (such as HTTPS).

This solution requires that the UDM/ARPF stores the decryption key. The storage of the decryption key at the UDM/ARPF is subject to the same security requirements as if the ARPF would store the long term keys. This is, the decryption key shall be protected from physical attacks and shall never leave the secure environment of the UDM/ARPF unprotected. This required security of the decryption key can be achieved as it is done in pre-5G networks (e.g. by using a Hardware Security Module in the UDM/ARPF). It may be desirable to export a protected copy of the decryption key to a backup location, to aid recovery if necessary.

## 7.6 Solution #6: Storage of the LTK in the UDR

### 7.6.1 Introduction

This solution addresses key issue 2, "protection of long-term key during storage in UDR ".

The solution trusts the access tokens created using the OAuth 2.0 based authorization framework to protect the long-term key from retrieval by unauthorised NFs, and that modification of the long-term key is restricted to the *sequenceNumber* attribute.

This solution is based on capabilities defined or planned to be defined in 3GPP TSs and does not require any additional specification work.

### 7.6.2 Solution details

The OAuth 2.0 based authorization framework defined in 3GPP 33.501, clause 13.4.1, is being enhanced in Release 16 to support the generation and validation of authorization tokens, including authorization at resource level. This allows the possibility of generating OAuth 2.0 access tokens to restrict retrieval of *AuthenticationSubscription* data to UDM/ARPF NF type service consumers only, preventing unauthorised access by another other NF type. Such access tokens can be required by the UDM to access the long-term key.

As defined in 3GPP TS 29.505, Clause 5.2.1, Table 5.2.1-1, any modification of the long term key with the *AuthenticationSubscription* data resource by the UDM/ARPF over Nudr is limited to the *sequenceNumber* attribute, and attempts to modify any other attribute shall be rejected by the UDR.

Editor’s Note: evaluation of this solution shall also consider the completeness of this solution against all threats to accessing the long-term key.

### 7.6.3 Evaluation

## 7.7 Solution #7: Transfer of the LTK out of the UDR

### 7.7.1 Introduction

This solution addresses key issue 3, "protection of long-term key during transfer out of UDR ".

The solution trusts the access tokens created using the OAuth 2.0 based authorization framework to protect the long-term key from retrieval by unauthorised NFs and to ensure it is only transported along the Nudr interface, the TLS protection on the Nudr interface, and that modification of the long-term key is restricted to the *sequenceNumber* attribute.

This solution is based on capabilities defined or planned to already to be defined in 3GPP TSs and does not require any additional specification work.

### 7.7.2 Solution details

The OAuth 2.0 based authorization framework defined in 3GPP 33.501, clause 13.4.1, is being enhanced in Release 16 to support the generation and validation of authorization tokens, including authorization at resource level. This allows the possibility of generating OAuth 2.0 access tokens to restrict retrieval of *AuthenticationSubscription* data to UDM/ARPF NF type service consumers only, for which the long-term key will be transported along the Nudr interface. As with any other SBA reference point, Nudr is protected at transport level using TLS as defined in 3GPP TS 33.501 clause 13.1.

As defined in 3GPP TS 29.505, any modification of the long term key with the *AuthenticationSubscription* data resource by the UDM/ARPF over Nudr is limited to the *sequenceNumber* attribute, and attempts to modify any other attribute shall be rejected by the UDR.

### 7.7.3 Evaluation

## 7.8 Solution #8: Encrypted transfer of Milenage OPc value between UDR and UDM/ARPF

### 7.8.1 Introduction

This solution addresses key issue #5 on "protection of Milenage OPc value during transfer out of UDR".

If stored in the UDR, the Milenage OPc value is always transported in encrypted form during its transfer from UDR to UDM/ARPF.

### 7.8.2 Solution details

If stored in the UDR, the Milenage OPc value is transferred in encrypted form between UDR and UDM/ARPF. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

The transfer of the encrypted Milenage OPc value over the Nudr interface is protected at transport level using the security mechanisms defined in 3GPP TS 33.501 [2], clause 13.1, as any other SBA interface.

During transfer, a key identifier is associated to the encrypted Milenage OPc value to enable identification of the decryption key in the UDM/ARPF.

NOTE: The implementation of how to identify the decryption key is out of scope of 3GPP.

### 7.8.3 Evaluation

Editor's note: to be provided.

## 7.9 Solution #9: Encrypted transfer of Milenage OP value between UDR and UDM/ARPF

### 7.9.1 Introduction

This solution addresses key issue #7 on "protection of Milenage OP value during transfer out of UDR".

If stored in the UDR, the Milenage OP value is always transported in encrypted form during its transfer from UDR to UDM/ARPF.

### 7.9.2 Solution details

If stored in the UDR, the Milenage OP value is transferred in encrypted form between UDR and UDM/ARPF. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

The transfer of the encrypted Milenage OP value over the Nudr interface is protected at transport level using the security mechanisms defined in 3GPP TS 33.501 [2], clause 13.1, as any other SBA interface.

During transfer, a key identifier is associated to the encrypted Milenage OP value to enable identification of the decryption key in the UDM/ARPF.

NOTE: The implementation of how to identify the decryption key is out of scope of 3GPP.

### 7.9.3 Evaluation

Editor's note: to be provided.

## 7.10 Solution #10: Encrypted storage of Milenage OPc value in the UDR

### 7.10.1 Introduction

This solution addresses key issue #4 on "protection of Milenage OPc value during storage in UDR".

If the Milenage OPc value is stored in the UDR, it is stored in encrypted form in the UDR. During primary authentication, the UDM/ARPF retrieves authentication subscription data for the UE which can include the Milenage OPc value as stored in UDR. That is, the Milenage OPc value is never provided by the UDR in clear text and there is no need for the UDR to decrypt the Milenage OPc value.

At generation of the Milenage OPc value an encryption key is used that is shared with the UDM/ARPF where it is decrypted during primary authentication. The generation of the Milenage OPc value can be performed in the network of an operator or it can be performed at the facility where USIMs are being provisioned.

### 7.10.2 Solution details

If stored in the UDR, the Milenage OPc value is stored in encrypted form. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

### 7.10.3 Evaluation

Editor's note: to be provided.

## 7.11 Solution #11: Encrypted storage of Milenage OP value in the UDR

### 7.11.1 Introduction

This solution addresses key issue #6 on "protection of Milenage OP value during storage in UDR".

If the Milenage OP value is stored in the UDR, it is stored in encrypted form in the UDR. During primary authentication, the UDM/ARPF retrieves authentication subscription data for the UE which can include the Milenage OP value as stored in UDR. That is, the Milenage OP value is never provided by the UDR in clear text and there is no need for the UDR to decrypt the Milenage OP value.

At selection of the Milenage OP value an encryption key is used that is shared with the UDM/ARPF where it is decrypted during primary authentication. The selection of the Milenage OP value can be performed in the network of an operator or it can be performed at the facility where USIMs are being provisioned.

### 7.11.2 Solution details

If stored in the UDR, the Milenage OP value is stored in encrypted form. The encryption algorithm used and the method for the handling of the encryption/decryption key(s) needs to conform to the security policy requirements of the operator. This solution recommends the use of NIST approved algorithms.

Editor’s note: the encryption algorithm used and the method for the handling of the encryption/decryption key(s) is FFS.

### 7.11.3 Evaluation

Editor's note: to be provided.

## 7.x Solution #<x>: <Solution Title>

### 7.x.1 Introduction

### 7.x.2 Solution details

### 7.x.3 Evaluation

# 8 Conclusions

Editor's Note: Content to be added to this section

# Annex A

## Models for ARPF deployment

### A.1 General

This clause describes the different deployment models for ARPF considering the following aspects:

- Existing architectural decision in TS 33.501 [2] that defines the ARPF as a function provided by the UDM.

- Deployment of the UDM as a fully stateless NF, where subscription data (including the subscription credentials) is stored in the UDR. Stateful deployment options where subscription credentials are stored within the UDM/ARPF are depicted but these do not require any further analysis within the scope of this TR.

- Coexistence with Authentication vector generation functions in other domains (i.e. HSS/AuC).

### A.2 ARPF deployment options in 3GPP TS 33.501 and TS 23.501

In TS 33.501 [2], the ARPF is defined as a function to be provided within the UDM.

For interworking with EPC (and IMS), in TS 23.501 [10], the HSS and the UDM are also defined as a combined NF, i.e. HSS+UDM where interactions between the HSS and the UDM are not specified. The HSS also includes the function to generate authentication vectors in EPS, IMS, GBA and 2G/3G domains; i.e. the AuC.

The HSS+UDM may be deployed as a stateful or stateless NF.

Figure A.2-1 shows the ARPF deployment option when the HSS+UDM is deployed as a stateful NF and subscription credentials are stored within the HSS+UDM (i.e. within the AuC+ARPF).



Figure A.2-1: Stateful ARPF deployment

Figure A.2-2 shows the ARPF deployment option when the HSS+UDM is deployed as a stateless NF and subscription credentials are stored in the UDR (i.e. EPS + 5GS UDR).



Figure A.2-2: Stateless ARPF deployment

### A.3 ARPF deployment options in UDICOM

TS 23.632 [5], defines the Stage 2 architecture, procedures, flows and Network Function Services for User Data Interworking, Coexistence and Migration (UDICOM) between the 5G System and EPS (and IMS).

In the context of UDICOM, HSS and UDM are defined as separate NFs interacting with each other using SBA based interactions over a new NU1 reference point. However, since the subscription credentials shall only be stored centralized in one single place within the system, the UDICOM TS 23.632 [5] defines various options for the generation of authentication vectors.

Figure A.3-1 shows the ARPF deployment option in the context of UDICOM when the HSS and the UDM are deployed as stateful NFs and subscription credentials are stored within the UDM/ARPF.



Figure A.3-1: Stateful ARPF+AuC deployment in UDM according to UDICOM (TS 23.632 [5])

Figure A.3-2 shows the ARPF deployment option in the context of UDICOM when the HSS and the UDM are deployed as stateless NFs and subscription credentials are stored within the 5GS-UDR.



Figure A.3-2: Stateless ARPF+AuC deployment in UDM according to UDICOM (TS 23.632 [5])

In these cases (stateful and stateless ARPF+AuC deployment in UDM), the HSS requests authentication vectors for EPS/IMS/GBA-AKA to the UDM via the new UDICOM NU1 reference point using Nudm services. The UDM does not only support the ARPF functionality but also acts as AuC to generate authentication vectors as defined in 3GPP TS 33.401 [6], 3GPP TS 33.402 [7], 3GPP TS 33.203 [8] and 3GPP TS 33.220 [9].

Figure A.3-3 shows the ARPF deployment option in the context of UDICOM when the HSS and the UDM are deployed as stateful NFs and subscription credentials are stored within the HSS/AuC instead.



Figure A.3-3: Stateful AuC+ARPF deployment in HSS according to UDICOM (TS 23.632 [5])

Figure A.3-4 shows the ARPF deployment option in the context of UDICOM when the HSS and the UDM are deployed as stateless NFs and subscription credentials are kept within the EPS-UDR.



Figure A.3-4: Stateless AuC+ARPF deployment in HSS according to UDICOM (TS 23.632 [5])

In these cases (stateful and stateless AuC+ARPF deployment in HSS), the UDM requests authentication vectors for 5G-AKA or EAP-AKA’ to the HSS via the new UDICOM NU1 reference point using Nhss services. The HSS does not only support the AuC functionality but also acts as ARPF to generate authentication vectors as defined in 3GPP TS 33.501 [2]. In these cases, the ARPF functionality related to the storage of the Home Network Public Key Identifier(s) is always a function provided by the UDM.

Editor's Note: The collocation of ARPF within HSS/AuC conflicts with TS 33.501 which states that the ARPF is a function located within the UDM. SA3 needs to confirm if this ARPF deployment option can be allowed in Release 16 onwards. Dependencies with SIDF functionality in UDM when ARPF is not provided by the UDM need to be checked as well.

Finally, Figure A.3-5 shows the ARPF deployment option in the context of UDICOM when the HSS and the UDM are deployed as stateless NFs and subscription credentials are stored within a common EPS+5GS-UDR.



Figure A.3-5: Stateless ARPF deployment in UDM according to UDICOM (TS 23.632 [5]

In this case, the ARPF is function provided by the UDM while the AuC remains as a function provided by the HSS. HSS/AuC and UDM/ARPF generates authentication vectors for their respective domains accessing to the subscription credentials stored in the common EPS+5GS UDR. The UDICOM NU1 reference point is not used for authentication vector retrieval but it is still required to fulfil HSS and UDM interworking related to other use cases (e.g. intersystem mobility).

# Annex <B> (informative): Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2019-10 | SA3#96Ad-Hoc | S3-193744 | - | - | - | Initial template | 0.0.0 |
| 2019-10 | SA3#96Ad-Hoc | S3-193745 | - | - | - | Version after SA3#96Ad-Hoc incorporating changes from S3-193747 and S3-193748 | 0.1.0 |
| 2019-11 | SA3#97 | S3-194663 | - | - | - | Updated with: S3-194660, S3-194661, S3-194662, S3‑194291, S3-194664, S3-194669 and S3-194670 | 0.2.0 |
| 2020-05 | SA3#99e | S3-201491 | - | - | - | Updated with S3-201025, S3-201428, S3-201027, S3-201170, S3-201171, s3-201362, S3-201364, S3-201174, S3-201175, S3-201184, S3-201404 and S3-201186. | 0.3.0 |
| 2020-08 | SA3#100e | S3-202261 | - | - | - | Added S3-202061, S3-201626, S3-202110, S3-201628, S3-202060 and S3-202059 | 0.4.0 |
| 2020-09 | SA3#100bis-e | S3-20xxxx |  |  |  | Updated with S3-202675, S3-202676, S3-202677, S3-202680, S3-202311, S3-202671, S3-202405, S3-202672, S3-202407 | 0.5.0 |