|  |  |
| --- | --- |
| 3GPP TR 23.700-25 V1.1.0 (2022-10) | |
| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Services and System Aspects;  Study on timing resiliency and TSC  and URLLC enhancements  (Release 18) | |
|  | |
|  |  |
|  | |
| The present document has been developed within the 3rd Generation Partnership Project (3GPP TM) and may be further elaborated for the purposes of 3GPP. The present document has not been subject to any approval process by the 3GPPOrganizational Partners and shall not be implemented. This Specification is provided for future development work within 3GPPonly. The Organizational Partners accept no liability for any use of this Specification. Specifications and Reports for implementation of the 3GPP TM system should be obtained via the 3GPP Organizational Partners' Publications Offices. | |

|  |
| --- |
|  |
| ***3GPP***  Postal address  3GPP support office address  650 Route des Lucioles - Sophia Antipolis  Valbonne - FRANCE  Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16  Internet  http://www.3gpp.org |
| ***Copyright Notification***  No part may be reproduced except as authorized by written permission. The copyright and the foregoing restriction extend to reproduction in all media.  © 2022, 3GPP Organizational Partners (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC).  All rights reserved.  UMTS™ is a Trade Mark of ETSI registered for the benefit of its members  3GPP™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners LTE™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners  GSM® and the GSM logo are registered and owned by the GSM Association |

Contents

Foreword 6

1 Scope 8

2 References 8

3 Definitions of terms, symbols and abbreviations 9

3.1 Terms 9

3.2 Symbols 9

3.3 Abbreviations 9

4 Architectural Assumptions and Requirements 9

4.1 Architectural Assumptions 9

4.2 Architectural Requirements 10

5 Key Issues 10

5.1 Key Issue #1: 5GS network timing synchronization status and reporting 10

5.1.1 Description 10

5.2 Key Issue #2: Time synchronization service enhancements 11

5.2.1 Description 11

5.3 Key Issue #3: Support for controlling 5G time synchronization service based on subscription 11

5.3.1 Description 11

5.4 Key Issue #4: How to enable an AF to explicitly provide PER to NEF/PCF 11

5.4.1 Description 11

5.5 Key Issue #5: Interworking with TSN network deployed in the transport network 11

5.5.1 Description 11

5.6 Key Issue #6: Adapting downstream scheduling based on RAN feedback for low latency communication 12

5.6.1 Description 12

6 Solutions 13

6.0 Mapping of Solutions to Key Issues 13

6.1 Solution #1: Inform UE and AF about network timing synchronization status 13

6.1.1 Introduction 13

6.1.2 Functional Description 14

6.1.3 Procedures 16

6.1.4 Impacts on services, entities and interfaces 16

6.2 Solution #2: Burst arrival time adaptation 17

6.2.1 Introduction 17

6.2.2 Functional Description 17

6.2.3 Procedures 18

6.2.4 Impacts on services, entities and interfaces 18

6.3 Solution #3: Timing synchronization resiliency and status reporting 18

6.3.1 Introduction 18

6.3.2 Functional Description 19

6.3.3 Procedures 19

6.3.4 Impacts on services, entities and interfaces 20

6.4 Solution #4: 5GC learning and reporting network timing synchronization status 21

6.4.1 Introduction 21

6.4.2 Functional Description 22

6.4.2.1 Functional Description for 5GC learning network timing synchronization status 22

6.4.2.2 Functional Description for network timing synchronization status information 23

6.4.2.3 Functional Description for AF requested network timing synchronization status 23

6.4.2.4 Functional Description for network timing synchronization status reporting to UE(s) 24

6.4.3 Procedures 25

6.4.3.1 Procedure for AF requested network timing synchronization status 25

6.4.3.2 Procedure for UE provisioning network timing synchronization status 28

6.4.4 Impacts on services, entities and interfaces 30

6.5 Solution #5: Inform UE and AF about 5GS network timing synchronization status for PTP 31

6.5.1 Introduction 31

6.5.2 Functional Description 31

6.5.3 Procedures 31

6.5.4 Impacts on services, entities and interfaces 31

6.6 Solution #6: Support for 5G Timing Exposure Enhancement. 32

6.6.1 Introduction 32

6.6.2 General description 32

6.6.3 Procedures 32

6.6.4 Impacts on services, entities and interfaces 34

6.7 Solution #7: RequestedCoverage area filters for time synchronization service 34

6.7.1 Introduction 34

6.7.2 Functional Description 34

6.7.3 Procedures 35

6.7.3.1 Procedure for AF requested (g)PTP timing synchronization with Requested Coverage Area 35

6.7.3.1a Procedure for AF requested (g)PTP timing synchronization with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR 37

6.7.3.2 Procedure for AF requested 5G access stratum timing synchronization with Requested Coverage Area 39

6.7.3.2a Procedure for AF requested 5G access stratum timing synchronization with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR 40

6.7.4 Impacts on services, entities and interfaces 42

6.8 Solution #8: AF Request of PER for QoS and Alt-QoS 42

6.8.1 Introduction 42

6.8.2 Functional Description 42

6.8.3 Procedures 42

6.8.4 Impacts on services, entities and interfaces 43

6.9 Solution #9: Interworking with TSN network deployed in the transport network 43

6.9.1 Introduction 43

6.9.2 Functional Description 44

6.9.3 Procedures 47

6.9.4 Impacts on services, entities and interfaces 47

6.10 Solution #10: 5GC acting as a CUC for CNC in TN 48

6.10.1 Introduction 48

6.10.2 Functional Description 48

6.10.3 Procedures 49

6.10.4 Impacts on services, entities and interfaces 51

6.11 Solution #11: Interworking with TSN enabled N3 transport network for deterministic traffic delivery 52

6.11.1 Introduction 52

6.11.2 Functional Description 52

6.11.3 Procedures 54

6.11.4 Impacts on services, entities and interfaces 55

6.12 Solution #12: Cross layer scheduling optimization based on RAN feedback 55

6.12.1 Introduction 55

6.12.2 Functional Description 55

6.12.3 Procedures 56

6.12.4 Impacts on services, entities and interfaces 57

6.13 Solution #13: Pro-active RAN burst timing preference provision 57

6.13.1 Introduction 57

6.13.2 Functional Description 57

6.13.3 Procedures 58

6.13.4 Impacts on existing services and interfaces 59

6.14 Solution #14: Assisted and Complement Timing Support 60

6.14.1 General 60

6.14.2 Functional Description 60

6.14.3 Procedures 61

6.14.3.1 Procedures for (g)PTP time distribution 61

6.14.3.2 Procedures for 5G access stratum time distribution 64

6.14.4 Impacts on services, entities and interfaces 67

6.15 Solution #15: Burst arrival time adaptation 68

6.15.1 Introduction 68

6.15.2 Functional Description 68

6.15.3 Procedures 68

6.15.4 Impacts on services, entities and interfaces 69

6.16 Solution #16: BAT adjustment during a QoS Flow setup or modification 69

6.16.1 Introduction 69

6.16.2 Functional Description 69

6.16.3 Procedures 70

6.16.4 Impacts on services, entities and interfaces 71

6.17 Solution #17: DS-TT and NW-TT assisted 5GS synchronization error detection 71

6.17.1 Introduction 71

6.17.2 Functional Description 72

6.17.3 Procedures 72

6.17.4 Impacts on services, entities and interfaces 73

6.18 Solution #18: Subscription based control of time synchronization service 73

6.18.1 Introduction 73

6.18.2 Functional Description 73

6.18.3 Procedures 75

6.18.3.1 Procedure for subscription based control of access stratum time synchronization service without AF request 75

6.18.3.2 Procedure for subscription based control of access stratum time synchronization service with AF request 76

6.18.3.3 Procedure for subscription based control of (g)PTP time synchronization service without AF request 77

6.18.3.4 Procedure for (g)PTP time synchronization service with AF request 78

6.18.4 Impacts on services, entities and interfaces 78

6.19 Solution 19: Support for controlling 5G time synchronization service based on subscription 79

6.19.1 Introduction 79

6.19.2 General description 79

6.19.3 Procedures 80

6.19.3.1 AF requesting time synchronization service for targeted UE 80

6.19.4 Impacts on services, entities and interfaces 81

6.20 Solution #20: NG-RAN acting as CUC towards CNC of the N3 transport network 81

6.20.1 Introduction 81

6.20.2 Functional Description 81

6.20.3 Procedures 82

6.20.4 Impacts on services, entities and interfaces 82

6.21 Solution #21: BAT adjustment by TSNCF to TSN in the transport network 82

6.21.1 Introduction 82

6.21.2 Functional Description 82

6.21.3 Procedures 83

6.21.4 Impacts on services, entities and interfaces 84

6.22 Solution #22: Transmission opportunities exposure 84

6.22.1 Introduction 84

6.22.2 Functional Description 84

6.22.3 Procedures 85

6.22.4 Impacts on services, entities and interfaces 86

7 Evaluation 86

7.1 Key Issue #3: Support for controlling 5G time synchronization service based on subscription 86

7.2 Key Issue #5: Interworking with TSN network deployed in the transport network 87

7.3 Evaluation for KI #6: Adapting downstream scheduling based on RAN feedback for low latency communication 88

8 Conclusions 89

8.1 Conclusion for KI #4: AF Request of PER for QoS and Alt-QoS 89

8.2 Key Issue #2: Time synchronization service enhancements 89

8.3 Conclusion for KI #5: Interworking with TSN network deployed in the transport network 90

8.4 Key issue #6: Adapting downstream scheduling based on RAN feedback for low latency communication 91

Annex A: Change history 93

# Foreword

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 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.

# 1 Scope

The objective of this Technical Report is to study and perform an evaluation of potential architecture enhancements for supporting 5G Timing Resiliency and TSC & URLLC enhancements for 5G System (5GS). The following aspects are covered:

- Study how to report 5GS network timing synchronization status (such as divergence from UTC and 5GS network timing source degradation) to UEs and 3rd party applications (AFs):

- Study how RAN and 5GC learn about network 5GS network timing synchronization status to be able to inform UEs and AFs.

- Study if additional information needs to be provided to UEs and AFs to inform about 5GS network timing synchronization status.

- Study how to enable AFs to request time synchronization service in a specific coverage area and how to enforce the coverage area.

- Study how to control 5G time synchronization service based on subscription (i.e. introducing subscription parameter for time synchronization and enforcing it).

- Study how to enable an AF to explicitly provide PER to NEF/PCF.

- Study mechanisms for interworking with TSN transport networks. Study interworking mechanisms with TSN networks deployed in the transport network in order to support of E2E determinism and low latency communication and efficient N3 transmission.

- Study if there is a need for applications to adapt downstream scheduling in order for 5GS to meet really low latency (e.g. 2msecs) requirement and if there is a need to have feedback from RAN (e.g. for application to consider DL packet transmission time slots to avoid buffering in the RAN) for this purpose.

# 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 23.501: "System Architecture for the 5G System (5GS); Stage 2".

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

[4] 3GPP TS 23.503: "Policy and charging control framework for the 5G System (5GS); Stage 2".

[5] 3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".

[6] IEEE 802.1Qcc: "IEEE Standard for Local and Metropolitan Area Networks--Bridges and Bridged Networks -- Amendment 31: Stream Reservation Protocol (SRP) Enhancements and Performance Improvements".

[7] IEEE Std 802.1AS: "IEEE Standard for Local and Metropolitan Area Networks-Timing and Synchronization for Time-Sensitive Applications".

[8] IEEE Std 1588: "Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems".

[9] 3GPP TR 22.878: "Feasibility Study on 5G Timing Resiliency System".

[10] IEEE P802.1Qdj d0.2: "Configuration Enhancements for Time-Sensitive Networking".

[11] 3GPP TS 38.321: "Medium Access Control (MAC) protocol specification".

[12] 3GPP TS 38.413: "NG-RAN; NG Application Protocol (NGAP)".

[13] 3GPP TS 38.300: "NR and NG-RAN Overall Description; Stage 2".

[14] IEEE Std 802.1AB-2016: "IEEE Standard for Local and metropolitan area networks - Station and Media Access Control Connectivity Discovery".

[15] ITU-T Recommendation G.8271.1: "Network limits for time synchronization in packet networks with full timing support from the network".

[16] 3GPP TS 23.273: "5G System (5GS) Location Services (LCS); Stage 2".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 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 TR 21.905 [1].

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

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 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 TR 21.905 [1].

<ABBREVIATION> <Expansion>

# 4 Architectural Assumptions and Requirements

## 4.1 Architectural Assumptions

The following architectural assumptions apply:

- The architecture defined in clause 4.4.8 of TS 23.501 [2] is as a baseline for the study.

- The TSN network deployed in the transport network supports the fully centralised model defined in IEEE 802.1 Qcc [6].

NOTE: The transport network and 5GS may belong to the same operator or different operator.

- Configuration and operation of the external synchronization network (i.e. timing synchronization provided by network external to 5GS network) and mitigation actions when time source fails or degrades are assumed to be outside the scope of 3GPP.

- This study is assumed to inherit the time synchronization architecture, methods, and exposure framework as defined in Rel-17 for 5G System in TS 23.501 [2]. This includes the support for time synchronization service based on 5G Access Stratum timing distribution, (g)PTP time sync based on IEEE Std 802.1AS [7] with 5GS acting as Grand-master or PTP time sync with 5GS acting as grand-master based on IEEE Std 1588 [8], along with support for DS-TT, NW-TT and TSCTSF in the time synchronization architecture.

- How the 5GS network is time synchronized is assumed to be deployment specific thus outside the scope of this study (e.g. 5GS may use local GNSS server, may be time synchronized with an external clock using transport network synchronization protocols, etc.).

- The study assumes that sync network design complies with applicable performance requirements also during network rearrangements (for example, in case of ITU-T Recommendation G.8271.1 [15], where budget is allocated to Sync network rearrangements).

## 4.2 Architectural Requirements

The following architectural requirements apply:

- Solutions for timing resilience and time synchronization shall support the already defined time synchronization distribution methods as defined in clause 4.1.

Editor's note: In case of PTP-based time sync, for which IEEE Std 1588 [8] profile(s) to support timing resilience is FFS.

- Solutions for main 5G time resiliency use cases shall at least support that the UEs are static to address financial and power grid scenarios, see TR 22.878 [9]), but may also support the scenarios where the UEs may not be static.

# 5 Key Issues

## 5.1 Key Issue #1: 5GS network timing synchronization status and reporting

### 5.1.1 Description

The objective of this Key Issue is to study the monitoring and reporting for timing synchronization status in 5GS.

For this Key Issue the following areas should be studied:

- Study how RAN and 5GC learn about 5GS network timing synchronization status to be able to inform UEs (e.g. application running in the UE), devices attached to the UE (i.e. that receive time information from 5GS) and AFs.

- Study how to report 5GS network timing synchronization status (such as divergence from UTC and 5GS network timing source degradation) to UEs (e.g. application running in the UE), devices attached to the UE (i.e. that receive time information from 5GS) and 3rd party applications (AFs).

- Study if additional information needs to be provided to UEs and AFs to inform about 5GS network timing synchronization status.

## 5.2 Key Issue #2: Time synchronization service enhancements

### 5.2.1 Description

The objective of this Key Issue is to study enhancements for 5GS time synchronization considering the coverage area where the service is configured.

For this Key Issue the following areas should be studied:

- How to enable AFs to request time synchronization service in a specific coverage area and whether and how to enforce the coverage area.

## 5.3 Key Issue #3: Support for controlling 5G time synchronization service based on subscription

### 5.3.1 Description

Control of time synchronization service based on UE subscription is important for the operator in managing time critical services such as smart grid or financial services.

This key issue aims at studying how to control 5G time synchronization service based on subscription (i.e. introducing subscription parameter for time synchronization and enforcing it).

The following technical issues will be studied:

- How to authorize time synchronization service based on UE subscription.

- How to enforce time synchronization service on a per UE basis based on subscription.

- What parts of time synchronization service require a separate UE subscription (and authorization), if any.

## 5.4 Key Issue #4: How to enable an AF to explicitly provide PER to NEF/PCF

### 5.4.1 Description

For this Key Issue the following areas should be studied:

1. Enable an AF to explicitly provide the required PER to the NEF/PCF for QoS and Alt-QoS.

## 5.5 Key Issue #5: Interworking with TSN network deployed in the transport network

### 5.5.1 Description

The objective of this Key Issue is to study interworking mechanisms with TSN networks deployed in the transport network in order to support of E2E determinism and low latency communication and efficient N3 transmission.

This Key Issues applies only to 3GPP layer traffic flows that fall in the category of "periodic deterministic communication" as defined in clause 5.27.1a of TS 23.501 [2], i.e. for 3GPP layer traffic flows that can be associated with the TSCAI parameters - namely, burst arrival time, periodicity and flow direction.

For this Key Issue the following areas should be studied:

a) The architecture enhancement to support the interworking between 5GS and TSN networks deployed in the transport network.

b) What information are needed and how to collect these information from 5GS (e.g. NG-RAN, 5GC NF), so that the 5GS can interact with TSN network. Also, determine which 5GS entity is responsible to provide it to the TSN network deployed in the transport network.

NOTE: In the context of interworking with a TSN-based transport network, 5GS is assumed to take the role of the CUC towards the CNC of the TSN transport network. It is assumed to rely on on-going work in IEEE for the interaction between CUC and CNC (P802.1Qdj), i.e. no new interface to the CNC will be specified as part of this work.

## 5.6 Key Issue #6: Adapting downstream scheduling based on RAN feedback for low latency communication

### 5.6.1 Description

This key issue is targeting how for applications to adapt downstream scheduling in order for 5GS to meet really low latency (e.g. 2ms) requirement.

For this key issue, the following areas should be studied:

- Need for application transmission schedule adaptation and the ability to meet extremely low PDB for a QoS Flow from the 5GS perspective for periodic traffic streams (based on feedback from RAN WGs).

- How to enable the RAN to provide feedback to application for low latency communication (e.g. for application to consider DL packet transmission time slots to avoid buffering in the RAN) for this purpose.

NOTE 1: The key issue needs to consider also the downlink scheduling in N3 transport network as studied under the Key Issue #x: Interworking with TSN network deployed in the transport network.

NOTE 2: Although the focus is on downstream scheduling, any optimization on upstream scheduling should not be precluded if similar enhancement as for downstream scheduling applies.

# 6 Solutions

## 6.0 Mapping of Solutions to Key Issues

Table 6.0-1: Mapping of Solutions to Key Issues

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Key Issue #1 | Key Issue #2 | Key Issue #3 | Key Issue #4 | Key Issue #5 | Key Issue #6 |
| Solutions |  |  |  |  |  |  |
| #1 | X |  |  |  |  |  |
| #2 |  |  |  |  |  | X |
| #3 | X |  |  |  |  |  |
| #4 | X |  |  |  |  |  |
| #5 | X |  |  |  |  |  |
| #6 |  | X |  |  |  |  |
| #7 |  | X |  |  |  |  |
| #8 |  |  |  | X |  |  |
| #9 |  |  |  |  | X |  |
| #10 |  |  |  |  | X |  |
| #11 |  |  |  |  | X |  |
| #12 |  |  |  |  |  | X |
| #13 |  |  |  |  |  | X |
| #14 | X |  |  |  |  |  |
| #15 |  |  |  |  |  | X |
| #16 |  |  |  |  |  | X |
| #17 | X |  |  |  |  |  |
| #18 |  |  | X |  |  |  |
| #19 |  |  | X |  |  |  |
| #20 |  |  |  |  | X |  |
| #21 |  |  |  |  |  | X |
| #22 |  |  |  |  |  | X |

## 6.1 Solution #1: Inform UE and AF about network timing synchronization status

### 6.1.1 Introduction

This solution enables UE and AF to learn about network timing synchronization status, addressing KI #1.

This solution makes the following assumptions:

- NG-RAN is time synchronized with an external clock using transport network synchronization protocols or using a local GNSS receiver.

- NG-RAN can detect network timing synchronization degradation/improvement or timing synchronization failures locally, e.g. based on information provided by the transport network time synchronization protocols or based on information provided by the local GNSS receiver. The details of how NG-RAN detects timing synchronization degradation/improvement or timing synchronization failures are beyond the scope of 3GPP.

- If UPF/NW-TT is involved in providing timing information to UEs, UPF/NW-TT is time synchronized e.g. using transport network-based time synchronization protocols.

- UPF can detect network timing synchronization degradation/improvement or timing synchronization failures locally, e.g. based on information provided by the transport network time synchronization protocols. The details of how the UPF detects timing synchronization degradation/improvement or timing synchronization failures are beyond the scope of 3GPP.

This solution addresses the following scenarios for 5G internal timing distribution:

- 5GS distributes timing information to UEs using access stratum signalling.

- 5GS is acting as GM and distributes timing information to UEs using PTP or gPTP.

### 6.1.2 Functional Description

The solution is based on the following principles:

- Informing 5GC and AFs about network timing synchronization status:

- Informing 5GC about RAN and UPF time synchronization status:

- TSCTSF subscribes for receiving RAN time synchronization status on a per RAN node level from NWDAF:

- NWDAF subscribes for RAN time synchronization status information from OAM. RAN time synchronization internal status information includes e.g. synchronization state, primary source information (e.g. type, quality, lock state), relevant PTP dataset members such as clock class (if PTP applies), the more general UTC traceability information, stability and clock accuracy.

- As an alternative option, TSCTSF subscribes for RAN time synchronization status information from OAM. RAN time synchronization status information includes e.g. synchronization state, primary source information (e.g. type, quality, lock state), relevant PTP dataset members such clock class (if PTP applies), the more general UTC traceability, stability and clock accuracy information.

- If UPF/NW-TT is involved in providing time information to DS-TT, TSCTSF subscribes for receiving time synchronization status from UPF (i.e. the status of the synchronization of the UPF with the transport network timing):

- Based on this, UPF reports transport network time synch status (e.g. relevant PTP dataset members such as clock class (if PTP applies), UTC traceability information and clock accuracy and stability) to TSCTSF.

NOTE 1: UPF time synchronization status is only needed for the option when UPF/NW-TT is generating and timestamping messages for the DS-TT, which are forwarded from DS-TT adding residence time.

- Determining UEs impacted by RAN time synchronization status degradation or improvement:

- TSCTSF subscribes to receive location information (RAN node granularity) from AMF for UEs that AF requested time synchronization for.

- TSCTSF requests UEs for which an AF requested time synchronization to perform a Registration Update if the UE is in CM-IDLE and detects a change in the RAN time synchronization status information (see below) for the current cell or when re-selecting to a different cell. This ensures that the CN is made aware of the location of a UE in case the RAN time synchronization status changes while a UE that has been configured to receive time information is in CM-IDLE.

- Determining UEs impacted by UPF time synchronization status degradation or improvement (only for the case when UPF/NW-TT is involved in providing time information to DS-TT):

- If TSCTSF receives time synchronization status information for NG-RAN nodes from NWDAF (or from OAM directly) indicating time synchronization status degradation or improvement, then TSCTSF determines the UEs served by those NG-RAN nodes based on location information received from AMF.

- If TSCTSF receives time synchronization status information from UPF indicating time synchronization status degradation or improvement, then the TSCTSF determines the UEs for which the UPF/NW-TT or the DS-TT co-located with those UEs is configured to send (g)PTP messages.

- Inform AFs about network timing synchronization status degradation or improvement:

- If TSCTSF has determined UEs impacted by RAN or UPF time synchronization status degradation or improvement then TSCTSF informs the AF about the network timing synchronization status for those UEs as follows:

- For UEs impacted by RAN time synchronization status degradation or improvement for which the AF has requested 5G access stratum time distribution, TSCTSF determines if the Time synchronization error budget provided by the AF can be met given the change of clock accuracy for the RAN node serving the UE:

- If the sum of the clock accuracy of the RAN node serving a UE and the Uu time synchronization error budget previously calculated for the UE (see clause 5.27.1.9 of TS 23.501 [2]) exceeds the Time synchronization error budget provided by the AF, then the TSCTSF informs the AF that the time synchronization request cannot be fulfilled for the impacted UE.

- Otherwise, the TSCTSF informs the AF that the time synchronization request can be fulfilled again for the impacted UE.

- For UEs for which the AF has requested (g)PTP based time distribution and which are impacted by RAN and/or UPF time synchronization status degradation or improvement, TSCTSF determines if the Time synchronization error budget provided by the AF can be met given the change of clock accuracy for the RAN node serving the UE and/or the change of clock accuracy reported by the UPF:

- If the sum of:

- the clock accuracy of the RAN node serving a UE;

the Uu time synchronization error budget previously calculated for the UE (see clause 5.27.1.9 of TS 23.501 [2]); and

- (in case NW-TT is configured to act as Grandmaster on behalf of the UE/DS-TT) the clock accuracy reported by the UPF;

- exceeds the Time synchronization error budget provided by the AF, the TSCTSF informs the AF that the time synchronization request cannot be fulfilled for the impacted UE by indicating the PTP port state as Inactive for the related DS-TT PTP port.

- Otherwise, the TSCTSF informs the AF that the time synchronization request can be fulfilled again for the impacted UE by indicating the PTP port state as Active for the related DS-TT PTP port.

Editor's note: Whether and how to provide network timing synchronization status for the case that an AF requested time synchronization service in a specific coverage area depends on the progress of the related key issue.

- Informing UEs and devices attached to UE/DS-TT about network timing synchronization status:

- NG-RAN detects network timing synchronization degradation or failure based on implementation-specific means.

- NG-RAN informs UEs that receive 5G access stratum time about the time synchronization status by providing additional time synchronization status information (e.g. synchronization state, primary source description (e.g. type, quality, lock state), clock class and information about traceability to UTC, clock accuracy and stability) to UEs in SIB or using dedicated RRC.

- Reflecting RAN and UPF time synchronization status degradation and improvement in Announce messages sent by DS-TT and NW-TT:

- If TSCTSF has determined that UEs that are part of a PTP instance are impacted by RAN or UPF time synchronization status degradation or improvement for which the Time synchronization error budget provided by the AF can still be met (see above), then TSCTSF may update the clockQuality information sent in Announce messages (see IEEE 1588 [8] clause 7.6.2) for the PTP instance. For example, TSCTSF may change the clockQuality information to reflect that the clock has entered holdover state or to reflect a change in clock accuracy.

- If a DS-TT is configured to send Announce messages for the related PTP port, then TSCTSF changes the clockQuality information for the related PTP port using PMIC.

- If NW-TT is configured to send Announce messages on behalf of the DS-TT, then TSCTSF changes the clockQuality information for the related PTP port using UMIC.

- The handling of Announce messages follow existing procedures as described in TS 23.501 [2].

NOTE 2: ClockQuality information included in Announce message needs to be the same for all PTP ports of the same PTP instance. Therefore TSCTSF needs to configure the same clockQuality information for all UEs that are part of the same instance PTP instance even if only some UEs are impacted. For example, if one UE that is part of a PTP instance is served by a RAN node that lost synchronization to a primary reference time source (e.g. GNSS) and enters holdover mode, then the clockClass attribute needs to be changed for all UEs that are part of that PTP instance. Alternatively, disabling the impacted UE PTP port would preserve the other UEs' status.

NOTE 3: Time synchronization status information provided to the UE using RRC is assumed to be used by the UE, e.g. for applications running on the UE or to provide time information to devices attached to the UE using implementation specific means. Time synchronization status information provided to UE/DS-TT by 5GC in (g)PTP (e.g. clock class, clock accuracy) is assumed to be consumed by devices attached to the UE to which UE/DS-TT forwards the (g)PTP frames/packets.

- Deactivation and re-activation of (g)PTP based time synchronization due to RAN or UPF time synchronization status degradation and improvement:

- If TSCTSF has determined UEs impacted by RAN or UPF time synchronization status degradation (see above) for which the AF has requested (g)PTP based time distribution and for which the Time synchronization error budget provided by the AF cannot be met (see above) then TSCTSF temporarily removes the UE/DS-TT from the PTP instance:

- If the DS-TT is configured to send Sync, Follow\_Up and Announce messages for the related PTP instance, then TSCTSF deactivates the Grandmaster functionality in the DS-TT using PMIC (see also clause K.2.2.4 of TS 23.501 [2]) and removes the DS-TT from the PTP instance (see also clause K.2.2.1 of TS 23.501 [2]).

- If NW-TT is configured to send Sync, Follow\_Up and Announce messages on behalf of the DS-TT, then TSCTSF deactivates the Grandmaster functionality on behalf of the DS-TT in NW-TT using UMIC (see also clause K.2.2.4 of TS 23.501 [2]) and removes the DS-TT from the PTP instance (see also clause K.2.2.1 of TS 23.501 [2]).

- If TSCTSF has determined UEs impacted by RAN or UPF time synchronization status improvement for which the AF has requested (g)PTP based time distribution and for which the Time synchronization error budget provided by the AF can be met again (see above) then TSCTSF adds the DS-TT PTP port to the PTP instance again and also re-activates the Grandmaster functionality.

### 6.1.3 Procedures

### 6.1.4 Impacts on services, entities and interfaces

NG-RAN:

- Indicate RAN network timing synchronization status to UEs in RRC signalling or SIB9.

UE:

- Support receiving RAN network timing synchronization status information.

- Support performing a Registration request when RAN network timing synchronization status information changes while the UE is in CM-IDLE, if requested by TSCTSF.

NWDAF:

- Support subscribing for RAN time synchronization status information from OAM and providing RAN time synchronization status information to TSCTSF.

TSCTSF:

- Receive time synchronization status information from NWDAF (or OAM) and UPF.

- Subscribe for receiving location information from AMF.

- Support for requesting UEs to perform a Registration request if the UE detects a change in RAN network timing synchronization status information and the UE is in CM-IDLE.

- Inform AFs about time synchronization status (i.e. for which UEs time synchronization can be provided or not due to 5GS time synchronization status).

- Discover serving AMF for a UE.

UPF:

- Report transport network time synch status (e.g. primary source information and status, clock class UTC traceability and clock accuracy and stability) to TSCTSF in case NW-TT is configured to generate (g)PTP messages (see case (a) in clause 5.27.1.7 of TS 23.501 [2].

## 6.2 Solution #2: Burst arrival time adaptation

### 6.2.1 Introduction

This solution enables the network to adjust the burst arrival time by signalling positive or negative offset values (e.g. +3 ms) to the AF so that the AF can adjust the burst sending time accordingly.

Providing a burst arrival time offset value to an AF does not require 5GS and AF to be time synchronized.

The solution builds on top of the QoS notification control mechanism (clause 5.7.2.4.1a (without Alternative QoS Profiles) or clause 5.7.2.4.1b (with Alternative QoS Profiles) of TS 23.501 [2]). In line with the assumptions for the existing QoS notification control mechanism, also this solution applies only if the application traffic is able to adapt to the change in QoS, i.e. if an application can tolerate that the PDB target is temporarily not met.

### 6.2.2 Functional Description

This solution is based on the following principles:

- When requesting QoS for a flow as defined in clause 6.1.3.22 of TS 23.503 [4], AF may also indicate support of Burst arrival time adaptation to5GS. AF also subscribes to receive notifications for successful resource allocation and when the QoS targets can no longer (or can again) be fulfilled as described in clause 6.1.3.18 of TS 23.503 [4].

- PCF forwards the support of Burst arrival time adaptation indication to SMF together with a PCC rule and other parameters (burst size, flow direction, burst periodicity), BAT (optional)), if provided by the AF. PCF enables QoS Notification Control in the PCC rule.

NOTE 1: If AF and 5GS are time synchronized, then the AF may additionally include BAT.

- SMF creates TSCAI based on the received periodicity , flow direction and BAT (if provided by PCF). If PCF indicated support of Burst arrival adaptation, SMF includes support of Burst arrival time adaptation indication in TSCAI and signals TSCAI to NG-RAN as described in clause 4.3.3.2 of TS 23.501 [2]. As part of this, SMF also activates QoS notification control.

- At any time after the flow has started, if NG-RAN has received the indication of support of Burst arrival time adaptation in TSCAI for the given QoS Flow and NG-RAN determines that the PDB of the QoS profile cannot be fulfilled in DL direction, then NG-RAN sends a notification to SMF as defined in clause 5.7.2.4.1a of TS 23.501 [2] (if no Alternative QoS parameters have been provided) or as defined in clause 5.7.2.4.1b of TS 23.501 [2] (if Alternative QoS parameters have been provided). As part of the notification to SMF, NG-RAN may include a burst arrival time offset value. The burst arrival offset can take positive or negative values.

NOTE 2: NG-RAN determines a relative burst arrival time offset value in reference to the current Burst Arrival Time experienced by RAN (i.e. in reference to when RAN currently receives bursts). Since it is a relative offset it can also be applied by the AF for adapting when it sends bursts, i.e. for the AF to adapt the burst sending time (see further below).

NOTE 3: Since NG-RAN is aware of the radio resource situation NG-RAN can determine whether it would be possible to support the PDB of the QoS profile again if the burst was shifted in the time domain and calculate the required offset value.

NOTE 4: The QoS notification procedure, which is reused by this solution already avoids too frequent signalling to the SMF (see NOTE 2 in clause 5.7.2.4.1b of TS 23.501 [2]).

- The burst arrival time offset value is signalled from SMF to AF via PCF/TSCTSF/NEF using existing Notification control signalling.

- For downlink flows AF adapts the burst sending time based on the received offset.

### 6.2.3 Procedures

Existing procedures are reused (PDU session modification to signal support of Burst arrival time adaptation indication in TSCAI to NG-RAN; Notification control as defined in clause 5.7.2.4.1a or clause 5.7.2.4.1b of TS 23.501 [2]. to signal burst arrival time offset value to PCF/TSCTSF/NEF/AF).

### 6.2.4 Impacts on services, entities and interfaces

AF:

- Support of sending burst arrival time adaptation indication and receiving burst arrival time offset.

NEF, PCF, TSCTSF, SMF:

- Support of signalling burst arrival time adaptation indication and burst arrival time offset.

NG-RAN:

- Support of receiving burst time arrival adaptation indication, determining and signalling burst arrival time offset.

## 6.3 Solution #3: Timing synchronization resiliency and status reporting

### 6.3.1 Introduction

This solution aims to address Key issue #1: 5GS network timing synchronization status and reporting. When 5GS provides timing resiliency service e.g. in the smart grid or financial sector, the timing synchronization status (such as divergence from UTC, timing source degradation) needs to be able to inform UEs (e.g. application running in the UE), devices attached to the UE (i.e. that receive time information from 5GS) and AFs. The AF can configure 5GS with the requirements about the timing resiliency service to meet when timing synchronization event happens.

This solution makes the following assumptions:

- UEs are consuming (g)PTP timing synchronization service from UPF/NW-TT that acts as Grand-master based on IEEE Std 802.1AS [7] or IEEE Std 1588 [8];

- 5G GM may have different sources of time/frequency like GNSS signal, Synchronous Ethernet (SyncE), PTP transport network, PPS input, etc. It is assumed that UPF is synchronized with 5G GM by PTP compatible transport, etc.

- When UPF detects 5GS networking timing synchronization status for original 5G GM timing source, it sends the reporting to 5GC. Additionally, the UPF activates the timing synchronization configuration for PTP GM functionality as configured by TSCTSF in case of degradation for original 5G GM timing source, so as to provide seamless time synchronization service for the UEs; or the UPF de-activates the timing synchronization configuration for PTP GM functionality as configured by TSCTSF in case of recovery for original 5G GM timing source.

NOTE: This solution assumes the time synchronization service is offered by (g)PTP based timing distribution, and can be used in combination with other solutions (e.g. sol#4 in clause 6.4) to address the case where the time synchronization service is offered based on 5G Access Stratum timing distribution.

### 6.3.2 Functional Description

This solution uses the following principles:

- TSCTSF collects timing synchronization capability of UPF. The TSCTSF retrieves the timing synchronization capability via PMIC or UMIC, and then TSCTSF sends the collected information to AF if it subscribes:

- The timing synchronization capability can indicate holdover time or traceability capability information. For example, clock class, synchronization accuracy, holdover time parameters for the smart grid scenario, or UTC divergence scale and synchronization accuracy parameters for financial scenario.

- TSCTSF creates timing synchronization configuration on the UPF upon reception of AF request:

- TSCTSF receives timing synchronization requirement from AFs. The timing synchronization requirement consists of the time synchronization error budget. AF may also request to subscribe network timing synchronization status from TSCTSF (if it is a trusted AF, or via NEF).

- TSCTSF confirms that the 5GS can meet the requirement based on UPF reported timing synchronization capability.

- TSCTSF creates a timing synchronization configuration on UPF.

- With the timing synchronization configuration, the UPF detects and reports the networking timing synchronization status, and (de)activates the timing synchronization configuration for PTP GM functionality accordingly.

- UEs are consuming (g)PTP timing synchronization service from UPF/NW-TT that acts as grand-master based on IEEE Std 802.1AS [7] or IEEE Std 1588 [8].

- When UPF detects networking timing synchronization status for original 5G GM timing source, it sends the status reporting to TSCTSF, and the TSCTSF forwards the reporting to AFs:

- When UPF detects recovery for original 5G GM timing source, the UPF activates the timing synchronization configuration for PTP GM functionality as configured by TSCTSF, and the status reporting contains: 5GS timing synchronization enabled status, the timing source clock class, time validity.

- When UPF detects degradation or unavailable for original 5G GM timing source, the UPF de-activates the timing synchronization configuration for PTP GM functionality, and status reporting contains: 5GS timing synchronization disabled status, the timing source clock class, time validity.

- Inform the status to UE:

- When UPF detects networking timing synchronization status for original 5G GM timing source, the UPF/NW-TT may update (g)PTP attributes as configured by the TSCTSF via UMIC and sends the updated (g)PTP messages to the UE(s).

### 6.3.3 Procedures

Existing PDU Session establishment procedures are reused in timing synchronization capability configuration. Enhanced the procedure for exposure of capability of time sync service defined in clause 4.15.9.2 of TS 23.502 [3] to support exposure of timing synchronization capability. Existing timing distribution procedures are reused for UEs using (g)PTP messages.



Figure 6.3.3-1: Timing synchronization resiliency and status reporting

0. PDU session establishment procedure with UPF timing resiliency capability, UPF exchanges timing resiliency capability to TSCTSF via UMIC/PMIC.

1. AF requests for time synchronization service status, with time synchronization error budget for specific UE(s).

2. TSCTSF confirms that the 5GS can meet the requirement based on UPF reported timing synchronization capability, and determinates UPF to provide time sync service.

3. TSCTSF creates a timing synchronization configuration on UPF via PMIC/UMIC.

Editor's note: It is FFS the information in timing synchronization configuration.

4. The UPF detects and reports the networking timing synchronization status degradation or recovery, and (de)activates the timing synchronization configuration for PTP GM functionality accordingly.

5. When UPF detects degradation or recovery for original 5G GM timing source, the UPF sends the status reporting contains 5GS timing synchronization enabled or disable status, the timing source clock class, time validity to AF, via TSCTSF.

6. The TSCTSF may reconfigure (g)PTP operation at the UPF/NW-TT via PMIC/UMIC.

7. UEs are consuming (g)PTP timing synchronization service from UPF or RAN that acts as grand-master based on IEEE Std 802.1AS [7] or IEEE Std 1588 [8]. UPF/NW-TT sends updated PTP messages to the UE(s).

### 6.3.4 Impacts on services, entities and interfaces

UPF:

- Support of signalling the timing synchronization capability to TSCTSF and AF.

- Support of reporting time synchronization status (e.g. holdover time or UTC divergence status) to TSCTSF.

TSCTSF:

- Support of receiving timing synchronization requirement from AFs.

- Support of timing synchronization with timing resiliency capability configuration.

- Support of timing synchronization status report to AFs.

AF:

- Support of providing timing synchronization requirement (time synchronization error budget) to TSCTSF, and receiving status reporting from TSCTSF.

- Support of subscribing timing synchronization capability.

## 6.4 Solution #4: 5GC learning and reporting network timing synchronization status

### 6.4.1 Introduction

This solution is proposed to solve Key Issue #1: 5GS network timing synchronization status and reporting.

In this key issue, the 5GS has a synchronization plane that synchronizes the 5G network functions (e.g. UPFs and RAN nodes) to a common time reference. The synchronization plane may have different sources of time/frequency like GNSS signal, Synchronous Ethernet (SyncE), PTP transport network, PPS input, etc. Thus, the following assumptions are considered for the synchronization plane:

- NG-RAN is time synchronized with an external clock using transport network synchronization protocols or using a local GNSS receiver.

- NG-RAN is frequency synchronized (i.e. synchronization) with an external clock using transport network syntonization methods or using a local GNSS receiver.

NOTE 1: The syntonization aspect is included in the assumptions because it may have an important role when the primary time reference source is lost but still the base station has a frequency reference (e.g. SyncE), then the holdover period can be longer. This is taking for example the long interruption failure scenarios considered in ITU-T Recommendation G.8271.1 [15], Appendix V.

- NG-RAN can detect network timing synchronization degradation/improvement or timing synchronization failures locally, e.g. based on information provided by the transport network time or frequency synchronization methods or based on information provided by the local GNSS receiver. The details of how NG-RAN detects timing synchronization degradation/improvement or timing synchronization failures are beyond the scope of 3GPP.

- UPF/NW-TT is time synchronized with an external clock using transport network-based time synchronization protocols if UPF/NW-TT is involved in providing time information to UEs/DS-TTs.

- UPF can detect network timing synchronization degradation/improvement or timing synchronization failures locally, e.g. based on information provided by the transport network time synchronization protocols. The details of how the UPF detects timing synchronization degradation/improvement or timing synchronization failures are beyond the scope of 3GPP.

This solution addresses the following scenarios:

- 5GS distributes time information to UEs using access stratum signalling.

- 5GS distributes time information to UEs using PTP or gPTP messages and the 5GS (i.e. UPF/NW-TT) is acting as the grand-master.

NOTE 2: How the performance of the 5G clock distribution across the 5GS impact the external (g)PTP clock scenario is out of scope.

From UE/DS-TT perspective, the 5GS time information received can be the primary time source the UE/DS-TT is consuming or can be a back-up time source alternative to a time source already present at the UE/DS-TT side. For both cases, this solution proposes enablers to allow the 5GC to retrieve 5GS network timing synchronization status from NG-RAN nodes and UPF/NW-TT (if needed) and report this information to subscribed UEs and AFs.

### 6.4.2 Functional Description

#### 6.4.2.1 Functional Description for 5GC learning network timing synchronization status

The following principles are proposed to enable the 5GC to learn the network timing synchronization status at the NG-RAN and UPF/NW-TT:

- The TSCTSF can retrieve and store timing synchronization status from NG-RAN and UPF/NW-TT.

- The NG-RAN timing synchronization status and the UPF/NW-TT timing synchronization status provide information for different time synchronization processes the UE/DS-TT(s) may have configured. The TSCTSF checks the time synchronization distribution method the target UE(s) have configured and determines the network functions to subscribe:

- The NG-RAN timing synchronization status informs the synchronization performance of the time distribution process the gNB and UE execute at Uu interface using access stratum signalling.

- On top of the access stratum time distribution method, if the UE/DS-TT receives 5G clock via (g)PTP with the UPF/NW-TT acting as a PTP grandmaster, the (g)PTP Announce messages already include GM quality attributes to determine UPF/NW-TT timing synchronization status at the UE/DS-TT.

NOTE 3: If the UE/DS-TT is acting as a PTP grandmaster, it might not be required for the UE to receive gPTP or PTP messages over user plane (i.e. the UE and DS-TT use the 5G timing information and generate the necessary gPTP or PTP message for the end station as described in 23.501 clause 5.27.1.1). In this case, there is no need for the UPF reporting time synch status to TSCTSF.

- For TSCTSF subscription to NG-RAN timing synchronization status, three reporting alternatives via AMF are possible as follows:

- Alternative 1 for NG-RAN Time Sync Status reporting: The TSCTSF is responsible for determining the impacted UE(s) based on their location and the NG-RAN timing synchronization status reports received from AMF.

- Alternative 2 for NG-RAN Time Sync Status reporting: The AMF is responsible for determining the impacted UE(s) based on their location and the NG-RAN timing synchronization status reports received. Per impacted UE, the AMF forwards the notification to the TSCTSF subscribed to it.

- Alternative 3 for NG-RAN Time Sync Status reporting: The NG-RAN is responsible for determining the impacted UE(s) and sending the NG-RAN timing synchronization status reports to the AMF. Per impacted UE, the AMF forwards the notification to the TSCTSF subscribed to it.

- For TSCTSF subscription to UPF/NW-TT timing synchronization status, three reporting alternatives are possible as follows:

- Alternative 1 for UPF/NW-TT Time Sync Status reporting: Using UPF event exposure service operation. The TSCTSF can be a new consumer of the service and node level signalling is used between UPF and TSCTSF.

- Alternative 2 for UPF/NW-TT Time Sync Status reporting: Using N4 Node Level procedures between the UPF and the SMF to report the update from the UPF. The TSCTSF subscribes to this information at the SMF on a per UE level or node level (between UPF and SMF or between SMF and TSCTSF). If UE level signalling is preferred, the SMF is responsible for determining the impacted UE(s) and notify the TSCTSF per UE level basis using PDU Session information available.

- Alternative 3 for UPF/NW-TT Time Sync Status reporting: Using UMIC to forward the status update from the UPF to the TSCTSF. Node level signalling is used between UPF and TSCTSF.

- The TSCTSF can determine time source degradation/failure/recovery events using the event flags and/or comparing numeric attributes included within the network timing synchronization status update received from NG-RAN and UPF/NW-TT.

- The TSCTSF can use the primary source quality attributes included within the NG-RAN and UPF/NW-TT timing synchronization status update to recalculate Uu time synchronization error budget for the time synchronization service offered to UE(s) to assist time synchronization enforcement (i.e. to notify the AF if the time synchronization error budget provided cannot be fulfilled, or to provide an updated Uu time synchronization error budget to the serving NG-RAN node).

#### 6.4.2.2 Functional Description for network timing synchronization status information

Editor's note: What type of information is needed and how it is used is FFS.

#### 6.4.2.3 Functional Description for AF requested network timing synchronization status

The following capabilities are proposed for AF requesting network timing synchronization status:

- The AF requests network timing synchronization status monitoring from the NEF or TSCTSF (if it is a trusted AF). Existing Time synchronization APIs (i.e. Ntsctsf\_TimeSynchronization\_Config and Ntsctsf\_ASTI) are extended with Subscribe/Unsubscribe/Notify operations to enable the AF to perform this request for monitoring. The request may contain:

- Targets of the monitoring and filtering information (e.g. UE IDs, spatial validity, DNN/S-NSSAI, or time synchronization service identifier (i.e. PTP instance reference for the (g)PTP service scenario or time synchronization configuration ID for the ASTI service scenario)).

- The subscription events or information elements it wants to be notified.

- Request for UE side reporting (i.e. the UE(s) that are targets of the monitoring receive also the network timing synchronization status report) and reporting criterion (e.g. as soon as new information is available, when the UE is reachable).

- AF Identification.

- To determine the targets of the monitoring, AF request for network timing synchronization status provides the filter information. Four criteria to determine the targets of the network timing synchronization status exposure framework can be considered as summarized in Table 6.4.2.3 based on UE identities, known location, or connectivity.

Table 6.4.2.3: Criteria alternatives for network timing synchronization status exposure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | Spatial validity | All UEs within the spatial validity | All UEs connected to the DNN/S-NSSAI | A UE or group of UEs |
| Target of Monitoring Reporting | an optional SUPI or any UE | any UE | any UE | one or more SUPI(s) or Internal Group Identifier(s) |
| Monitoring Filter information | spatial validity; | Spatial validity | DNN;  S-NSSAI; |  |

- If AF's request includes geographical area filter(s), the AF can provide them in spatial validity format (e.g. a civic address or shapes), or area(s) of interest. If the AF provides spatial validity, the NEF maps the spatial validity to validity area(s) (based on pre-configuration). Later, the TSCTSF or PCF determines the area(s) of interest based on validity area(s). The TSCTSF or AMF subscriptions use area of interest that may be the same as spatial validity condition or may be a subset of the spatial validity condition (e.g. a list of TAs or list of Cells) based on the latest known UE location.

- AMF or TSCTSF uses Location reports or UE presence in Area of Interest services at the AMF to identify the UE(s) to which the AF request with geographical area filter(s) applies, following the description of clause 6.4.2.1.

- If AF's request includes DNN/S-NSSAI filters, service events related to PDU Sessions (e.g. establishment or release) can be used at the SMF or TSCTSF to identify the UE(s) to which the request applies.

- Based on the network timing synchronization status reports the TSCTSF receives from NG-RAN and UPF/NW-TT (if applicable) nodes, the TSCTSF re-evaluates if the time synchronization service configured for the UE(s) impacted for which the AF has requested time synchronization service can be fulfilled:

- If TSCTSF determines that the service requirements (time synchronization error budget) cannot be met:

- For ASTI based time synchronization service, the TSCTSF updates access stratum time distribution indication to "disable" and forwards the attribute to the serving NG-RAN nodes for the impacted UEs via AMF (following Release-17 operation as described in clause 4.15.9.4 of TS 23.502 [3]).

- For (g)PTP based time synchronization service, the TSCTSF temporarily removes the UE/DS-TT from the PTP instance and reconfigures the UPF/NW-TT accordingly (following Release-17 operation described in clause K.2.2 of TS 23.501 [2]). The TSCTSF may update the clockQuality information (via PMIC if DS-TT or via UMIC if NW-TT is configured to send Announce messages) for the PTP instance (see IEEE 1588 [8] clause 7.6.2).

NOTE 4: ClockQuality information included in Announce message needs to be the same for all PTP ports of the same PTP instance. Therefore, TSCTSF needs to configure the same clockQuality information for all UEs that are part of the same instance PTP instance even if only some UEs are impacted. For example, if one UE that is part of a PTP instance is served by a RAN node that lost synchronization to a primary reference time source (e.g. GNSS) and enters holdover mode, then the clockClass attribute needs to be changed for all UEs that are part of that PTP instance. Instead of changing the clockClass of all related UEs, an alternative way is to mark the impacted UE PTP port disabled and other UEs of the PTP instance unchanged. This is up to implementation.

NOTE 5: When DS-TT is configured to generate Announce messages for one or more PTP ports, the TSN AF or TSCTSF shall use the elements in defaultDS in PMIC for the respective DS-TT(s) and in UMIC for NW-TT to ensure that all PTP ports in the DS-TT(s) and NW-TT in particular PTP instance are distributing the same values of grandmasterPriority1, grandmasterClockQuality, grandmasterPriority2, grandmasterIdentity, and timeSource message fields in Announce messages as described in clause K.2.2.4 of TS 23.501 [2]).

- If TSCTSF determines that the service requirements can be met:

- For ASTI based time synchronization service, the TSCTSF updates access stratum time distribution indication to "enable" and forwards the attribute to the serving NG-RAN nodes for the impacted UEs via AMF (following Release-17 operation as described in clause 4.15.9.4 of TS 23.502 [3]).

- For (g)PTP based time synchronization service, the TSCTSF adds the UE/DS-TT to the PTP instance again (or changes the status of the impacted UE PTP port) and reconfigures the UPF/NW-TT accordingly (following Release-17 operation described in clause K.2.2 of TS 23.501 [2]).

#### 6.4.2.4 Functional Description for network timing synchronization status reporting to UE(s)

The following capabilities are proposed for UE(s) receiving network timing synchronization status:

- Based on TSCTSF policies or the received AF's network timing synchronization status request as described in clause 6.4.2.3 and the time synchronization service the UE has configured, the TSCTSF is responsible for subscribing to network timing synchronization status as described in clause 6.4.2.1 (i.e. to the serving NG-RAN via AMF and if needed to the UPF/NW-TT via SMF or UPF directly).

- The trigger conditions of UE side reporting include,

- AF's request for UE side reporting

Editor's note: Need for UE side reporting depends e.g. on how timing status information is reported to the UE and is FFS.

- TSCTSF policies (e.g. whether there exists AF's request or not, TSCTSF reports status to UEs who have network timing synchronization services)

- UE's authorization (e.g. newly defining UE's subscription data stored in the UDM, which indicates whether the UE is authorized to receive the network timing synchronization status reports)

NOTE: Whether and how to define UE's subscription data for the case that an UE authorize the network timing synchronization status reporting depends on the progress of the related key issue (i.e. KI#3).

- When access stratum time distribution method is configured for the UE, the TSCTSF could configure the NG-RAN node (via AMF) to generate and send the NG-RAN timing synchronization status report to the UE(s) via SIB9/RRC signalling. The report shall be made available to DS-TT by the UE.

- When (g)PTP time distribution method is configured for the UE/DS-TT, the PTP attributes received via PTP announce messages are enough to describe the status of the UPF/NW-TT timing synchronization status.

- If the DS-TT is the last recipient of the network timing synchronization status reports (if only access stratum time distribution method is configured), it is up to the DS-TT implementation the determination of how the time source status update impacts the total degradation of the timing service the DS-TT is running.

### 6.4.3 Procedures

#### 6.4.3.1 Procedure for AF requested network timing synchronization status

An overall procedure for AF requested network timing synchronization status is illustrated in Figure 6.4.3.1-1. Note this procedure is focusing on NG-RAN network timing synchronization status reporting and uses ASTI based time synchronization service as an example how the report can be exposed to the AF. For (g)PTP based time synchronization service, the exposure API should be Nxxx\_TimeSynchronization\_ConfigSubscribe/Notify in steps 1, 2, 9, 10, 16, and 17.



Figure 6.4.3.1-1: Procedure for AF requested network timing synchronization status

1-2. The AF sends network timing synchronization status request to the NEF or TSCTSF. The request may include targets of the monitoring and filtering information (as described in Table 6.4.2.3), the subscription events or information elements it wants to be notified, request for UE side reporting and reporting criterion, AF Identification.

If the request is received at the NEF, it checks whether the AF is authorized to send the request and forwards the request to the TSCTSF.

If spatial validity is included in AF's request, NEF maps the spatial validity to list of TA(s) or Cell(s).

3. Based on the filters the request contains, the TSCTSF determines the target(s) UE(s) for the request.

4. The TSCTSF determines the AMF(s) and the UPF/NW-TT nodes (if applicable) that needs to initiate network timing synchronization status subscription considering the time synchronization service the target UE(s) have configured in the 5GS.

To determine the serving AMF(s), the TSCTSF can use different methods such as:

- Method 1: NRF services (Nnrf\_NFDiscovery, illustrated in Figure 6.4.3.1-1) or UDM UE Context Management services (Nudm\_UECM\_Get) to discover the AMF of the target TAI(s) or UE(s). This method enables the TSCTSF to directly interact with the AMF to retrieve NG-RAN Time Sync Status reports at UE or NG-RAN node level.

- Method 2: AM policy procedures via PCF. The TSCTSF can discover the PCF for the UE using the BSF and interact with the AMF via PCF AM Policy services. This method only enables the TSCTSF to retrieve NG-RAN Time Sync Status reports at UE level.

To determine the serving UPF/NW-TT(s) the TSCTSF can use the PTP instance information already configured for the (g)PTP service provided to the UE(s). That is, the TSCTSF can reuse the time synchronization capability exchange via UMIC with the UPF/NW-TT (e.g. attribute List of UEs associated with the User-Plane Node ID in Table 5.2.6.25.8-1 of TS 23.502 [3]).

5-7. The TSCTSF request NG-RAN timing synchronization status (TSS) subscription to the AMF. First the TSCTSF may send the configuration of the TSS reporting to the NG\_RAN via AMF using Namf\_NonUeN2MsgTransfer. The AMF interacts with the NG-RAN to configure the reporting. Finally, the TSCTSF initiates the subscription to TSS reporting at the AMF. Three alternatives are possible (as described in clause 6.4.2.1):

- Alternative 1 for NG-RAN Time Sync Status reporting (option illustrated in Figure 6.4.3.1-1): TSCTSF subscribes for receiving NG-RAN timing synchronization status at the AMF on a per RAN node level. The AMF forwards the received status report from the NG-RAN node to the TSCTSF. The TSCTSF is responsible for determining the impacted UE(s) based on their location.

- Alternative 2 for NG-RAN Time Sync Status reporting: TSCTSF subscribes for receiving NG-RAN timing synchronization status at the AMF on a per UE level. The AMF is responsible for determining the impacted UE(s) based on the NG-RAN node level report received and UE(s) location. Per impacted UE, the AMF forwards the NG-RAN time synchronization status report to the TSCTSF subscribed to it.

- Alternative 3 for NG-RAN Time Sync Status reporting: TSCTSF subscribes for receiving NG-RAN timing synchronization status at the AMF on a per UE level. The NG-RAN is responsible for determining the impacted UE(s) and sending the NG-RAN timing synchronization status reports to the AMF. Per impacted UE, the AMF forwards the notification to the TSCTSF subscribed to it.

If (g)PTP time distribution is configured for a UE, the TSCTSF request UPF/NW-TT timing synchronization status subscription to the SMF (at UE level or node level) or directly at the UPF/NW-TT (node level), as described in clause 6.4.2.1.

8. If AF's request contains a spatial validity filter and the TSCTSF subscribes to node level information at the AMF in step 4, the TSCTSF is responsible for determining if a serving NG-RAN timing synchronization status update received at node level signalling impacts the UE(s) matching AF's request condition. To support this, the TSCTSF subscribes to location services at the AMF (e.g. Namf\_EventExposure service for events like Location Report (TAI, Cell ID) or UE moving in or out of a subscribed "Area Of Interest").

If AF's request contains a spatial validity filter and (g)PTP time distribution is configured for a UE, the TSCTSF is responsible of determining the UE(s) matching AF's request condition based in their location and the serving UPF/NW-TT for the PTP instance.

9-10. The TSCTSF responds the AF.

11. The AMF subscribes to UE(s) location services reporting from NG-RAN node using Location reporting Request procedure.

12. The NG-RAN node detects a primary source event (e.g. degradation, failure, recovery).

13. The NG-RAN node notifies the AMF providing a NG-RAN timing synchronization status report. The report message may include, for example, the gNB node information, time status information, relevant UE information. The gNB node information indicates which 5G access stratum time distribution is impacted. The time status information might include the clock status in gNB node, and it can refer to the time service indication (disabled, enabled and holdover status). The relevant UE info represents those UE using the involved gNB access stratum time.

Editor's note: The actual details of the parameters to be provided by NG-RAN and to AF are FFS.

14. The AMF forwards the NG-RAN timing synchronization status report to the TSCTSF. If TSCTSF subscription is at NG-RAN node level (alternative 1 for NG-RAN Time Sync Status reporting, illustrated in Figure 6.4.3.1-1), the AMF can directly forward the report received from NG-RAN node. If TSCTSF subscription is at UE level (alternative 2 and 3 for NG-RAN Time Sync Status reporting), the AMF or RAN determines the UE(s) impacted by the status update received from NG-RAN before notifying the TSCTSF (e.g. based on UE locations or UE identities).

15. The TSCTSF revaluates if the time synchronization service configured for the UE(s) impacted can still be fulfilled ( time synchronization error budget provided by AF). If the service requirements cannot be met, then the TSCTSF may temporarily deactivate time synchronization service for the impacted UE(s).

For ASTI based time synchronization service, this implies the TSCTSF updates access stratum time distribution indication to "disable" and forwards the attribute to the serving NG-RAN nodes for the impacted UEs via AMF (following Release-17 operation as described in clause 4.15.9.4 of TS 23.502 [3]).

For (g)PTP based time synchronization service (not illustrated in Figure 6.4.3.1-1), this implies the TSCTSF temporarily removes the UE/DS-TT from the PTP instance or marks the impacted DS-TT ports disabled and reconfigures the UPF/NW-TT accordingly (following Release-17 operation described in clause K.2.2 of TS 23.501 [2]).

16-17. The TSCTSF stores the network timing synchronization status update received and notifies the subscribed AF via exposure framework. If the notification from gNB provides the time status information (e.g. disabled, enabled and holdover status, actual status information values is FFS), TSCTSF stores the time status information locally. If the notification from the gNB has triggered the (de)activation of time synchronization service for the impacted UE(s), the TSCTSF notifies the AF.

Figure 6.4.3.1-1 illustrates the NG-RAN timing synchronization status subscription example, if the TSCTSF requires UPF/NW-TT timing synchronization status (determined in step 3), a similar signalling exchange between UPF/NW-TT, SMF, and TSCTSF is required to subscribe to UPF/NW-TT updates (directly or via the SMF), as described in clause 6.4.2.1.

#### 6.4.3.2 Procedure for UE provisioning network timing synchronization status

An overall procedure for UE provisioned network timing synchronization status is illustrated in Figure 6.4.3.2-1.



Figure 6.4.3.2-1: Procedure for UE provisioning network timing synchronization status

1. The AF sends network timing synchronization status request to the NEF or TSCTSF. The subscription configuration of NG-RAN nodes and UPF/NW-TT (if applicable) is performed as described in clause 6.4.3.1.

2. The NG-RAN node detects a primary source event (e.g. degradation, failure, recovery).

3. The NG-RAN node notifies the AMF providing a NG-RAN timing synchronization status report. The TSCTSF may have already configured the NG-RAN node to provide updates to the UE directly via SIB9/RRC signalling, in that case, steps 5 7 can be skipped.

4. The AMF forwards the NG-RAN timing synchronization status report to the TSCTSF. If TSCTSF subscription is at NG-RAN node level (alternative 1 for NG-RAN Time Sync Status reporting, illustrated in Figure 6.4.3.2-1), the AMF can directly forward the report received from NG-RAN node. If TSCTSF subscription is at UE level (alternative 2 and 3 for NG-RAN Time Sync Status reporting), the AMF or RAN determines the UE(s) impacted by the status update received from NG-RAN before notifying the TSCTSF (e.g. based on UE locations or UE identities).

5. The TSCTSF determines the UE(s) to notify and the method to use to forward the network timing synchronization status notification.

Similar to step 15 in clause 6.4.3.1, when the TSCTSF receives a status notification revaluates if the time synchronization service configured for the UE(s) impacted can still be fulfilled (time synchronization error budget). If the service requirements cannot be met, then the TSCTSF may temporarily deactivate time synchronization service for the impacted UE(s) following Release-17 operation.

6. The TSCTSF can initiate a network triggered procedure to forward the notification to the UE via AMF. When the AMF receives the notification, it will forward it to the NG-RAN node. Two alternatives are possible: send the report to the UE using RRC signalling or NAS signalling.

7a. If RRC signalling is preferred, the AMF sends a N2 message to forward the UE's report from AMF to the NG-RAN node. The serving NG-RAN node forwards the network timing synchronization status to the UE using RRC signalling.

7b. If NAS signalling is preferred, the AMF initiates DL NAS Transport procedure to forward the UE's report transparently via the NG-RAN node to the UE using NAS signalling.

### 6.4.4 Impacts on services, entities and interfaces

UE:

- Support receiving RAN timing synchronization status information.

- Support performing a registration request when RAN network timing synchronization status information changes while the UE is in CM-IDLE, if requested by TSCTSF or AMF.

DS-TT:

- Support receiving network timing synchronization status information.

NG-RAN:

- Indicate NG-RAN network timing synchronization status to UEs via SIB9 or RRC signalling.

- Report NG-RAN network timing synchronization status to AMF.

AMF:

- Subscribe for network timing synchronization status reports from NG-RAN nodes.

- Report NG-RAN timing synchronization status to the TSCTSF (at UE level or NG-RAN node level).

SMF:

- If SMF is involved in UPF/NW-TT timing sync status reporting, subscribe for network timing synchronization status reports from UPF/NW-TT nodes.

- Report UPF/NW-TT timing synchronization status to the TSCTSF (at UE level or UPF node level).

TSCTSF:

- Receive network timing synchronization status information from NG-RAN (via AMF) and UPF/NW-TT (via SMF or directly).

- Discover serving AMF for a UE.

- Subscribe for receiving UE's location, UE's presence in Area of Interest, and reachability information from AMF.

- Subscribe for receiving UE's PDU Session events from SMF.

- Support for requesting UEs to perform a Registration request if the UE detects a change in RAN network timing synchronization status information and the UE is in CM-IDLE.

- Inform AFs about network timing synchronization status and time synchronization service status for the impacted UE(s).

- Initiate network-triggered procedures to reach the UE if is in CM-IDLE.

- Inform UE about RAN timing synchronization status using NAS signalling, or configuration of NG-RAN node to notify the UE via RRC/SIB.

UPF:

- Report transport network timing synchronization status to TSCTSF (directly or via SMF).

AF:

- Request for network timing synchronization status.

- Support receiving network timing synchronization status information.

## 6.5 Solution #5: Inform UE and AF about 5GS network timing synchronization status for PTP

### 6.5.1 Introduction

The solution is proposed to solve Key Issue #1: 5GS network timing synchronization status and reporting.

This solution addresses the following scenarios:

- 5GS is acting as Bridge to distribute time information to UEs using PTP or gPTP, as defined in clause 5.27.1.7 of TS 23.501 [2].

This solution makes the following assumptions:

- The UE/DS-TT, NG-RAN, UPF/NW-TT are synchronized with the 5G GM (i.e. the 5G internal system clock) as specified in TS 23.501 [2] and TS 38.331 [5].

- The UE/DS-TT and UPF/NW-TT handle the (g)PTP message as TS 23.501 [2].

### 6.5.2 Functional Description

This solution only get time synchronization status from UPF/NW-TT. To enable NG-RAN time synchronization status case, this solution can be used in combination with other KI#1 solutions (like solution #1 or solution #4).

The solution is based on the following principles:

- The AF/NEF subscribes the time synchronization status with TSCTSF.

- TSCTSF subscribes for receiving time synchronization status from UPF/NW-TT via PMIC/UMIC (i.e. the status of the synchronization of the UPF/NW-TT with the 5G GM and PTP GM):

- According to the status subscription, the UPF/NW-TT reports 5G GM and PTP GM (e.g. clock class and traceability) to TSCTSF/TSN AF via PMIC/UMIC.

- When TSCTSF receives the time synchronization status, it determines the impacted PTP ports and related UE (i.e. AF sessions):

- The TSCTSF notifies the AF with the time synchronization status.

### 6.5.3 Procedures

The exchange of PMIC/UMIC between TSCTSF and UE/DS-TT and between TSCTSF and UPF/NW-TT is specified in clause 5.28.3 of TS 23.501 [2].

### 6.5.4 Impacts on services, entities and interfaces

TSCTSF:

- Receive time synchronization status from UPF/NW-TT.

- Inform AFs about time synchronization status.

UPF/NW-TT:

- Report 5G GM or PTP GM time sync status (e.g. clock class and UTC traceability) to TSCTSF via PMIC/UMIC.

## 6.6 Solution #6: Support for 5G Timing Exposure Enhancement.

### 6.6.1 Introduction

The solution enables AF to request time synchronization service in a specific coverage area. 5GS enforces the time synchronization service according to the requested coverage area.

### 6.6.2 General description

- The AF requested time synchronization service is for one UE or a group of UE.

- UEs get time synchronization service by receiving 5GS access stratum time or time-synchronized UPF/NW-TT.

The general idea of the solution is structured as follows:

- AF requests time synchronization service for targeted UE(s), and the coverage area info is included in the request.

- NEF authorizes the AF request and sends it to TSCSTF.

- TSCTSF determines the time source for the requested AF.

- AMF reports UE location information to PCF when the PCF initiates the AM policy association modification.

- If UE moves out of the coverage area, the requirements of time synchronization service in the AF request will not be met any more. When TSCTSF receives the notification from AMF about UE leave, TSCTSF will deactivate the time synchronization service and the RAN node will stop to provide 5G access stratum information to the UE.

- The coverage area information in the AF request can be per cell, per RAN nodes or a geographical area. If the requested coverage area information is presented in per cell or per RAN nodes, TSCTSF will update the access stratum time indication combined with coverage area information. If the requested area is a geographical area, it is assumed that the requested information can be interpreted by NEF to a 3GPP defined location information. It may be a pre-configured area mapping or depending on specific implement.

### 6.6.3 Procedures

Flow chart for the AF requested time synchronization service in a specific area is illustrated as following.



Figure 6.6.3-1: AF requesting time synchronization service in a specific area

1. AM policy association establishment is finalized during UE registration procedure.

2. The procedure is triggered by the AF request to influence the 5G time distribution. The coverage area information is added in step 2 when the AF requests the service in a specific area.

3. The NEF authorizes the request and invokes the operation with the corresponding TSCTSF. TSCTSF calculates the Uu time synchronization error budget if the AF provides the error budget requirements. The coverage area information is considered together with the 5G access stratum time distribution indication by the TSCSTF. If 5G access stratum time distribution is enabled in the coverage area, it can meet the request. If another gNB not in the coverage area or time-synchronized UPF/NW-TT can meet the request requirements, it provides reference time to the targeted UE in the area to enforce AF request if possible.

4. If the 5G access stratum time distribution parameters in UDR are associated with a DNN/S-NSSAI for the PCF for the UE may discover the PCF for the PDU Session using SUPI and (DNN, S-NSSAI) as parameters.

5. TSCTSF selects for the PCF that handles the AM Policy Association of the targeted UE with SUPI (step 4) as an input parameter and informs the PCF to consider UE location information when determining AM policy.

6. If the TSCTSF sends multiple time synchronization error budgets for a given UE, the PCF would pick the most stringent budget. The PCF takes a policy decision and then it may initiate an AM Policy Association Modification procedure. In the step, the AMF is responsible for reporting UE location information to PCF. When PCF receives UE location information, it determines to provide which 5GS access stratum time information to UE based on time synchronization date sent by TSCTSF. As part of this, the 5G access stratum time distribution indication and the Uu time synchronization error budget are provided to NG-RAN. Based on this, NG-RAN provides the 5GS access stratum time to the UE according to the Uu time synchronization error budget as provided by the TSCTSF (if supported by UE and NG-RAN).

7. The PCF of the UE replies to the TSCTSF with the result of Npcf\_AMPolicyAuthenorization operation.

8. The TSCTSF responds to the NEF request in step 3.

9. The NEF informs the AF about the result of the operation in step 2.

### 6.6.4 Impacts on services, entities and interfaces

AF:

- Support to include the coverage area information in the time synchronization service request.

TSCTSF:

- Support to include the coverage area information in the time synchronization service request.

- Update the 5G access stratum time distribution indication based on coverage area information.

- Inform the PCF to consider UE location information.

PCF:

- Combine UE location information when AM policy decision.

## 6.7 Solution #7: RequestedCoverage area filters for time synchronization service

### 6.7.1 Introduction

This solution is proposed to solve Key Issue #2: Time synchronization service enhancements. In this Key Issue, the coverage area is taken into account for the configuration of the time synchronization service. Therefore, this solution addresses the time synchronization service scenarios already supported in 5G Release-17 based on access stratum or (g)PTP time distribution methods.

This solution proposes to use a list of Tracking Areas (TAs) identified by Tracking Area Identities (TAI) or a list of Cells to describe a specific geographical area (a so-called Requested Coverage Area) where an AF requests to enable a time synchronization (TS) service. Furthermore, in order to enforce that the requested TS service is enabled for UEs (a specific UE or a group of UEs) only in that Requested Coverage Area, the proposed solution exploits the 5GS functionality (provided by the AMF) of tracking and reporting "UE mobility on Area of Interest" events (clause 5.3.4.4 of TS 23.501 [2]). An Area of Interest (AoI) for each AMF is represented by a list of TA(s) or by a list of Cells, wherein the Area of Interest is identical to the Requested Coverage Area or the Area of Interest is a TA or cell subset of the Requested Coverage Area.

### 6.7.2 Functional Description

The existing time synchronization exposure procedures (clause 4.15.9 of TS 23.502 [3]) are enhanced.

The following principles are proposed to enable the use of coverage area for time synchronization service operation:

- An AF may optionally include a Requested Coverage Area within the timing synchronization service request using a spatial validity condition.

- As a spatial validity condition, the AF may use a geographical area (e.g. a civic address or shapes) or a TA/Cell list (if it is an AF within the operator's domain, it will have TA(s) or Cell(s) configured):

- If the AF uses a geographical area as a spatial validity condition, the NEF transforms this information into 3GPP identifiers (e.g. TAI(s) or Cell(s)) based on pre-configuration. Later, the TSCTSF discovers the AMF(s) serving the TAs/Cells comprising Area(s) of Interest. The TSCTSF or AMF subscriptions use Area of Interest that may be the same as the Requested Coverage Area or may be a subset of TAs/Cells from the list of TAs/Cells describing the Requested Coverage Area.

- If the AF is within the operator's domain, it uses a list of TAs or a list of Cells directly (based on pre-configuration) to formulate the spatial validity condition for the Requested Coverage Area.

- TSCTSF uses Location or UE presence in Area of Interest services at the AMF Event Exposure service (Namf\_EventExposure operations) to identify the UE(s) to which the AF request with a Requested Coverage Area applies. The TSCTSF subscribes to this information at the AMF(s), stores it, and determines the UE(s) presence in the Requested Coverage Area using the notification(s) from one or multiple AMFs.

- Requested Coverage Area will be used at the TSCTSF for triggering time synchronization service activation/modification/deactivation with the following differences:

1) the TSCTSF discovers the AMF(s) serving in the Tracking Areas (TAs) comprising the Requested Coverage Area;

2) the TSCTSF subscribes (using the Namf\_EventExposure\_Subscribe service operation specified in clause 5.2.2.3.2 of TS 23.502 [3]) to the UE mobility on Area of Interest event notification service from the AMF(s) to be notified the UE(s) presence in an Area of Interest for each AMF (e.g. UE location is IN or OUT an Area of Interest);

3) the TSCTSF determines (based on the notification from the AMF(s)) whether or not the targeted UE(s) are inside the Requested Coverage Area; and

4) the TSCTSF proceeds with the time synchronization service activation/deactivation only after the TSCTSF has determined which of the targeted UE(s) are in or out of the Requested Coverage Area. The subscription to reports of UE presence in the Area of Interest procedure is described in clause 5.3.4.4 of TS 23.501 [2].

- For access stratum distribution activation/deactivation, the TSCTSF will enable/disable ReferenceTimeInformation delivery to the UE at the serving NG-RAN node reusing the procedure in clause 4.15.9.4 of TS 23.502 [3]. For (g)PTP distribution activation/deactivation, the TSCTSF will modify the PTP instance configuration by means of sending a PMIC to the impacted UE/DS-TT and UMIC to the UPF/NW-TT, as described in clause K.2.2 of TS 23.501 [2].

- Alternatively, the TSCTSF can trigger a deferred 5GC-MT-LR procedure to GMLC with the type of event assigned to Area, where the area information is set to the Requested Coverage Area for time synchronization services provided by TSN AF. GLMC receives the deferred 5GC-MT-LR procedure and responds with location event notification indicating the UE entering or moving out of the coverage area.

### 6.7.3 Procedures

#### 6.7.3.1 Procedure for AF requested (g)PTP timing synchronization with Requested Coverage Area

An overall procedure for AF providing coverage area for (g)PTP based time synchronization service is illustrated in Figure 6.7.3.1-1.



Figure 6.7.3.1-1: (g)PTP time distribution configuration with Requested Coverage Area

1. The AF creates a time synchronization service configuration for a PTP instance by invoking Nnef\_TimeSynchronization\_ConfigCreate service operation. The request includes the parameters as described in table 4.15.9.3.1 in TS 23.502 [3] and optionally a spatial validity condition (i.e. Requested Coverage Area) in the format of a geographical area (e.g. a civic address or shapes) a list of TA(s), or a list of Cells.

2. The NEF authorizes the request. If the AF uses a geographical area as a spatial validity condition, the NEF transforms this information into a list of TA(s) or a list of Cells based on pre-configuration. The list of TA(s) or the list of Cells describes the Requested Coverage Area.

The AF within the operator's domain shall use a list of TA(s) or a list of Cells directly to formulate a spatial validity condition describing the Requested Coverage Area.

3. After successful authorization, the NEF invokes the Ntsctsf\_TimeSynchronization\_ConfigCreate service operation with the corresponding TSCTSF, with the parameters as received from the AF.

The AF that is part of operator's trust domain may invoke the services directly with TSCTSF.

4. TSCTSF determines whether the TSCTSF has subscribed for the UE presence for an area that is indicated in the TAs or Cell IDs in the spatial validity condition. If not, the TSCTSF discovers the AMF(s), serving in the TAs or serving the Cells that either comprise the spatial validity condition, using the NRF discovery service (Nnrf\_NFDiscovery\_Request) with the list of TAs or the list of Cells, respectively.

5. The spatial validity condition for the UE(s) is resolved at the TSCTSF. In order to do that, the TSCTSF subscribes to the AMF(s) to receive notifications about the UE presence in an area of interest (or UE location) using Namf\_EventExposure operation. The subscribed area of interest may be the same as the Requested Coverage Area specified by the spatial validity condition or may be a subset of the Requested Coverage Area (e.g. a list of TAs, or cell list) based on the latest known UE location.

6-7. The AMF(s) track the UE's location to determine the UE's presence in an Area of Interest as described in clause 4.15.4.2 of TS 23.502 [3]. Further, the AMF(s) notify the TSCTSF about the UE(s) presence (IN, OUT, or UNKNOWN) in the Area of Interest(s).

8. The AMF(s) accept TSCTSF's subscription and provide the first corresponding event report (if available).

9. According to the UE location of each UE that is targeted by the request and spatial validity condition in step 1, the TSCTSF determines whether to active time synchronization service for this UE:

- If the UE location is in an Area of Interest (and thus in the Requested Coverage Area), the TSCTSF determines to active time synchronization service and creates a PTP port in a DS-TT and assigns it into the PTP instance.

- If the UE location is out of Requested Coverage Area, the TSCTSF creates a PTP port in a DS-TT and assigns it into the PTP instance but temporarily removes the UE/DS-TT from the PTP instance and indicates the PTP port state as Inactive for the related DS-TT PTP port.

10. The TSCTSF responds with the Ntsctsf\_TimeSynchronization\_ConfigCreate response.

11. The NEF responds with the Nnef\_TimeSynchronization\_ConfigCreate response.

12. The TSCTSF uses the procedures described in clause K.2.2 of TS 23.501 [2] to configure and initialize the PTP instance in the DS-TT(s) and NW-TT.

13. The TSCTSF uses the procedure in clause 4.15.9.4 of TS 23.502 [3] to manage the 5G access stratum time distribution for the UEs that are part of the impacted PTP instance.

14. UE moves in/out of the determined area of interest (i.e. Requested Coverage Area).

15. NG-RAN determines the UE presence in the area of interest has changed and notifies the AMF.

16. The AMF detects the subscription change related event occurs and it sends the event report by means of Namf\_EventExposure\_Notify message to the TSCTSF.

17. If the TSCTSF receives the UE location change notification for AoI. The TSCTSF may update to activate or deactivate the time synchronization service for the given UE.

- If the UE moves out of the Requested Coverage Area, the TSCTSF temporarily removes the UE/DS-TT from the PTP instance and indicates the PTP port state as Inactive for the related DS-TT PTP port.

- If the UE moves into an Area of Interest, and according to Temporal Validity Condition (if this parameter is available, and current time is within validity time period), the TSCTSF determines to activate time synchronization service; the TSCTSF adds the DS-TT PTP port to the PTP instance again and indicates the PTP port state as Active for the related DS-TT PTP port.

- The TSCTSF keeps the requested TS service unchanged (i.e. active/inactive) when the UE presence in the Requested Coverage Area becomes UNKNOWN until the TSCSTF determines that the UE is inside/outside the Requested Coverage Area.

18. The TSCTSF updates the state of the time synchronization configuration and may notify the NEF (or AF) with the Ntsctsf\_TimeSynchronization\_ConfigUpdateNotify service operation. The notification indicates the identities of the UEs currently within the area of spatial validity.

19. The NEF notifies the AF with the Nnef\_TimeSynchronization\_ConfigUpdateNotify service operation.

#### 6.7.3.1a Procedure for AF requested (g)PTP timing synchronization with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR

An overall procedure for AF providing coverage area for (g)PTP based time synchronization service is illustrated in Figure 6.7.3.1a-1.



Figure 6.7.3.1a-1: (g)PTP time distribution configuration with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR

1. The AF creates a time synchronization service configuration for a PTP instance by invoking Nnef\_TimeSynchronization\_ConfigCreate service operation. The request includes the parameters as described in table 4.15.9.3.1 in TS 23.502 [3] and optionally a spatial validity condition (i.e. Requested Coverage Area) in the format of a geographical area (e.g., a civic address or shapes) a list of TA(s), or a list of Cells.

2. The NEF authorizes the request. If the AF uses a geographical area as a spatial validity condition.

3. After successful authorization, the NEF invokes the Ntsctsf\_TimeSynchronization\_ConfigCreate service operation with the corresponding TSCTSF, with the parameters as received from the AF.

The AF that is part of operator's trust domain may invoke the services directly with TSCTSF.

4. TSCTSF triggers a deferred 5GC-MT-LR procedure to GMLC with the type of event assigned to Area, where the area information is set to the Requested Coverage Area for time synchronization services provided by TSN AF.

5. GLMC performs deferred 5GC-MT-LR procedure as defined from step 2 to 20 in Figure 6.7.3.1-1 of TS 23.273 [16] v17.5.0 with the type of event assigned to Area.

6. The GLMC notifies the TSCTSF about the UE(s) presence (IN, OUT, or UNKNOWN) in the Area of Interest(s).

7. TSCTSF determines whether to activate time synchronization service. According to the UE location of each UE that is targeted by the request and spatial validity condition in step 1, the TSCTSF determines whether to active time synchronization service for this UE:

- If the UE location is in an Area of Interest (and thus in the Requested Coverage Area), the TSCTSF determines to active time synchronization service and creates a PTP port in a DS-TT and assigns it into the PTP instance.

- If the UE location is out of Requested Coverage Area, the TSCTSF creates a PTP port in a DS-TT and assigns it into the PTP instance but temporarily removes the UE/DS-TT from the PTP instance and indicates the PTP port state as Inactive for the related DS-TT PTP port.

8 The following procedure is described from step 10 to 19 in Figure 6.7.3.1-1.

#### 6.7.3.2 Procedure for AF requested 5G access stratum timing synchronization with Requested Coverage Area

An overall procedure for AF requesting a specific coverage area for 5G access stratum based time synchronization service (see TS 23.502 [3]) is illustrated in Figure 6.7.3.2-1.



Figure 6.7.3.2-1: 5G access stratum time distribution configuration with Requested Coverage Area

1. The AF request to influence the 5G access stratum time distribution providing access stratum time distribution parameters to the NEF (together with the AF identifier and potentially further inputs as specified in table 4.15.9.4-1 of TS 23.502 [3]) and optionally a spatial validity condition (i.e. Requested Coverage Area) in the format of a geographical area (e.g. a civic address or shapes), a list of TA(s), or a list of Cells.

2. The NEF authorizes the request. If the AF uses a geographical area as a spatial validity condition, the NEF transforms this information into a list of TA(s) or a list of Cells based on pre-configuration. The list of TA(s) or the list of Cells describes the Requested Coverage Area.

The AF within the operator's domain shall use a list of TA(s) or a list of Cells directly to formulate a spatial validity condition describing the Requested Coverage Area.

3. After successful authorization, the NEF invokes the Ntsctsf\_ASTI\_Create service operation with the corresponding TSCTSF.

4. TSCTSF determines whether the TSCTSF has subscribed for the UE presence for an area that is indicated in the TAs or Cell IDs in the spatial validity condition. If not, the TSCTSF discovers the AMF(s), serving in the TAs or serving the Cell(s) that either comprise the spatial validity condition, using the NRF discovery service (Nnrf\_NFDiscovery\_Request) with the list of TAs or the list of Cells, respectively.

5. The spatial validity condition is resolved at the TSCTSF. In order to do that, the TSCTSF subscribes to the AMF to receive notifications about change of UE location in an area of interest using Namf\_EventExposure operation. The subscribed area of interest may be the same as the Requested Coverage Area specified by the spatial validity condition or may be a subset of the Requested Coverage Area (e.g. a list of TAs, a list of Cells) based on the latest known UE location.

6-7. The AMF(s) track the UE's location to determine the UE's presence in an Area of Interest as described in clause 4.15.4.2 of TS 23.502 [3]. Further, the AMF(s) notify the TSCTSF about the UE(s) presence (IN, OUT, or UNKNOWN) in the Area of Interest(s).

8. The AMF(s) accept TSCTSF's subscription and provide the first corresponding event report (if available).9. According to the UE location and spatial validity condition, the TSCTSF determines whether to activate time synchronization service:

- If the UE location is in an Area of Interest (and thus in the Requested Coverage Area), the TSCTSF determines to activate time synchronization service.

- If the UE location is out of Requested Coverage Area, the TSCTSF stores the UE identity and determines not to activate ASTI time synchronization service for the UE.

10. The TSCTSF responds the AF with the Ntsctsf\_ASTI\_Create service operation response.

11. The NEF informs the AF about the result of the Nnef\_ASTI\_Create service operation performed in step 1.

12. The TSCTSF uses the procedures described in clause 4.15.9.4 of TS 23.502 [3] to configure ReferenceTimeInformation delivery to the UE(s) at the serving NG-RAN nodes.

13. UE moves in/out of the configured Area(s) of Interest.

14. NG-RAN determines the change of the UE presence in the area of interest has changed and notifies the AMF.

15. The AMF detects the subscription change related event occurs and it sends the event report by means of Namf\_EventExposure\_Notify message to the TSCTSF.

16. If the TSCTSF receives the UE location change notification for AoI. The TSCTSF may update to activate or deactivate the time synchronization service.

- If the UE moves out of the Requested Coverage Area, the TSCTSF determines to temporarily deactivate ASTI time synchronization service as described in clause 4.15.9.4 of TS 23.502 [3].

- If the UE moves into an Area of Interest, and according to Temporal Validity Condition (if this parameter is available, and current time is within validity time period), the TSCTSF determines to activate ASTI time synchronization service as described in clause 4.15.9.4 of TS 23.502 [3].

- The TSCTSF keeps the requested TS service unchanged (i.e. active/inactive) when the UE presence in the Requested Coverage Area becomes UNKNOWN until the TSCSTF determines that the UE is inside/outside the Requested Coverage Area.

17. The TSCTSF updates the state of the time synchronization configuration and may notify the NEF (or AF) with the Ntsctsf\_ASTI\_UpdateNotify service operation for the UE identities that are inside or outside of the area in the spatial validity condition.

18. The NEF notifies the AF with the Nnef\_ASTI\_UpdateNotify service operation.

#### 6.7.3.2a Procedure for AF requested 5G access stratum timing synchronization with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR

An overall procedure for AF requesting a specific coverage area for 5G access stratum based time synchronization service (see TS 23.502 [3]) is illustrated in Figure 6.7.3.2-1.



Figure 6.7.3.2a-1: 5G access stratum time distribution configuration with Requested Coverage Area where UE's presence is obtained via TSCTSF triggered deferred 5GC-MT-LR

1. The AF request to influence the 5G access stratum time distribution providing access stratum time distribution parameters to the NEF (together with the AF identifier and potentially further inputs as specified in table 4.15.9.4-1 in TS 23.502 [3]) and optionally a spatial validity condition (i.e. Requested Coverage Area) in the format of a geographical area (e.g., a civic address or shapes), a list of TA(s), or a list of Cells.

2. The NEF authorizes the request. If the AF uses a geographical area as a spatial validity condition.

3. After successful authorization, the NEF invokes the Ntsctsf\_TimeSynchronization\_ConfigCreate service operation with the corresponding TSCTSF, with the parameters as received from the AF.

The AF that is part of operator's trust domain may invoke the services directly with TSCTSF.

4. TSCTSF triggers a deferred 5GC-MT-LR procedure to GMLC with the type of event assigned to Area, where the area information is set to the Requested Coverage Area for time synchronization services provided by TSN AF.

5. GLMC performs deferred 5GC-MT-LR procedure as defined from step 2 to 20 in Figure 6.7.3.1-1 of TS 23.273 [16] v17.5.0 with the type of event assigned to Area.

6. The GLMC notifies the TSCTSF about the UE(s) presence (IN, OUT, or UNKNOWN) in the Area of Interest(s).

7. TSCTSF determines whether to activate time synchronization service. According to the UE location of each UE that is targeted by the request and spatial validity condition in step 1, the TSCTSF determines whether to active time synchronization service for this UE:

- If the UE location is in an Area of Interest (and thus in the Requested Coverage Area), the TSCTSF determines to active time synchronization service and creates a PTP port in a DS-TT and assigns it into the PTP instance.

- If the UE location is out of Requested Coverage Area, the TSCTSF creates a PTP port in a DS-TT and assigns it into the PTP instance but temporarily removes the UE/DS-TT from the PTP instance and indicates the PTP port state as Inactive for the related DS-TT PTP port.

8 The following procedure is described from step 10 to 18 in Figure 6.7.3.2-1.

### 6.7.4 Impacts on services, entities and interfaces

TSCTSF:

- Subscribe for receiving UE's presence in Area of Interest from AMF or from GLMC as a deferred 5GC-MT-LR with the type of event assigned to Area.

- Determination of area of interest based on list of TAs or Cells.

- Support for time synchronization service configuration conditioned to the AF-Requested Coverage Area using a spatial validity condition.

- Discovers the related AMF(s) using the NRF's service operation Nnrf\_NFDiscovery\_Request.

- Notifies the AF/NEF via a new Ntsctsf\_ASTI\_UpdateNotify service operation for the UE identities that are inside or outside of the area in the spatial validity condition.

AMF:

- Tracks a UE's location to determine the UE's presence in an Area of Interest using the existing event reporting type, i.e. UE mobility on Area of Interest.

- Notifies the subscribed TSCTSF about the change of UE's status (IN, OUT, or UNKNOWN) in the Area of Interest using the (existing) Namf\_EventExposure\_Notify service operation.

AF:

- Includes the Spatial Validity Condition in AF request for time synchronization service configuration.

## 6.8 Solution #8: AF Request of PER for QoS and Alt-QoS

### 6.8.1 Introduction

This solution is proposed to solve Key Issue #4: Enable an AF to explicitly provide the required PER to the NEF/PCF for QoS and Alt-QoS.

In Release 17, the "Setting up an AF session with required QoS" procedure (clause 4.15.6.6 of TS 23.502 [3]) and the "AF Session with required QoS update" procedure (clause 4.15.6.6a of TS 23.502 [3]) were revised so the AF can provide individual parameters for QoS and Alt-QoS. Inclusion of PER as an individual parameter requested by the AF was postponed to Release18. PER is a QoS Characteristic as defined in clause 5.7.3.1 of TS 23.501 [2], similar to PDB which was included as an individual parameter. PER is also currently part of the Alternative QoS Profile, along with PDB and GFBR. PDB and GFBR as individual parameters for Alt-QoS were addressed in Release 17.

This solution adds Requested PER to the AF request for QoS and Alternative QoS.

### 6.8.2 Functional Description

When there is a single PDU session anchor for the UE, an AF request for QoS specifying a Requested PER value can sent to the PCF where it is mapped to a PCC rule with a 5QI that reflects the Requested PER. Similarly, a Requested PER value can be added to each Alternative-QoS Related parameter set (currently comprising Requested Delay and Requested GBR) in the Alternative QoS Requirements. Requested PER in the Alternative QoS requirements is mapped to the corresponding parameters in the Alternative QoS Profile (as defined in clause 5.7.1.2a of TS 23.501 [2]), in the same manner as was done for PDB and GFBR in Release 17. PCF selects the appropriate 5QI considering the requested PER and Requested 5GS Delay as in TS 23.503 [4].

### 6.8.3 Procedures

Following are the steps needed for the AF requested PER to be considered either using single or redundant user plane paths:

1. The AF provides Requested PER for QoS and Alternative QoS. If it is a trusted AF, it may provide it directly to the TSCTSF. If not, it provides it via the NEF which eventually forwards it to the TSCTSF.

2. The TSCTSF forwards the parameters to the PCF.

3. The PCF selects the appropriate 5QI considering the requested PER and the individual QoS Parameters as specified in clause 6.1.3.22 of TS 23.503 [4].

4. The PCF determines a PCC rule using the Requested PERs received from the AF/NEF.

5. The response to the AF (Nnef\_AFsessionWithQoS\_Create/Update response) indicates whether the PER request was achieved.

### 6.8.4 Impacts on services, entities and interfaces

SMF:

- Map Requested PER to QoS Profile for QoS and Alternative QoS.

PCF:

- Map Requested PER to PCC Rule for QoS and Alternative QoS.

TSCTSF:

- Support receiving Requested PER from NEF and sending to PCF.

NEF:

- Include Requested PER in Nnef\_AFSessionWithQoS service and send Requested PER to TSCTSF.

AF:

- Request PER for QoS and Alternative QoS.

## 6.9 Solution #9: Interworking with TSN network deployed in the transport network

### 6.9.1 Introduction

This solution enables enhancement to support TSN transport network (TN) for N3 tunnels.

NOTE: The same solution can be used also for N9 tunnels, if necessary.

This solution addresses the following areas:

a) The architecture enhancement to support the interworking between 5GS and TSN networks deployed in the transport network.

b) The information from 5GS to interact with TSN network.

This solution makes the following assumptions:

- The underlay transport network for N3 tunnels support TSN features and deploys a CNC.

- 5GC implements the UNI as defined in IEEE P802.1Qdj [10] towards the CNC in Transport Network. The related parameters are defined in IEEE Std 802.1Qcc [6].

- The solution can be used with both Ethernet and IP type PDU Sessions.

- The solution can be used when 5GS is integrated with external IEEE TSN networks as specified in TS 23.501 [2]. In this case the CNC in external TSN network controls the 5GS as an IEEE 802.1Q bridge via TSN AF.

- The solution can be used when integration with external IEEE TSN networks does not apply as specified in TS 23.501 [2]. In this case the AF uses the 3GPP QoS-service to indicate the QoS requirements and traffic characteristics to the TSCTSF.

- A dynamic value for the CN PDB of a Delay-critical GBR 5QI is determined by the SMF as described in clause 5.3.7.4 of TS 23.501 [2].

- NG-RAN may include AN-TL function and UPF may include CN-TL function, to support acting as a TSN Talker/Listener. SMF/CUC communicates with the AN-TL via Transparent Container that conveys the IEEE Std 802.1Qcc [6] data sets in N2 interface. SMF/CUC communicates with the CN-TL via Transparent Container that conveys the IEEE Std 802.1Qcc [6] data sets in N4 interface.

- AN-TL and CN-TL enable the following functions:

a) hold and buffer functionality in a case when the TSCAI contains a BAT in UL and/or DL direction. In this case the TimeAwareOffset is sent to the AN-TL and/or CN-TL in a Transparent Container, and the Talker in RAN/UPF must buffer the data burst until the time indicated in the TimeAwareOffset is reached.

b) for support of stream transformation, in this case the InterfaceConfiguration is sent in a Transparent Container to AN-TL and/or CN-TL, and the Talker in RAN/UPF must use the indicated MAC address, VLAN ID or IP-tuples for the data stream.

c) for SMF/CUC to retrieve the InterfaceCapabilities and/or EndStationInterfaces from the AN-TL or CN-TL via Transparent Container. Otherwise, this information must be preconfigured or determined by SMF/CUC.

- It is assumed that RAN, 5GC and Transport Network are time synchronized with each other in 5G internal system clock in this case.

### 6.9.2 Functional Description

5GC will act as CUC to interact with the TN CNC. RAN and UPF may act as Talker or Listener by implementing Access Network TSN Talker/Listener (AN-TL) and Core Network N3 interface TSN Talker/Listener (CN-TL) as network termination point for the N3 interface. AN-TL and CN-TL support the functionality of Talker and Listener (End Station).

The architecture is as Figure 6.9.2-1:



Figure 6.9.2-1: Architecture on interworking with TSN transport network

NOTE 1: The TN CNC in transport network (TN) is independent from the CNC in the DN.

NOTE 2: DS-TT and NW-TT are required when 5GS is integrated with external IEEE TSN networks.

It is proposed the SMF will act as the CUC or the CUC functionality is collocated with SMF. SMF/CUC provides merged stream requirements on QoS Flow basis (i.e. translated Talker group and Listener group information) as specified in clause 45.1.7 of IEEE P802.1Qdj [10] via the User/Network-Interface (UNI) to the TN CNC. TN CNC uses the merged stream requirements as input to select respective path(s) and calculate schedules in TN. Based on the results, the TN CNC provides merged end station communication-configuration back to the SMF/CUC. The SMF may further adjust the transmit time of the stream in UPF and RAN by including TimeAwareOffset in a Transparent Container in a QoS Flow modification request.

When the SMF setups a new QoS Flow, the SMF signals the dynamic value for the CN PDB and TSCAI for the QoS Flow to NG-RAN on QoS Flow basis. Upon receiving the TSCAI for a QoS Flow from the SMF, if the TSCAI includes a BAT in UL direction, the RAN may determine a dynamic value of 5G-AN PDB in UL direction that is determined on QoS Flow basis. The NG-RAN provides the dynamic value of 5G-AN PDB to the SMF in a response to the QoS Flow request.

The details of providing End Station related information to generate the merged stream requirements for the QoS Flow by the SMF/CUC are as follows:

For the Talker group:

‐ Stream ID and Stream Rank can be generated by the SMF/CUC based on pre-configuration.

‐ EndStationInterfaces and Interface Capabilities (optional) are either pre-configured in the SMF/CUC or the SMF/CUC can collect them during PDU Session Establishment from AN-TL and CN-TL. The pre-configured information at the SMF/CUC leaves the InterfaceCapabilities empty.

- DataFrameSpecification (optional) is present if stream transformation is not performed in AN-TL and CN-TL.

or if AN-TL and CN-TL functions are not supported. In this case, the TN CNC configures the edge bridge to perform the stream transformation based on the provided the DataFrameSpecification. The SMF/CUC populates the attribute with the N3 tunnel end point addresses/ports during the QoS Flow setup.

If the TL-functions are not supported, two options can be considered for identifying the traffic on QoS Flow basis in the TN:

a) The SMF can instruct the UPF and NG-RAN to assign a separate CN tunnel end point address for each QFI of the N4 Session. This ensures the TN can distinguish the QoS Flows based on the N3 tunnel destination IP addresses. For example IPv6 can be used in the N3 tunnel end point addresses to provide sufficient address space.

b) The interface between the SMF/CUC and TN CNC allows the SMF /CUC to indicate the TEID and QFI of the given QoS Flow to the TN CNC. For example, the SMF/CUC indicates a Stream Filter including the source/destination IP addresses/ports and QFI and/or TEID, and merged stream requirements that are associated with this Stream Filter. TN can distinguish the QoS Flows based on the TEID and QFI as carried in the GTP-U. This option impacts the IEEE P802.1Qdj [10].

NOTE 3: Option b) will be abandoned if it is not supported by IEEE P802.1Qdj [10].

‐ In TrafficSpecification elements, there are several parameters related to the TSC traffic within 5GS:

‐ MaxFrameSize, SMF/CUC could generate it from the Burst Size of the TSC traffic. PCF needs to transfer the Burst Size to the SMF. SMF also needs to consider the framing bits which is not used for transferring in 5GS, (e.g. CRC), the GTP-U tunnel overhead.

‐ MaxFramesPerInterval, SMF could set it as 1.

‐ Interval, SMF could generate it from the Periodicity of the traffic as indicated in the TSCAI.

‐ TSpecTimeAware group (optional, present only if the traffic is time-synchronized):

‐ EarliestTransmitOffset, the earliest offset within the Interval.

- For uplink, EarliestTransmitOffset should be set based on the BAT in UL in TSCAI, 5G-AN PDB, and Interval using the following formula:

The sum of (UL BAT + 5G-AN PDB) (presented in TAI time and corrected for clock drifting as specified in TS 23.501) - M x Interval, where M is the largest integer for which the relation:

UL BAT + 5G-AN PDB > M x Interval duration.

would be true.

- For downlink, EarliestTransmitOffset should be set based on the BAT in DL in TSCAC, and UPF Residence Time and Interval using the following formula:

The sum of (DL BAT + UPF Residence Time) (presented in TAI time and corrected for clock drifting as specified in TS 23.501) - CN PDB - M x Interval, where M is the largest integer for which the relation:

DL BAT + UPF Residence Time > M x Interval duration.

would be true.

‐ LatestTransmitOffset, the last chance within an interval should leave enough time to transfer a packet with MaxFrameSize. Thus, the SMF could generate it from the EarliestTransmitOffset plus the interval subtracting subtracting the sum of jitter and the time to transfer a packet with MaxFrameSize.

‐ Jitter, SMF could generate it based on local configuration.

‐ UserToNetworkRequirements.MaxLatency:

‐ NumSeamlessTrees, SMF/CUC could set it as 0 if no redundancy is needed, otherwise it could use other values.

‐ MaxLatency, SMF/CUC could generate it based on CN PDB and UPF Residence Time, i.e. it should be CN PDB minus UPF Residence Time.

The Listener group contains Stream ID, EndStationInterfaces, UserToNetworkRequirements, and Interface Capabilities. The SMF could generate the corresponding information in the same way as defined for the Talker group.

NOTE 4: It is assumed that the merged stream requirements will contain at least the same information as defined for the User/network configuration information (i.e. Talker group and Listener group).

The merged end station communication-configuration provided by TN CNC to the SMF/CUC includes:

‐ Stream ID.

‐ StatusInfo.

‐ AccumulatedLatency.

‐ InterfaceConfiguration (optional):

‐ MAC Address (optional, present only if stream transformation is performed).

‐ VLAN Tag (optional, present only if stream transformation is performed).

‐ IPv4/IPv6 Tuples (optional, present only if stream transformation is performed).

‐ TimeAwareOffset (optional, present only if the traffic is time-synchronized).

‐ FailedInterfaces.

The details of the above information are described in IEEE Std 802.1Qcc [6]. When the SMF/CUC receives the merged end station communication-configuration from TN CNC, the configuration may include InterfaceConfiguration, optionally with TimeAwareOffset element.

If the InterfaceConfiguration is included from TN CNC to SMF/CUC, and if the NG-RAN and UPF include the AN-TL/CN-TL and support the Stream Transformation as described in IEEE 8021.Qdj [10], SMF can instruct the UPF and NG-RAN to assign for each TSC stream an individual TSN Transport address by providing the InterfaceConfiguration to the AN-TL/CN-TL. The Talker in AN-TL/CN-TL shall use the indicated InterfaceConfiguration, e.g. Multicast destination MAC address as assigned by the TN CNC. In this case the TN can identify the streams based on the Stream Transformation that is applied in the Talker in the AN-TL/CN-TL. This allows to use a single GTP-U tunnel as defined for non TSN Transport networks. The TSN transport address used for identification in TN can be a Destination MAC address, a Source MAC address and a VLAN ID (optional).

If the TimeAwareOffset is included from TN CNC to SMF/CUC, the SMF/CUC should configure the AN-TL and CN-TL based on the TimeAwareOffset. The SMF/CUC adjusts the TimeAwareOffset to be relative from the start of the BAT before sending it to the AN-TL or CN-TL. The AN-TL and CN-TL should set the sending time of the traffic (e.g. AdminBaseTime and OperBaseTime in 802.1Qbv data sets) in the transport layer accordingly.

NOTE 5: It is assumed that the merged end station communication-configuration will contain at least the same information as defined for the status.

### 6.9.3 Procedures

Figure 6.9.3-1 shows the procedure for this solution:



Figure 6.9.3-1: Procedure for interworking with TSN transport network

1. UE triggers the PDU Session Establishment procedure as described in clause 4.3.2 of TS 23.502 [3]. If the RAN/UPF support the TL-function, the RAN and UPF report InterfaceCapabilities to the SMF/CUC via a Transparent Container.

2. During QoS Flow setup, the SMF received PCC rules with TSC Assistance Container from the PCF. The PCF needs to send Burst Size of the TSC traffic as described in clause 6.9.2.

2a. SMF setups the QoS Flow with UPF and NG-RAN.

3. The SMF/CUC generates merged stream requirements as described in clause 6.9.2.

4. The SMF/CUC sends the merged stream requirements to the TN CNC.

5. The TN CNC returns the merged end station communication-configuration to the SMF/CUC.

6. The SMF/CUC configures the Talker and Listener based on the merged end station communication-configuration returned by the TN CNC. The SMF/CUC could send the TimeAwareOffset to theCN-TL and AN-TL in a Transparent Container. The CN-TL and AN-TL should adjust the sending time of the traffic (e.g. AdminBaseTime and OperBaseTime) accordingly.

### 6.9.4 Impacts on services, entities and interfaces

SMF:

- Support the collocation with CUC, i.e.:

- Provide input related to the Talker/Listener Group based on the above description. Passes the merged stream requirements to the TN CNC. Receives the merged end station communication-configuration from the TN CNC.

- Optionally transfer received merged end station communication-configuration from the TN CNC to the Talker/Listener accordingly.

PCF:

- sends the TSCAC including Burst Size of the TSC traffic to the SMF.

RAN:

- optionally support the functionality of Listener/Talker as described above.

UPF:

- optionally support the functionality of Talker/Listener as described above.

## 6.10 Solution #10: 5GC acting as a CUC for CNC in TN

### 6.10.1 Introduction

This solution is merged into Solution #9.

This solution enables the 5GC to act as a TSN CUC (Centralized User Configuration).

This solution makes the following assumptions:

- The underlay transport network for N3 and N9 tunnels support TSN features and deploys a CNC.

- 5GC implements the UNI as defined in IEEE P802.1Qdj [10] towards the CNC in Transport Network.

- The solution can be used with both Ethernet and IP type PDU Sessions.

- The solution can be used when 5GS is integrated with external IEEE TSN networks as specified in TS 23.501 [2]. In this case the CNC in external TSN network controls the 5GS as an IEEE 802.1Q bridge via TSN AF.

- The solution can be used when integration with external IEEE TSN networks does not apply as specified in TS 23.501 [2]. In this case the AF uses the 3GPP QoS-service to indicate the QoS requirements and traffic characteristics to the TSCTSF.

- A dynamic value for the CN PDB of a Delay-critical GBR 5QI is determined by the SMF as described in clause 5.3.7.4 of TS 23.501 [2].

### 6.10.2 Functional Description

The solution is based on the architecture in Figure 6.10.2-1:



Figure 6.10.2-1: Architecture to support the control of TSN features in TN

- The solution supports deployments with and without external TSN network:

a) When integration with IEEE TSN applies: CNC in external TSN network provides bridge configuration to the TSN AF. TSN AF uses the PSFP (IEEE 802.1Qci) information as provided by the CNC to derive the TSC Assistance Container (TSCAC). TSCAC is provided to the SMF (via PCF), and SMF determines the TSC Assistance Information (TSCAI) as specified in TS 23.501 [2].

b) When integration with IEEE TSN does not apply: The AF provides a Ntsctsf\_QoSandTSCAssistance service request to the TSCTSF (directly or via NEF). The request contains the flow description and may contain one or more of the Requested 5GS delay, Burst Size, Burst Arrival Time, Periodicity, and Time Domain as specified in clause 4.15.6.6 of TS 23.502 [3]. TSCTSF determines the TSCAC and provides it to the SMF (via PCF), and SMF determines the TSCAI. DS-TT and NW-TT are optional as in Release 17.

- TSN Transport Network (TN) deploys a CNC that communicates with a CUC residing in the 5GC. The SMF is collocated with the CUC and information is exchanged between SMF and CUC by implementation specific means (out of scope of 3GPP). Once the SMF has established a QoS Flow between UPF and NG-RAN, the SMF/CUC determines the merged stream requirements for the QoS Flow in the transport network and communicates them to the CNC in TN.

- The CUC implements the UNI as defined in IEEE P802.1Qdj [10] towards the CNC in Transport Network.

- CNC in TN configures the TN according to the merged stream requirements reflecting the required traffic characteristics of the QoS Flow.

Editor's note: Stream Aggregation is FFS.

### 6.10.3 Procedures

Figure 6.10.3-1 describes the overall procedure how QoS Flows are established with the solution.



Figure 6.10.3-1: Overview of the QoS Flow establishment

1. PCF receives the Policy Authorization service request from the AF/NEF/TSCTSF. The PCF composes the PCC Rules as specified in Release 17. PCF includes the TSCAC in the request when it invokes the SMF.

2. SMF receives the PCC Rules from the PCF. The SMF binds the PCC rule to a QoS Flow.

3. SMF indicates N4 rules for a QoS Flow to the UPF. The UPF assigns the CN tunnel endpoint address. The SMF determines a dynamic value for the CN PDB, based on the UPF and NG-RAN of the PDU Session.

4. The SMF provides the QoS profile for the QoS Flow to the NG-RAN. The SMF signals the dynamic value for the CN PDB for the QoS Flow to NG-RAN. NG-RAN assigns the AN tunnel endpoint address.

SMF provides the TSCAI to the NG-RAN on QoS Flow basis. The TSCAI may contain Burst Arrival Time (BAT) at the UE egress for UL traffic, and BAT at the gNB ingress for DL traffic, as specified in Release 17.

Upon receiving the TSCAI for a QoS Flow from the SMF, if the TSCAI includes a BAT in UL direction, the RAN determines the corresponding BAT offset in UL direction at the gNB egress. The NG-RAN provides the value to the SMF in a response.

BAT offset is relative to the BAT value in UL direction NG-RAN has received from the SMF in TSCAI. BAT offset can take positive or negative values. The NG-RAN estimates the value of BAT offset at the time of QoS Flow establishment or modification. If necessary, the NG-RAN can update the BAT offset to the SMF e.g. if certain threshold is exceeded.

If (g)PTP time synchronization is used and the TSCAC contains the Burst Arrival Time expressed in external GM time, the SMF adjusts the TSCAI to be expressed in 5GS time based on the clock drifting reports from the UPF as in Release 17. In this case the SMF may update the TSCAI of the QoS Flow to the NG-RAN.

5. After the SMF has setup a QoS Flow between UPF and NG-RAN, the SMF deducts the received BAT offset from the current BAT in UL direction in the TSCAI for the given QoS Flow.

The SMF provides the corresponding flow identification (AN tunnel end point address/port and CN tunnel endpoint address/port) along with the traffic requirements and characteristic for the QoS Flow (BAT at RAN egress in UL direction, BAT at UPF egress in DL direction, Periodicity, maximum latency, maximum jitter, max number of frames per interval, maximum frame size, etc) While the collocated CUC translates this information to merged stream requirements. The CUC communicates the merged stream requirements to the CNC in the TN. The SMF sets the maximum latency to the value of the CN PDB.

Editor's note: It is FFS if also the UPF residence time needs to be considered when calculating the maximum latency that is indicated in the stream requirements.

The CUC and CNC in TN may use the data frame specification for IP to identify at UNI the TN stream on QoS Flow basis, in order to treat the data flow according to the traffic requirements assigned for the QoS Flow. The CNC in TN can then use the provided merged stream requirements to ensure that sufficient resources are reserved in the TN for the TN stream e.g. to select the path(s) and calculate schedules for the traffic that can guarantee the required maximum latency.

NG-RAN and UPF may support the Stream Transformation as described in IEEE P802.1.Qdj [10], e.g. Talker uses the Multicast MAC address as assigned by the TN-CNC and indicated to the NG-RAN and UPF from the SMF/CUC. Alternatively, if the NG-RAN and UPF do not support Stream Transformation, two options can be considered for identifying the traffic on QoS Flow basis in the TN:

a) The SMF can instruct the UPF and NG-RAN to assign a separate CN tunnel end point address for each QFI of the N4 Session. This ensures the TN can distinguish the QoS Flows based on the AN and CN tunnel destination IP addresses. It is assumed that IPv6 is used in the CN tunnel addresses to provide sufficient number of addresses.

b) The interface between the CUC and CNC in the TN allows the SMF and CUC to indicate the TEID and QFI of the given QoS Flow to the CNC in the TN. For example, the CUC indicates a Stream Filter including the source/destination IP addresses/ports and QFI and/or TEID, and merged stream requirements that are associated with this Stream Filter. TN can distinguish the QoS Flows based on the TEID and QFI as carried in the GTP-U. This option impacts the IEEE P802.1Qdj [10].

### 6.10.4 Impacts on services, entities and interfaces

SMF:

- Allows information access with the collocated CUC to support UNI as described in IEEE P802.1Qdj [10].

- Determines the traffic requirements for a QoS Flow and initiates that CUC translates them to merged stream requirements which are then passed to the CNC in Transport Network.

NG-RAN:

- Determines a BAT offset in UL direction at the gNB egress, based on the BAT in UL direction the NG-RAN receives from the SMF in TSCAI. The NG-RAN provides the BAT offset value to the SMF in a response to the QoS Flow establishment or modification request. If Option a) is used to identify the flows in TN, assigns a separate AN tunnel end point address for each QFI of the PDU Session.

UPF:

- If Option a) is used to identify the flows in TN, assigns a separate CN tunnel end point address for each QFI of the N4 Session.

## 6.11 Solution #11: Interworking with TSN enabled N3 transport network for deterministic traffic delivery

### 6.11.1 Introduction

The solution is proposed to solve Key Issue #5: Interworking with TSN network deployed in the transport network. In the 3GPP Rel-16 and Rel-17, the 5GS has supported "periodic deterministic communication", so called TSC communication.

The E2E delay for the service flow in the 5GS (called as PDB) includes AN-PDB between UE and NG-RAN, and CN-PDB between NG-RAN and UPF. The CN-PDB is guaranteed by N3 transport network.

If the TSN is deployed in the N3 transport network, the 5GS can utilize the TSN capability in the N3 to provide the deterministic CN-PDB.

### 6.11.2 Functional Description

In the figure 6.11.2-1, it proposes an enhanced 5GS architecture to utilize the TSN capability in the N3 transport network.



Figure 6.11.2-1: The enhanced 5GS interworking with CNC in transport network

The solution is based on the following principles:

- It is assumed that RAN, 5GC and Transport Network are time synchronized with each other in 5G internal system clock in this case.

- There may be a logical functionality, NG-TT (NG-RAN TSN translator) in the NG-RAN, which act as the TSN end station in the N3 transport network.

- it may support LLDP to provide topology information to the TSN Transport Network.

- As TSN end station, it acts as Talker when it sends UL packets, and as Listener when it receives DL packets.

- it may support PMIC and UMIC to communicate with TSNCF.

- There may be a logical functionality, TNW-TT (Transport NW-TT) in the UPF, which acts as TSN end station in the N3 transport network.

- it may support LLDP to provide topology information to CNC the TSN Transport Network.

- As TSN end station, it acts as Talker when it sends to DL packets, and as Listener when it receives UL packets.

- it may support PMIC and UMIC to communicate with TSNCF.

- When LLDP is supported, the u-plane is performing the LLDP functionality without the need for c-plane interaction with CNC of the transport network for the purpose of LLDP. This can be achieved with following measures:

- The TSN End Station (UPF, NG-RAN, or respective End Station TSN Translator) implements the Transmit Only operation mode as defined in clause 9.1 of IEEE Std 802.1AB-2016 [14].

- The TSN End Station is pre-configured with parameter set for Transmit Only operating mode as defined in clause 9.2 of IEEE Std 802.1AB-2016 [14].

- The System Capabilities TLV may also be set to Station Only as defined in clause 8.5.8 of IEEE Std 802.1AB-2016 [14].

NOTE 1: It may reuse the PMIC/UMIC for the NW-TT.

- There is TSN CUC Function (TSNCF) in the 5GC. It act as the CUC to communicate with CNC in the N3 transport network.

- The TSNCF may be in the TSN AF, or TSCTSF.

- During TSC communication establishment, it collect the Talker/Listener stream requirement as specified in IEEE Std 802.1Qcc [6] from NG-TT and TNW-TT.

- The TSNCF provides the Talker/Listener status to CNC and receives the status of stream configuration from CNC.

- The TSNCF provides the Talker/Listener configuration status to NG-TT and TNW-TT via PMIC/UMIC.

- The Talker/Listener stream requirement and Talker/Listener configuration status as specified in IEEE Std 802.1Qcc [6] are encoded as container in the PMIC which is transferred between TSNCF and UPF/TNW-TT.

- The Talker/Listener stream requirement and Talker/Listener configuration status as specified in IEEE Std 802.1Qcc [6] are encoded as container in N2 container which is transferred between TSNCF and NG-RAN.

- The NG-TT/TNW-TT provides the CN PDB to TSN CUC Function (TSNCF) in the 5GC.

- The NG-TT/TNW-TT provides the following Talker status to TSN CUC Function (TSNCF) in the 5GC.

- EndStationInterfaces.

- DataFrameSpecification. DataFrameSpecification is present if stream transformation IEEE Std 802.1Qcc [6] clause 46.1.4 is not performed in the End Station. This solution proposes the Talker (NG-TT/TNW-TT) always send this IE.

There are two methods in DataFrameSpecification, which can be used by TSN to identify the TSN stream.

Option A): For each Qos flow for the TSN, there is a distinct GTP tunnel, i.e. source IP address + source UDP port + destination IP address shall be unique. (Destination UDP port is well known, i.e. 2152).

Option B): There is no impact to the usage of existing GTP-U. For each Qos flow for the TSN, it used the source MAC address + destination MAC address + VLAN ID identify the stream. Because the VLAN tag value is less than 4096, so the NG-TT/TNW-TT need to maintain a MAC address pool for each interface.

- TrafficSpecification.

- InterfaceCapabilities.

- The NG-TT/TNW-TT provides the following Listener status to TSN CUC Function (TSNCF) in the 5GC.

- EndStationInterfaces.

- InterfaceCapabilities.

- The TSN CUC Function (TSNCF) in the 5GC create the following IE for the talker and Listener.

- StreamID.

- StreamRank.

- UserToNetworkRequirements.

NOTE 2: The value of Listener and Talker status refer to solution 9 except the DataFrameSpecification.

### 6.11.3 Procedures

The procedure in Figure 6.11.3-1 shows a signalling flow in which the 5GS reserve the resource in the TSN enabled N3 transport network.



Figure 6.11.3-1: Procedure for reserve the resource in TSN transport network

The signalling procedure is similar with the network requested PDU Session Modification specified in clause 4.3.3.2 of TS 23.502 [3]. The enhancement are:

8. The NG-RAN send the PMIC/UMIC in the N2 request, which carry the stream information needed for CUC. For the UL traffic, the stream information is for the Talker, and for the DL traffic, the stream information is for the Listener. The stream information detail see clauses 46.2.3 and 46.2.4 of IEEE Std 802.1Qcc [6].

9. The PMIC/UMIC from NG-TT is sent to SMF.

10. The UPF/TNW-TT send the PMIC/UMIC in the N4 response, which carry the stream information needed for CUC. For the DL traffic, the stream information is for the Talker, and for the UL traffic, the stream information is for the Listener. The stream information detail see clauses 46.2.3 and 46.2.4 of IEEE Std 802.1Qcc [6].

11, 12. The PMIC/UMIC from NG-TT and TNW-TT is sent to TSNCF via PCF.

13. The TSNCF send the Talker/Listener status to CNC. The CNC response with stream configuration.

14-18. The TSNCF send the stream configuration to NG-TT and TNW-TT in the PMIC/UMIC.

### 6.11.4 Impacts on services, entities and interfaces

- NG-RAN/NG-TT: it may support LLDP to report the topology to CNC. As the TSN end station, it is Talker when it send to UL packet, and is Listener when it receives the DL packet. It support container to communicate with TSNCF.

- UPF/TNW-TT: it may support LLDP to report the topology to CNC. As the TSN end station, it is Talker when it send to DL packet, and is Listener when it receives the UL packet. It support PMIC and UMIC to communicate with TSNCF.

- TSNCF: It collect the Talker/Listener stream requirement as specified in IEEE Std 802.1Qcc [6] from NG-TT and TNW-TT via PMIC/UMIC. It provides the Talker/Listener status to CNC and receives the status of stream configuration from CNC. It provides the Talker/Listener configuration status to NG-TT and TNW-TT via PMIC/UMIC.

Editor's note: Additional impact is FFS.

## 6.12 Solution #12: Cross layer scheduling optimization based on RAN feedback

### 6.12.1 Introduction

This solution enables the RAN to provide time offset feedback to AF for low latency communication, and the solution addresses the following scenarios:

- adapting application transmission schedule in DL based on RAN feedback for low latency.

- The same solution can be used also in UL direction, if necessary

- The solution can be used together with the Solution 9 to configure the underlay network in the TN for the required traffic characteristics of the QoS Flow.

### 6.12.2 Functional Description

In the current specification, the AF/NEF provides the traffic characteristics information to the TSCTSF using the Ntsctsf\_QoSandTSCAssistance service. The TSCTSF constructs a TSC Assistance Container (including flow direction, periodicity and Burst Arrival Time) for an application and provides it to the SMF via PCF. In this solution, instead of the BAT, the AF provides BAT window (as indicated by BAT-early and BAT-late) showing the acceptable earliest and latest arrival time of the traffic (as experienced by the 5GS). The TSCTSF provides the BAT windows in the TSC Assistance Container to the SMF via PCF if included in the Ntsctsf\_QoSandTSCAssistance.

NOTE 1: This solution assumes that 5GS and AF are time synchronized.

The SMF determines the TSCAI for the QoS Flow based on the TSC Assistance Container of the PCC rule bound to the QoS Flow as described in clause 5.27.2.4 of TS 23.501 [2], i.e. the BAT-early and BAT-late in the TSCAI represent a range for the latest possible time when the first packet of the data burst arrives at the AN.

When NG-RAN receives the TSCAI, NG-RAN determines a Semi-Persistent Scheduling scheme according to the TSCAI and the PDB. To maximize the time for transmission/re-transmission over the air interface and to minimize the scheduling time (within the PDB available for the QoS Flow), the NG-RAN may calculate the offset time between the earliest arrival time of the Burst Arrival Time and the determined scheduling time.

NOTE 2: The timing of the arrival of the DL traffic can be made more accurate for the NG-RAN by using Solution 9 to configure the underlay network.

For example, the adjusted packet for DL traffic based on the offset should arrive at a time slot before and closest to the determined scheduling time slot so that it could be transferred immediately. The NG-RAN may select the BAT offset that is relative to the BAT-early, and is less or equal to the subtract of the BAT-late and BAT-early.

NG-RAN forwards the BAT offset in DL direction to the SMF. SMF will send it back to the AF via PCF/TSCTSF/NEF.

AF receives the BAT offset and notifies the application to adapt the DL transmission schedule to it.

In similar manner, NG-RAN may determine scheduling for configured grants in UL direction, and provide a BAT offset in UL direction to the SMF. The SMF sends it back to the AF via PCF/TSCTSF/NEF.

If the AF wishes to change the accepted BAT offset, the AF can update the TSCTSF with the new BAT window by initiating a new QoS update procedure. The TSCTSF updates the TSCAC based on the AF update.

NOTE 3: This solution could also be used for UL as BAT offset could be indicated separately for UL and DL directions.

The SMF configures the UPF for clock drifting reports as specified in TS 23.502 [3]. In a case the SMF receives a clock drifting report from UPF, the SMF adjusts the BAT offset based on the existing procedures in TS 23.502 [3] and provides the updated BAT offset to the AF via PCF/TSCTSF/NEF.

### 6.12.3 Procedures

Figure 6.12.3-1 describe the procedure for this solution:



Figure 6.12.3-1: Procedure for Cross layer scheduling optimization based on RAN feedback

1. AF/TSCTSF provides TSCAC to the SMF as described in clause 5.27.2 of TS 23.501 [2]. Optionally, the TSCTSF provides a BAT window (BAT-early and BAT-late) in UL and/or DL direction in the TSC Assistance Container to the SMF via PCF based on the AF request.

2. The SMF determines the TSCAI for the QoS Flow based on the TSC Assistance Container of the PCC rule (including BAT windows) bound to the QoS Flow as described in clause 5.27.2.4 of TS 23.501 [2].

3. The SMF transfer the TSCAI generated in step 2 to the RAN.

4. NG-RAN determines the BAT offset(s) as described in clause 6.12.2.

5. NG-RAN provides the BAT offset(s) to SMF.

6. [OPTIONAL] If Solution 9 is used to interwork with TSN in the transport network, the SMF adds the received BAT offset in UL or DL direction to the BAT-early in UL or DL direction, respectively. The SMF uses the resulted new BAT value(s) as an input to the formula as described in Solution 9, when the SMF calculates the EarliestTransmitOffset(s) to the CNC in Transport Network.

7. SMF provides the BAT offset(s) to the TSCTSF/AF.

8. The AF receives the offset time or expected BAT and notifies the application to adapt the DL transmission schedule to it.

If the AF wishes to change the accepted BAT offset, the AF can update the TSCTSF with the new BAT window by initiating a new QoS update procedure as in step 1. The TSCTSF updates the TSCAC based on the AF update.

### 6.12.4 Impacts on services, entities and interfaces

NG-RAN:

- Supports of BAT offset calculating and reporting.

AF:

- Receiving BAT offset.

- Providing a BAT window.

- Notifying the applications to adapt the DL transmission schedule to it.

SMF:

- Mapping the BAT offset between external clock and the 5G clock.

- Support of signalling the BAT offset and BAT window.

PCF/TSCTSF/NEF

- Support of signalling the BAT offset BAT window.

## 6.13 Solution #13: Pro-active RAN burst timing preference provision

### 6.13.1 Introduction

This solution enables AF to configure burst transmission scheduling (transmission time and/or periodicity) optimally considering the radio configuration. This is achieved by signalling RAN burst timing preferences pro-actively to AF at the time of QoS configuration phase.

### 6.13.2 Functional Description

This solution is based on the following principles:

- The AF indicates its burst timing adaptation capabilities in QoS request together with the TSC stream characteristics to TSCTSF. The TSCTSF sends burst timing adaption capabilities in TSCAC to the PCF:

- The application may be capable of adapting burst sending time and/or burst periodicity proactively based on the feedback.

- The SMF receives the TSCAC including burst timing adaptation capability from the PCF and sends it to the RAN in TSCAI.

- For a given UE, the RAN node derives the preferred time window for burst arrival taking at least radio configuration and radio resource status into account and communicates the derived burst timing preferences to 5GC. RAN burst timing preferences includes both the burst arrival window (BAW) in absolute time and burst periodicit(ies) separately for UL and DL in order to align periodic burst optimally to the radio configuration at the radio interface. Burst arrival window (BAW) refers to the time period that is provided by RAN, including the earliest possible absolute time and the latest possible absolute time (taking radio configuration and radio resources status into account).

- RAN can provide one/multiple of periodicities as part of feedback to AF based on the periodicity values of the TDD cycle specified in TS 38.331 [5].

NOTE 1: If the application is unable to adapt the traffic according to burst timing preferences provided by the AF, there could be misalignment between incoming traffic and transmission opportunity in the RAN.

- The SMF translates the (absolute time) burst arrival window from 5G clock to external clock (depending on AF time domain) and from RAN reference point to 5G ingress reference point considering the clock drift between the 5G clock and external clock, UE/DS-TT residence time and CN PDB. The SMF forwards the preferred 5G Ingress BAW and preferred periodicity for UL and DL along with UE/DS-TT residence time to the PCF.

- The TSCTSF receives burst timing preferences (BAW and periodicity) from the PCF. The TSCTSF may derive exact 5G ingress burst arrival times from the burst arrival window from the RAN node.

- The TSCTSF forwards burst timing preferences to the AF.

NOTE 2: Achieving determinism for the transport network (i.e. to avoid inaccuracies with CN PDB) is out of scope for this solution.

### 6.13.3 Procedures

As shown in figure below, the solution utilizes existing procedures. Mainly following enhancements are proposed:

1. The AF session with requested QoS procedure (clause 4.15.6.6 of TS 23.502 [3]) is used for burst timing adaptation capability signalling from AF to PCF.

- The TSCTSF includes the burst timing adaptation capabilities in TSCAC.

2. The burst timing adaptation capability is forwarded to RAN by reusing PDU session modification procedure. The PDU session modification procedure is also used for RAN timing preference signalling to the PCF.

- The SMF derives the TSCAI and includes the burst timing adaptation capabilities in TSCAI.

- The RAN derives RAN burst timing preferences (preferred RAN BAW and periodicity) based on the radio configuration and radio resource status, and performs admission control. RAN communicates the derived timing preferences to SMF (through AMF).

- The SMF translates RAN BAW to 5GS ingress BAW and signals RAN preferences to PCF.

3. The notification procedures are utilized for burst timing preference signalling from PCF to TSCTSF and from TSCTSF to AF.

- The TSCTSF derives exact BAT from the BAW and includes BAT to the NEF.

- The TSCTSF provides the updated BAT value as part of TSC Assistance container which is eventually forwarded to the SMF and provided as updated TSCAI to the RAN.



Figure 6.13.3.1-1: Procedure for AF requested QoS with burst timing adaptation

### 6.13.4 Impacts on existing services and interfaces

AF:

- Indication of burst timing adaptation capabilities.

- Burst sending schedule adaptation according to the received timing preferences.

TSCTSF:

- Reception and forwarding of burst timing adaptation capabilities.

- Receptions of RAN timing preferences from the PCF.

- Derivation of the exact BAT from the wider BAW from the RAN and timing coordination between burst of different TSC streams and providing the BAT value as part of updated TSCAI to the RAN.

RAN:

- Reception of Adjustment Capability flag that triggers derivation of RAN Burst arrival window and periodicity.

- Derivation of RAN burst timing preferences based on the radio configurations and radio resource status.

SMF:

- Translation of RAN burst arrival window to 5GS ingress burst arrival window.

NEF, PCF:

- Support of signalling burst timing adaptation capabilities and RAN timing preferences.

## 6.14 Solution #14: Assisted and Complement Timing Support

### 6.14.1 General

Editor's note: Whether this solution is in scope of the key issue is FFS.

This solution is addressing the requirement for timing resiliency towards a client network (external network that requires a resilient timing service by the 5GS), as backup when the local primary time source fails, or as a complement to calibrate an inaccurate local primary timing source in the client network.

In these cases, delivering a stable and accurate phase or frequency is sufficient (no need to deliver time information over the 5G network).

This solution proposes to support Assisted Timing to provide backup timing service which if applied to 5GS implies a low impact since the only timing information to be provided is a stable phase or frequency only. As an alternative, the stable phase synchronization could be offered in order to complement (by calibrating) the external inaccurate primary local source, i.e. Complement Timing. In the case of Complement Timing where timing information is provided in terms of phase synchronization, NG-RAN is required to deliver phase synchronization (frequency synchronization is not sufficient).

If the client network supports receiving some form of assisted/complement timing and requires Timing Resiliency from 5GS via the already supported Time Synchronization service activation, the 5GS will be able to provide assisted/complement timing, where the timing information may be phase or frequency. The AF request therefore may indicate during the Time Synchronization service activation, that Timing Resiliency is required, whether assisted or complement timing is required, the type to timing information (phase or frequency). Additional parameters need to be provided such as service availability (including holdover time), and frequency/phase accuracy compared to UTC frequency/phase, respectively. Like with per-Uu interface time error budget, the frequency/phase accuracy has to be calculated per UE (per Uu interface) by TSCTSF and provided to NG-RAN. The timing service can be provided over different types of external interfaces, e.g. (g)PTP as defined in TS 23.501 [2] or by an implementation specific interface.

If Timing Resiliency is required, the client network should receive feedback (status report) whenever the service requirements (e.g. time error budget, UTC traceability, frequency/phase accuracy, etc.) are out of the agreed range. Moreover, status reports content just indicate that requirements were not achieved, instead of including the actual values of the parameters. How to provide the status report is out of the scope in this solution.

### 6.14.2 Functional Description

This solution is based on the following principles:

- AF may include in its request for time synchronization service the following:

- Timing Resiliency requirement, including the following parameters:

- Assisted or complement timing requirement;

- Type of timing information required (phase or frequency);

- Frequency/phase accuracy requirement compared to UTC frequency/phase, respectively.

Editor's note: It is FFS whether to include this list of specific parameters as part of the subscription data related to KI #3.

NOTE: Other parameters such as service availability (including holdover time) and stability level of the timing information (time, phase or frequency) are relevant and can apply to this solution.

- Status report is sent to UE application and to AF when one or more agreed requirements are out of range, indicating that service requirements are not achieved.

### 6.14.3 Procedures

Existing time synchronization activation procedures (see clause 4.15.9 of TS 23.502 [3]) are reused, where the AF request content is modified to include Timing Resiliency requirement, whether assisted/complement timing is required, the type of timing information (phase or frequency), frequency/phase accuracy.

Extract of clauses from TS 23.502 [3] (using approved S2-2203232 from SA WG2 meeting #150E for clause 4.15.9.4) are presented showing the changes proposed to support this solution.

NOTE: Except for clause 4.15.9.3.1, where time synchronization parameters are added, procedures in clause 4.15.9.3 remain unchanged.

Clause 4.15.9.4 of TS 23.502 [3] is also modified to add parameters to the time synchronization table, to state that TSCTSF calculates the Uu frequency/phase accuracy, and to transfer time resiliency parameters (including assisted or complement timing requirement, timing information type, frequency/phase accuracy), likewise Uu time synchronization error budget, to NG-RAN.

#### 6.14.3.1 Procedures for (g)PTP time distribution

To procedures are presented as changes (underlined text) to clause 4.15.9.3.1 of TS 23.502 [3], as follows:

This procedure can be used by the AF to activate, modify or deactivate the (g)PTP instances in 5GS.

The AF may activate the time synchronization service using the Nnef\_TimeSynchronization\_ConfigCreate service operation. The service operation creates a time synchronization configuration based on the service parameters as indicated in the create request. The AF may update the time synchronization configuration using the Nnef\_TimeSynchronization\_ConfigUpdate service operation. The AF may deactivate the time synchronization service using the Nnef\_TimeSynchronization\_ConfigDelete service operation, which deletes the corresponding time synchronization service configuration.

The Nnef\_TimeSynchronization\_ConfigCreate and Nnef\_TimeSynchronization\_ConfigUpdate request may contain the parameters as described in Table 6.14.3.1-1.

Table 6.14.3.1-1: Description of Time Synchronization service parameters

|  |  |
| --- | --- |
| Time Synchronization Parameter | Description |
| PTP instance type | Identifies the requested PTP instance type as described in clause 5.27.1.4 of TS 23.501 [2]. |
| Transport protocol | Identifies the requested transport protocol for PTP instance as described in clause 5.27.1.4 of TS 23.501 [2]. This is applicable for IEEE Std 1588 [8] Boundary Clock and Transparent Clock operation. |
| PTP Profile | Identifies the PTP profile for the PTP instance as requested by AF. |
| Grandmaster enabled | Indicates whether the AF requests the PTP instance in 5GS to be able to act as a grandmaster for PTP or gPTP (depending on the requested PTP instance type).  This is applicable for IEEE Std 1588 [8] Boundary Clock or IEEE Std 802.1AS [7] operation.  [optional] |
| Grandmaster priority | Indicates a priority used as defaultDS.priority1 when generating Announce message when 5GS acts as (g)PTP GM. Applicable only if the Grandmaster enabled = TRUE. If omitted, the default value as described in the PTP Profile is used.  [optional] |
| Time Domain | (g)PTP domain of the PTP instance as defined in IEEE Std 1588 [8]. |
| Temporal Validity Condition | Indicates start-time and stop-time attributes that describe the time period when the time synchronization service for a PTP instance is active.  [optional] |
| Time synchronization error budget | Indicates the time synchronization budget for the time synchronization service (as described in clause 5.27.1.9 of TS 23.501 [2]).  [optional] |
| Timing resiliency | Indicates whether the synchronization service will be used to provide timing resiliency. |
| >Assisted/Complement timing method | Indicates whether Assisted timing or Complement timing is used. |
| >Type of timing information | Indicates which type of timing information will be provided (time, frequency, phase). |
| >Required timing information accuracy | It provides the required phase or frequency (according to type of timing information specified) accuracy compared to the UTC phase or frequency (according to type of timing information specified). |
| **For each PTP port in the PTP instance** | |
| Either UE identity (for a DS-TT port), or "N6 interface" indication | Identifies the UE/DS-TT which the parameters below apply. "N6 interface" indicates that the parameters below apply to the N6 interface.  If the "PTP port" needs to be identified, this field refers to the UE identity (GPSI or SUPI).  If the N6 termination needs to be identified, then this field indicates "N6 interface" flag, instead of SUPI or GPSI. |
| PTP enabled | TRUE/FALSE. This is used to set the portDS.portEnable. If omitted, the default value as described in the PTP Profile is used.  [optional] |
| Log Sync Interval | Specifies the mean time interval between successive Sync messages. This is applicable for IEEE Std 1588 [8] Boundary Clock or IEEE Std 802.1AS [7] operation. If omitted, the default value as described in the PTP Profile is used.  [optional] |
| Use management settable Log Sync Interval | TRUE/FALSE. This is applicable if the PTP Profile is I IEEE Std 802.1AS [7].  When set to FALSE, the Log Sync Interval is used to set the initialLogSyncInterval as described in IEEE Std 802.1AS [7]. When set to TRUE, the Log Sync Interval is used to set the mgtSettableLogSyncInterval as described in IEEE Std 802.1AS [7].  If omitted, the default value as described in the IEEE Std 802.1AS [7] is used.  [optional] |
| Log Announce Interval | Specifies the mean time interval between successive Announce messages. This is applicable for IEEE Std 1588 [8] Boundary Clock or IEEE Std 802.1AS [7] operation. If omitted, the default value as described in the PTP Profile is used.  [optional] |
| Use management settable Log Announce Interval | TRUE/FALSE. This is applicable if the PTP Profile is IEEE Std 802.1AS [7].  When set to FALSE, the Log Announce Interval is used to set the initialLogAnnounceInterval as described in IEEE 802.1AS. When set to TRUE, the Log Announce Interval is used to set the mgtSettableLogAnnounceInterval as described in IEEE Std 802.1AS [7].  If omitted, the default value as described in the IEEE Std 802.1AS [7] is used.  [optional] |

Editor's note: The purpose of the timing resiliency parameters for (g)PTP-based time synchronization is FFS.

The AF may use Nnef\_TimeSynchronization\_CapsSubscribe service operation as described in clause 4.15.9.2 of TS 23.502 [3] to learn the UE capabilities for time synchronization service. The Nnef\_TimeSynchronization\_CapsNotify service operation indicates the list of UE identities, User-plane Node ID, and the Subscription Correlation ID. The AF can use the Subscription Correlation ID and the user-plane node ID received in the Nnef\_TimeSynchronization\_CapsNotify service operation as a target of the Nnef\_TimeSynchronization\_ConfigCreate request. The NEF uses the Subscription Correlation ID and user-plane node ID to determine the list of UEs and list of AF-sessions to which the Nnef\_TimeSynchronization\_ConfigCreate service operation is targeted to.

#### 6.14.3.2 Procedures for 5G access stratum time distribution

To procedures are presented as changes (underlined text) to clause 4.15.9.4 of TS 23.502 [3], (taken from approved S2‑2203232) as follows:

- The AF can use the procedure to activate, update or delete the 5G access stratum time distribution for one UE or a group of UEs.

- The AF may query the status of the 5G access stratum time distribution using Nnef\_ASTIGet service operation. The Nnef\_ASTICreate and Nnef\_ASTIUpdate request may contain the parameters as described in Table 6.14.3.2-1.

Table 6.14.3.2-1: Description of 5G access stratum time distribution parameters

|  |  |
| --- | --- |
| Parameter | Description |
| 5G access stratum time distribution indication (enable, disable) | Indicates that the access stratum time distribution via Uu reference point should be activated or deactivated for the associated UE identities. |
| Time synchronization error budget | Indicates the time synchronization error budget for the time synchronization service (as described in clause 5.27.1.9 of TS 23.501 [2]).  [optional] |
| Temporal Validity Condition | Indicates start-time and stop-time attributes that describe the time period when the time synchronization service is active.  [optional] |
| Timing resiliency | Indicates whether the synchronization service will be used to provide timing resiliency. |
| >Assisted/Complement timing method | Indicates whether Assisted timing or Complement timing is used. |
| >Type of timing information | Indicates which type of timing information will be provided (frequency, phase). |
| >Required timing information accuracy | It provides the required phase or frequency accuracy (according to type of timing information specified) compared to the UTC phase or frequency (according to type of timing information specified). |



Figure 6.14.3.2-1: Management of 5G access stratum time information

1. AM Policy Association establishment as described in clause 4.16.1 in TS 23.502 [3].

2. (When the procedure is triggered by the AF request to influence the 5G access stratum time distribution):

- To create a new request, the AF provides access stratum time distribution parameters to the NEF using the Nnef\_ASTI\_Create service operation (together with the AF identifier and potentially further inputs as specified in table 6.14.3.2-1), including a target (one UE identified by SUPI or GPSI, a group of UEs identified by an External Group Identifier. The NEF maps the External Group Identifier to an Internal Group Identifier and any GPSI to a SUPI.

- To update or remove an existing request, the AF invokes an Nnef\_ASTI\_Update or Nnef\_ASTI\_Delete service operation providing the corresponding time synchronization configuration id.

- To query the status of the access stratum time distribution, the AF invokes Nnef\_ASTI\_Get service operation providing the target (List of UE identities (SUPI or GPSI)).

The AF that is part of operator's trust domain may invoke the services directly with the TSCTSF.

NOTE 1: Steps 1 and 2 can occur in any order.

3. (When the procedure is triggered by the AF request to influence the 5G access stratum time distribution):

- The NEF authorizes the request. After successful authorization, the NEF invokes the Ntsctsf\_ASTI\_Create/Update/Delete/Get service operation with the TSCTSF discovered and selected as described in clause 6.3.24 of TS 23.501 [2].

- The TSCTSF determines whether the targeted UE is part of a PTP instance in 5GS, if so the TSCTSF rejects the request (steps 4-10 are skipped).

(When the procedure is triggered by PTP instance activation, modification, or deactivation in the TSCTSF):

- If time synchronization error budget is provided by the AF, the TSCTSF may use the PTP port state of each DS-TT to determine an Uu time synchronization error budget for corresponding SUPIs that are part of the PTP instance.

- If time synchronization error budget is provided by the AF, the TSCTSF calculates the Uu time synchronization error budget as described in clause 5.27.1.9 of TS 23.501 [2].

- If frequency or phase accuracy compared to UTC phase or frequency respectively, has been provided, the TSCTSF calculates the Uu accuracy value.

4. If the AF request targets a group of UEs, the TSCTSF uses the Nudm\_SDM\_Get request to retrieve the subscription information (SUPI list) from the UDM using the Internal Group ID.

5. The UDM provides the Nudm\_SDM\_Get response containing a SUPI list that identifies UEs that belong to that group of UEs.

6. The TSCTSF searches the PCF for the UE using Nbsf\_Management\_Subscribe with a SUPI as an input parameter, indicating that it is searching for the PCF that handles the AM Policy Association of the UE.

7. The BSF provides to the TSCTSF the identity of the PCF for the UE for the requested SUPI via an Nbsf\_Management\_Notify operation. If matching entries already existed in the BSF when step 6 is performed, this shall be immediately reported to the TSCTSF.

8. The TSCTSF sends to the PCF for the UE its request for the AM policy of the UE (identified by SUPI) using Npcf\_AMPolicyAuthorization request, containing the 5G access stratum time distribution indication (enable, disable) and optionally the calculated Uu time synchronization error budget, and the timing resiliency parameters (if provided), including the Uu frequency or phase accuracy.

9. If the PCF receives multiple time synchronization error budgets or frequency/phase accuracy for a given UE, then the PCF picks the most stringent budget or frequency/phase accuracy. The PCF takes a policy decision and then the PCF may initiate an AM Policy Association Modification procedure for the UE as described in clause 4.16.2.2 of TS 23.502 [3] to provide AMF the 5G access stratum time distribution parameters. As part of this, the AMF shall, if supported, send the 5G access stratum time distribution indication (enable, disable) and the Uu time synchronization error budget and timing resiliency parameters, when they are available, to an NG-RAN node using NGAP procedures (e.g. UE Context Setup/Modification) specified of TS 38.413 [12]. The NG-RAN node shall, if supported, store the information in the UE Context. Based on this information, the NG-RAN node provides the 5GS access stratum timing to the UE according to the Uu time synchronization error budget and timing resiliency parameters as provided by the TSCTSF (if supported by UE and NG-RAN).

NOTE 2: This release of the specification assumes that deployments ensure that the targeted UEs and the NG-RAN nodes serving those UEs support Rel-17 propagation delay compensation as defined in TS 38.300 [13].

10. The PCF of the UE replies to the TSCTSF with the result of Npcf\_AMPolicyAuthorization operation.

11. The TSCTSF responds the AF with the Ntsctsf\_ASTI\_Create/Update/Delete/Get service operation response.

12. The NEF informs the AF about the result of the Nnef\_ASTI\_Create/Update/Delete/Get service operation performed in step 2.

### 6.14.4 Impacts on services, entities and interfaces

AF:

- Formulation of the AF request that may include parameters indicating requirements for Timing Resiliency, assisted timing/complement timing and type of timing information. These parameters are delivered to RAN.

NOTE: There can be implications regarding the provided frequency/phase accuracy influencing the operation of (g)PTP (including correcting the content of (g)PTP messages) and certain parameters (such as clockClass) in the IEEE1588 data sets to be delivered to PMIC/BMIC. (g)PTP messages may not be used (e.g. in case of a frequency synchronization service, or because they may not be needed when the level of accuracy is out of range), however (g)PTP messages may be received and there might be the need to process them at the DS-TT/NW-TT and update certain fields in the Announce messages.

Editor's note: The reasons to update Announce messages at DS-TT/NW-TT and how to trigger this behaviour is FFS.

NG-RAN:

- Supporting delivery of frequency and phase synchronization. There is no expected impact to generate the frequency or phase synchronization, since these are subsets of the time synchronization, e.g. no SIB need to be sent. The phase/frequency can be extracted by client network (as defined in clause 6.14.1) using the SFNs of the regular radio signal, as long as this signal has guaranteed performance and UTC traceability. gNB may receive requirement parameters such as Timing Resiliency requirement, assisted/complement timing, the timing information type to be delivered, and frequency/phase accuracy compared to UTC frequency/phase respectively. This information enables NG-RAN to determine if and how to provide 5G reference timing information to the UE efficiently (i.e. RRC/SIB). How NG-RAN is using this information is up to RAN implementation.

Editor's note: Details of RAN behaviour for phase/frequency sync, and related to that the need for additional information to be sent to RAN to trigger such behaviour is FFS.

TSCTSF:

- Calculates the frequency/phase accuracy for the UE (Uu interface) and transfers to NG-RAN via PCF, AMF.

## 6.15 Solution #15: Burst arrival time adaptation

### 6.15.1 Introduction

This solution enables the network to adjust the burst arrival time by signalling positive or negative offset values (e.g. +3 ms) for UL scheduling and DL scheduling to the AF so that the AF can adjust the burst sending time accordingly.

### 6.15.2 Functional Description

This solution is based on the following principles:

- For DL scheduling: refer to solution #2.

- For UL scheduling: Upon reception of UL packets at UE from the application on the UE or from the device connected to the UE, UE determines a relative burst arrival time offset value in reference to the current Burst Arrival Time experienced by UE (i.e. in reference to when UE currently receives bursts) and the scheduling UL time slot at UE (e.g. in Configured Grants, as defined in TS 38.321 [11]). UE sends the time offset to RAN via RRC message when the time offset value reaches the configured threshold, and NG-RAN sends the burst arrival time offset value to SMF in the same way as for DL scheduling. Alternatively, UE may send the preferred burst arrival time offset to SMF using NAS SM signalling (providing the preferred time offset from UE AS layer to NAS layer is UE implementation specific).

- For downlink or uplink flows AF adapts the burst sending time based on the received offset. When receiving the burst arrival time offset for uplink flows, the AF determines the burst sending time by sending the offset to the application on the UE or the devices connected to the UE for adaption via application signalling.

### 6.15.3 Procedures

In addition to clause 6.2.3 in solution #2, RRC message or NAS SM message to signal support of burst arrival time offset value from UE to RAN and/or UE to SMF respectively.

### 6.15.4 Impacts on services, entities and interfaces

Besides the impacts documented in clause 6.2.4 of solution #2:

- UE: Support of determining and signalling burst arrival time offset to RAN via RRC message.

## 6.16 Solution #16: BAT adjustment during a QoS Flow setup or modification

This solution is merged into Solution 12.

### 6.16.1 Introduction

This solution enables the 5GC to adapt applications to the downstream scheduling, and to upstream scheduling if necessary, in Uu reference point to meet really low latency (e.g. 2 ms) requirement.

This solution makes the following assumptions:

- NG-RAN can indicate an adjustment to the Burst Arrival Time (BAT offset) in a response to QoS Flow establishment or modification request.

- The solution builds upon Solution 10: 5GC acting as a CUC for CNC in TN; Solution 10 is used to configure the underlay network in the TN for the required traffic characteristics of the QoS Flow. This ensures that jitter in the transport network in DL direction can be reduced and thus the accuracy of the Burst Arrival Time for DL packets at the ingress of NG-RAN is improved.

- The same assumptions as in Solution 10 apply.

### 6.16.2 Functional Description

The solution is based on the architecture in Figure 6.16.2-1:



Figure 6.16.2-1: Architecture to support adaptation to the upstream / downstream scheduling

- The solution supports deployments with and without external TSN network:

a) When integration with IEEE TSN applies: In addition what is described in Solution 10, this solution provides Burst Arrival Time (BAT) offset for DL direction from NG-RAN via SMF and PCF to the TSN AF. TSN AF can act as a CUC towards the CUC in external TSN network and provide the BAT offset as feedback to the external TSN network. The CUC then controls the CNC in external TSN network and adjusts the TSN streams accordingly.

b) When integration with IEEE TSN does not apply: In addition to what is described in Solution 10, this solution provides Burst Arrival Time (BAT) offset for DL direction from NG-RAN via SMF and PCF to the AF. The AF can then adjust the data streams accordingly by means that are out of scope of 3GPP.

- As described in Solution 10, Transport Network deploys a CNC that can be controlled by a CUC residing in the 5GC via the procedures specified in IEEE P802.1Qdj [10]. In addition what is described in Solution 10, this solution can provide an adjusted BAT for both UL and DL directions to the Transport Network, based on the feedback received from the NG-RAN.

### 6.16.3 Procedures

The figure 6.16.3-1 describes the overall procedure how QoS Flows are established with the solution.



Figure 6.16.3-1: Overview of the QoS Flow establishment

1. [No changes to Solution 10]: PCF receives the Policy Authorization service request from the AF/NEF/TSCTSF. The PCF composes the PCC Rules as specified in Release 17. PCF includes the TSCAC in the request when it invokes the SMF.

2. [No changes to Solution 10]: SMF receives the PCC Rules from the PCF. The SMF binds the PCC rule to a QoS Flow.

3. [No changes to Solution 10]: SMF indicates N4 rules for a QoS Flow to the UPF. The UPF assigns the CN tunnel endpoint address. The SMF determines a dynamic value for the CN PDB, based on the UPF and NG-RAN of the PDU Session.

4. As described in Solution 10, the SMF provides the QoS profile for the QoS Flow to the NG-RAN. The SMF signals the dynamic value for the CN PDB for the QoS Flow to NG-RAN. NG-RAN assigns the AN tunnel endpoint address.

As described in Solution 10, upon receiving the TSCAI for a QoS Flow from the SMF, if the TSCAI includes a BAT in UL direction, the RAN determines the corresponding BAT offset in UL direction at the gNB egress. The NG-RAN provides the value to the SMF in a response. As an enhancement to Solution 10, when the NG-RAN provides the offset value to SMF, the NG-RAN may adjust the offset value based on the upstream scheduling in Uu reference point.

As an enhancement to Solution 10, if the NG-RAN determines a need to adjust the Burst Arrival Time for DL direction to adapt the applications to the downstream scheduling in Uu reference point, NG-RAN includes a BAT offset for DL direction in the response to the SMF.

BAT offset is relative to the BAT value in corresponding direction NG-RAN has received from the SMF in TSCAI. BAT offset can take positive or negative values.

5. After the SMF has setup a QoS Flow between UPF and NG-RAN, if the NG-RAN indicated a BAT offset for UL or DL direction to the SMF, the SMF deducts the received BAT offset from the BAT in UL or DL direction, respectively, that the SMF has received in the TSCAI for the given QoS Flow, and indicates the resulted new BAT value(s) to the Transport Network using the procedure as described in Solution 10.

The SMF provides the BAT offset values in UL and DL direction (if available) to NEF/AF or TSN AF via PCF. When integration with IEEE TSN applies, TSN AF can act as a CUC towards the CUC in external TSN network and provide the BAT offset as feedback to the external TSN network. The CUC then controls the CNC in external TSN network and adjusts the TSN streams accordingly.

Editor's note: Typically for TSN flows there would be already an external CUC. Whether CNC can handle two CUCs for the same flows is FFS. Whether CNC can replan TSN flows after they have started is FFS.

When integration with IEEE TSN does not apply, the BAT offset values are provided to the AF, and the AF can then adjust the data streams accordingly by means that are out of scope of 3GPP.

### 6.16.4 Impacts on services, entities and interfaces

The same impacts as in Solution 10: 5GC acting as a CUC for CNC in TN. In addition, the following impacts are caused by this solution:

SMF:

- If the NG-RAN indicates a BAT offset for UL or DL direction to the SMF in a response to the QoS Flow establishment or modification request, the SMF deducts the received BAT offset from the current BAT in UL or DL direction, respectively, in the TSCAI for the given QoS Flow, and indicates the resulted new BAT value(s) to the Transport Network using the procedure as described in Solution 10.

NG-RAN:

- Determines a BAT offset in UL direction, based on the BAT in UL direction the NG-RAN receives from the SMF in TSCAI and the upstream scheduling in Uu reference point.

- Determines a BAT offset in DL direction, based on the BAT in DL direction the NG-RAN receives from the SMF in TSCAI and the downstream scheduling in Uu reference point.

- Provides the BAT offset values to the SMF in a response to the QoS Flow establishment or modification request.

## 6.17 Solution #17: DS-TT and NW-TT assisted 5GS synchronization error detection

### 6.17.1 Introduction

The solution is proposed to solve Key Issue #1 for the object: "Study how RAN and 5GC learn about 5GS network timing synchronization status" and can be used by the other solutions.

This solution addresses the following scenarios:

- 5GS is acting as Bridge to distribute time information to UEs using PTP or gPTP, as defined in clause 5.27.1.7 of TS 23.501 [2].

- The NG-RAN node is not able to detect the 5GS timing synchronization error due to implementation limits.

Editor's note: It is FFS whether scenarios exist where the NG-RAN node cannot detect the 5GS timing synchronization error by itself.

This solution has the following assumptions:

- The UE/DS-TT, NG-RAN, UPF/NW-TT are synchronized with the 5G GM (i.e. the 5G internal system clock) as specified in TS 23.501 [2] and TS 38.331 [5].

- The UE/DS-TT and UPF/NW-TT handle the (g)PTP messages by making timestamping according to 5G GM as specified in clause 5.27.1.2.2 of TS 23.501 [2].

- The DS-TT and NW-TT can detect (g)PTP timing synchronization error by comparing the (g)PTP clock and 5G GM clock.

- If 5G GM degradation occurs, there is timing error when calculating the residence time in 5GS according to 5G GM timestamping. Then DS-TT or NW-TT can detect the (g)PTP time sync error.

Editor's note: How DS-TT or NW-TT can detect time synch error is FFS.

### 6.17.2 Functional Description

The solution is based on the following principles:

- The AF/NEF subscribes the time synchronization status notification from TSCTSF.

- TSCTSF subscribes for time synchronization status information report from NW-TT and DS-TT via PMIC/UMIC (i.e. the status of the synchronization of the PTP GM in NW-TT and DS-TT):

- When receiving the (g)PTP time synchronization signals, the DS-TT/NW-TT can detect the (g)PTP time synchronization offset between the (g)PTP local clock (i.e. the clock maintained by the device locally) and the (g)PTP clock calculated according to the time synchronization signal. If the (g)PTP time synchronization offset exceeds the configured threshold and the jitter of the time synchronization offset between the (g)PTP local clock and 5GS internal local clock does not exceed jitter threshold, DS-TT/NW-TT can decide that there is a timing synchronization error (i.e. Timing Sync Signal is not correct). If the time synchronization offset and the jitter both exceed their thresholds, DS-TT/NW-TT can decide that the (g)PTP local clock should be adjusted according to the time synchronization signal as in this case it can be assumed there is an error in the (g)PTP local clock.

Editor's note: How DS-TT and NW-TT can decide that there is a timing synchronization error only based on observing an offset between their local clock and the time reported in (g)PTP is FFS.

- If TSCTSF has subscribed the status report, the NW-TT and DS-TT reports (g)PTP timing synchronization status information to TSCTSF via PMIC/UMIC.

- When TSCTSF receives the (g)PTP time synchronization status information, it determines whether the (g)PTP synchronization error occurs in the ingress port of the (g)PTP domain or 5G GM synchronization error occurs in the serving RAN:

- The TSCTSF can determine the affected UE according to the time domain (for (g)PTP synchronization error) or the UE's RAN information (for 5G GM synchronization error).

### 6.17.3 Procedures

The exchange of PMIC/UMIC between TSCTSF and DS-TT/NW-TT is specified in clause 5.28.3 of TS 23.501 [2]. The enhancement is that DS-TT and NW-TT should report the (g)PTP timing synchronization status to TSCTSF via PMIC/UMIC.

TSCTSF can determine the time synchronization error according to the (g)PTP timing synchronization status information as following:

- Case A: Both DS-TT (maybe multiple DS-TTs belonging to the same time domain) and NW-TT report the (g)PTP timing synchronization error. TSCTSF can determine that the (g)PTP synchronization error occurs in the ingress port of the (g)PTP domain.

- Case B: Only DS-TT(s) or NW-TT reports the (g)PTP timing synchronization error (normally the egress port reports the timing synchronization error, while the ingress port does not). TSCTSF can determine that the (g)PTP timing synchronization error is caused by 5G GM synchronization error in the RAN serving the DS-TT related UE.

TSCTSF may subscribe to the AMF to get the serving RAN of the UE(s) to determine the affected UE(s).

### 6.17.4 Impacts on services, entities and interfaces

DS-TT:

- Support reporting the (g)PTP timing synchronization status information to TSCTSF via PMIC

TSCTSF:

- Receive (g)PTP time synchronization status information report from DS-TT and NW-TT and decide time synchronization error as above.

NW-TT:

- Report (g)PTP GM timing synchronization status information to TSCTSF via PMIC/UMIC.

## 6.18 Solution #18: Subscription based control of time synchronization service

### 6.18.1 Introduction

This solution is proposed to solve Key Issue #3: Support for controlling 5G time synchronization service based on subscription. In this Key Issue, the time synchronization service scenarios already supported in 5G Release-17 and Release-16 based on access stratum or (g)PTP time distribution methods are addressed.

### 6.18.2 Functional Description

The solution is based on the following principles:

- UE subscription data types stored in the UDM are extended to include two new data structures related to time synchronization service:

- The "Access and Mobility Subscription data" is extended with the following field:

- Access Stratum Time Synchronization Service Authorization:

- Indication whether the UE is authorized to receive RTI reception via RRC dedicated signaling Note this field applies to the gNB using dedicated RRC signaling to disseminate access stratum time information to the UE.

- (Optionally) Uu time synchronization error budget

- (Optionally) Start and stop time defining active times of Access Stratum Time Synchronization Service for the UE. Start and stop times do not include the date information

- (Optionally) Coverage Area: defining a list of TAs where the ASTI-based time synchronization is available for the UE.

- The AMF retrieves "Access Stratum Time Synchronization Service Authorization" in the UDM when the UE registers with the 5GS. If "Access Stratum Time Synchronization Service Authorization" is available, the AMF configures the access stratum time distribution information at the NG-RAN accordingly using Rel-17 NGAP signalling.

- The TSCTSF may retrieve "Access Stratum Time Synchronization Service Authorization" in the UDM for getting the UE's subscribed Uu time synchronization error budget. The TSCTSF should not configure the Uu time synchronization error budget to the NG-RAN exceeding the value in the UDM.

- A new subscription data "Time Synchronization Subscription data" with the following fields:

1) AF request Authorization:

- Indicates whether the UE is authorized for an AF-requested time synchronization services (either (g)PTP based or ASTI based).

2) The "Time Synchronization Service Authorization":

- One or more Subscribed time synchronization service ID(s): Provides reference to a PTP configuration pre-configured at the TSCTSF (i.e. DNN/S-NSSAI, PTP instance configuration within the 5GS, including e.g. PTP profile, PTP domain, etc).

3) (Optionally) Start and stop times defining active times of Time Synchronization Service for the UE. Start and stop time do not include the date information.

4) (Optionally) Coverage Area: defining a list of TAs where the (g)PTP-based time synchronization is available for the UEs in the PTP instance.

5) Access Stratum Time Synchronization Service Authorization:

- Indication whether the UE is authorized to receive RTI reception via RRC dedicated signaling

NOTE: This field applies to the gNB using dedicated RRC signaling to disseminate access stratum time information to the UE.

- (Optionally) Uu time synchronization error budget

- For (g)PTP time distribution method, the TSCTSF accesses Time Synchronization Subscription data in the UDM and based on the subscription data, the TSCTSF may enable/disable time synchronization configuration for the UE with or without an AF request for the service. The trigger for the TSCTSF to retrieve this subscription data from the UDM is the notification from the PCF that a UE has established a PDU Session for a specific DNN/S-NSSAI (based on the PCF using Npcf\_PolicyAuthorization\_Notify service operation).

- For access stratum time distribution method with AF request, the TSCTSF retrieves Time Synchronization Subscription data available at the UDM and checks if the AF is allowed to request access stratum time synchronization as a service or not.

- The configuration of access stratum time distribution for a UE via Access Stratum Time Synchronization Service Authorization in the Access and Mobility Subscription data or AF request is assumed to mutually exclusive meaning that the AF is not allowed to modify the 5GS access stratum time distribution parameters if the UE is authorized to receive RTI according to the "Access and Mobility Subscription data". This is enforced by the AMF.

- The configuration of access stratum time distribution for a UE via Access Stratum Time Synchronization Service Authorization in the Time Synchronization Subscription data and Access and Mobility Subscription data simultaneously is considered as a configuration error.

- Access Stratum Time Synchronization Service Authorization and Time Synchronization Subscription Data is stored at the UDR. The UDM retrieves this subscription data from the UDR for other NFs to access it.

- For (g)PTP time distribution method, the TSCTSF may modify the PTP instance configuration by means of sending a PMIC to the impacted UE/DS-TT and UMIC to the UPF/NW-TT, as described in clause K.2.2 of TS 23.501 [2].

- For access stratum time distribution method, if AMF receives Access Stratum Time Synchronization Service Authorization from UDM, then AMF provides 5G access stratum time distribution indication and Uu time synchronization error budget (if part of the Access Stratum Time Synchronization Service Authorization received from the UDM) to NG-RAN.

### 6.18.3 Procedures

#### 6.18.3.1 Procedure for subscription based control of access stratum time synchronization service without AF request

An overall procedure for subscription based control of access stratum time synchronization service without AF request for time synchronization is illustrated in Figure 6.18.3.1-1.



Figure 6.18.3.1-1: Subscription based control of access stratum time synchronization service

1. The UE performs the registration procedure with the 5GS.

2. While the registration procedure is configured, the AMF retrieves the UE subscription data stored at the UDM as described in step 14b in clause 4.2.2.2. in TS 23.502 [3].

3. If Access Stratum Time Synchronization Service Authorization is available at the UDM, the UDM provides it to the AMF. Optionally, if a valid start and stop time for time synchronization are included in the UE subscription data, the AMF should enable the ASTI time synchronization service only during this time period.

4. If the AMF receives Access Stratum Time Synchronization Service Authorization from the UDM in step 3, the AMF may subscribe to notifications for updates at the UDM. Optionally, if a valid geographical area for time synchronization is included in the UE subscription data, the AMF tracks the UE's location to determine the UE's presence (i.e. in or out of the subscribed " valid geographic area"). If the UE location is out of the " valid geographic area", the AMF determines not to activate ASTI time synchronization service for the UE.

If the Access Stratum Time Synchronization Service Authorization contains a Coverage Area, the AMF subscribes for the UE mobility events locally.

5. When the AMF is setting up or modifying the UE Context in the NG-RAN and AMF has received Access Stratum Time Synchronization Service Authorization from the UDM, then AMF provides access stratum attributes to NG-RAN via N2 message (5G access stratum time distribution indication and Uu time synchronization error budget). If Uu time synchronization error budget is not part of the Access Stratum Time Synchronization Service Authorization received from the UDM then AMF may send to NG-RAN a Uu time synchronization error budget based on a default pre-configured default value.

The registration procedure continues as described in TS 23.502 [3].

If the Access Stratum Time Synchronization Service Authorization contains Start and stop times, the AMF enables and disables the 5G access stratum time distribution indication to the NG-RAN according to the expiry of start and stop times.

If the Access Stratum Time Synchronization Service Authorization contains Coverage Area, the AMF enables and disables the 5G access stratum time distribution indication to the NG-RAN when the UE moves inside or outside of the Coverage Area, respectively.

#### 6.18.3.2 Procedure for subscription based control of access stratum time synchronization service with AF request

An overall procedure for subscription based control of access stratum time synchronization service with asynchronous reception of an AF request for ASTI service is illustrated in Figure 6.18.3.2-1.



Figure 6.18.3.2-1: Subscription based control of access stratum time synchronization service with AF request

1. The AF request to influence the 5G access stratum time distribution.

2. The TSCSTF retrieves Time Synchronization Subscription Data available at the UDM:

3. The TSCTSF determines if the AF is allowed to request ASTI service. If authorized, the TSCTSF proceeds with ASTI service configuration. Otherwise, if the AF is not authorized, steps 4-7 are skipped.

4. The TSCTSF sends to the PCF for the UE its request to update the AM policy of the UE (identified by SUPI) containing the 5G access stratum time distribution indication (enable, disable) and optionally the calculated Uu time synchronization error budget (if available).

5. The PCF takes a policy decision and then the PCF may initiate an AM Policy Association Modification procedure for the UE as described in clause 4.16.2.2 of TS 23.502 [3] to provide AMF the 5G access stratum time distribution parameters. The PCF includes a Policy Control Request Trigger for the 5G access stratum time distribution into the request.

6. The AMF sends the 5G access stratum time distribution indication (enable, disable) and the Uu time synchronization error budget (if available) to the NG-RAN via N2 signalling.

If the AMF has received Access Stratum Time Synchronization Service Authorization from the UDM as described in clause 6.18.3.1, the AMF ignores the 5G access stratum time distribution parameters received from the PCF. If the PCF included a Policy Control Request Trigger for the 5G access stratum time distribution into the request in step 5, the AMF initiates AM Policy Association Modification procedure for the UE as described in TS 23.502[3] clause 4.16.2.1, indicating the 5G access stratum time distribution parameters as stored in the Access Stratum Time Synchronization Service Authorization.

7. The PCF of the UE replies to the TSCTSF with the result of Npcf\_AMPolicyAuthorization operation.

8. The TSCTSF responds the AF with the Ntsctsf\_ASTI\_Create service operation response.

#### 6.18.3.3 Procedure for subscription based control of (g)PTP time synchronization service without AF request

An overall procedure for subscription based control of (g)PTP time synchronization service without AF request is illustrated in Figure 6.18.3.3-1.



Figure 6.18.3.3-1: Subscription based control of (g)PTP time synchronization service without AF request

1. The UE performs the UE-requested PDU Session Establishment for data establishing connectivity.

2. The PCF determines if the PDU Session is potentially impacted by time synchronization service and invokes Npcf\_PolicyAuthorization\_Notify service operation to the TSCTSF discovered and selected for time synchronization to indicate there is a UE connected to a specific DNN/S-NSSAI configured for (g)PTP services.

3. The TSCSTF uses the SUPI to retrieve the Time Synchronization Subscription Data available at the UDM.

4. If the Time Synchronization Subscription Data contains:

a) one or more Subscribed Time Synchronization Service ID(s) that can be mapped to PTP instance configuration(s), the TSCTSF determines if one or more of the PTP instance configurations match with the DNN/S-NSSAI of the given PDU Session. The TSCTSF assumes that the time-synchronization service cannot be controlled by an AF for the given SUPI.

b) An indication that an AF-requested (g)PTP time synchronization service is allowed for the given UE and DNN/S-NSSAI, the TSCTSF adds the given SUPI to the list of SUPIs for which the time-synchronization service can be controlled by an AF.

c) If TSCTSF receives neither a) nor b), the TSCTSF assumes that the time-synchronization service cannot be controlled by an AF for the given SUPI. The TSCTSF releases the AF-session with the PCF.

5. For each matching PTP instance configuration determined in step 4, if no PTP instance exists for the given PTP instance configuration, the TSCTSF initializes the PTP instance in 5GS as described in clause K.2.2 of TS 23.501 [2]. The TSCTSF configures a PTP port in DS-TT and adds it to the corresponding PTP instance in NW-TT as described in clause K.2.2 of TS 23.501 [2].

If the Time Synchronization Subscription data for the UE in UDR contains start and stop times, the TSCTSF sets a timer for the expiration of start and stop time. Upon expiry of start time, the TSCTSF adds the PTP port in DS-TT to the corresponding PTP instance. Upon expiry of stop time, the TSCTSF temporarily removes the PTP port in DS-TT from the corresponding PTP instance.

If the Time Synchronization Subscription data for the UE in UDR contains Coverage Area, the TSCTSF subscribes to UE's presence in Area of Interest at the discovered AMF(s) in similar manner as concluded for KI#2. When the TSCTSF determines that the UE has moved inside or outside of the Coverage Area, the TSCTSF adds or temporarily removes the PTP port in DS-TT from the corresponding PTP instance, in similar manner as concluded for KI#2.

#### 6.18.3.4 Procedure for (g)PTP time synchronization service with AF request

An overall procedure for (g)PTP time synchronization service with AF request. Steps 1 to 4 below are illustrated in figure 6.18.3.3-1.

1. The UE performs the UE-requested PDU Session Establishment for data establishing connectivity.

2. Upon PDU Session establishment, the PCF determines if the PDU Session is potentially impacted by time synchronization service and invokes Npcf\_PolicyAuthorization\_Notify with the TSCTSF as configured in the PCF. The TSCTSF setups an AF-session with the PCF as described in clause 4.15.9.2 of TS 23.502 [3].

3. The TSCSTF uses the SUPI to retrieve the Time Synchronization Subscription Data available at the UDM.

4. If the Time Synchronization Subscription Data contains:

a) one or more Subscribed Time Synchronization Service ID(s) that can be mapped to PTP instance configuration(s), the TSCTSF determines if one or more of the PTP instance configurations match with the DNN/S-NSSAI of the given PDU Session. In this case, for each such PTP instance configuration, if no PTP instance exists for the given PTP instance configuration, the TSCTSF initializes the PTP instance in 5GS as described in clause K.2.2 of TS 23.501 [2]. The TSCTSF configures a PTP port in DS-TT and adds it to the corresponding PTP instance in NW-TT as described in clause K.2.2 of TS 23.501 [2]. The TSCTSF assumes that the time-synchronization service cannot be controlled by an AF for the given SUPI.

b) An indication that an AF-requested (g)PTP time synchronization service is allowed for the given UE and DNN/S-NSSAI, the TSCTSF adds the given SUPI to the list of SUPIs for which the time-synchronization service can be controlled by an AF.

c) If TSCTSF receives neither a) nor b), the TSCTSF assumes that the time-synchronization service cannot be controlled by an AF for the given SUPI. The TSCTSF releases the AF-session with the PCF.

5. Based on received subscription data in step 4, the TSCTSF determines that the UE is authorized for the service, and the TSCTSF proceeds with rest of the procedure as described in clause 4.15.9.2 of TS 23.502 [3].

When the TSCTSF receives Ntsctsf\_TimeSynchronization\_CapsSubscribe service operation from the AF, the TSCTSF determines the matching AF-session(s) as described in clause 4.15.9.2 of TS 23.502 [3]. If the UE is not authorized for the service for the given DNN/S-NSSAI in the UDM, the TSCTSF does not consider the AF-session as matching. This implies that the time synchronization capability event notification does not list any of the SUPIs that cannot be controlled by an AF.

### 6.18.4 Impacts on services, entities and interfaces

UDR:

- Storage and retrieval of Time Synchronization Subscription Data by the UDM.

UDM:

- Time Synchronization Subscription Data and Access Stratum Time Synchronization Service Authorization fields management.

AMF:

- Receive Access Stratum Time Synchronization Service Authorization from UDM.

- Provide access stratum time distribution indication and Uu time synchronization error budget to RAN based on Access Stratum Time Synchronization Service Authorization received from UDM

- Manage timers for start and stop times as indicated by the start and stop times in the Access Stratum Time Synchronization Service Authorization.

- Enables and disables the 5G access stratum time distribution for the UE based on the UE location and Coverage Area in the Access Stratum Time Synchronization Service Authorization.

TSCTSF:

- Time synchronization service configuration (i.e. ASTI and/or (g)PTP time distribution) based on UE's Time Synchronization Subscription Data.

- Manages the Coverage Area in the Time Synchronization Subscription Data in the same way as if it was received from the AF as concluded in KI#2.

- Subscription to Time Synchronization Subscription Data at the UDM.

## 6.19 Solution 19: Support for controlling 5G time synchronization service based on subscription

### 6.19.1 Introduction

The solution enables the operator to control time synchronization service based on UE subscription for time critical services management.

### 6.19.2 General description

The following assumptions are made:

- For specific UEs which the holdover capability is not supported or supported badly, the operator should provide them reference time information continuously.

- UE subscription should be taken into account when TSCTSF chooses a time information provider in 5GS. The subscription data may include time synchronization enable parameters or timing resiliency services parameters. According to the subscription data, TSCTSF can determinate whether and which timing source to provide timing synchronization service.

- UEs get time synchronization service by receiving 5GS access stratum time or time-synchronized UPF/NW-TT. 5G GM may have different sources of time/frequency like GNSS signal, Synchronous Ethernet (Sync E), PTP transport network, PPS input, etc. Besides, 5G GM may collocate with UPF or RAN, not limited with the deployment.

Following are the principles for the solution:

- In order to provide continuous time synchronization service for targeted UEs, 5GC should be informed if the time synchronization status of those UEs change. The time status changes can be resulted from some unexpected cases, e.g. time sources failure or UE mobility.

- The AF could send a request to TSCTSF (directly or via NEF) to control the (g)PTP time synchronization service and may target to a set of AF-sessions with a UE or multiple UE(s). In addition, the AF may request time synchronization distribution method, such as a Boundary Clock, peer-to-peer Transparent Clock, or end-to-end Transparent Clock or as s PTP relay instance. For all the AF-request, TSCTSF should check targeted UE(s) subscription data from the UDM first before it invokes time synchronization service. If necessary, the SMF would check the per UE subscription data again when PDU session establishment.

- The AF may request to use the 5G access stratum timing information for UE(s) or the attached DS-TT(s). When TSCTSF receives the request, it should get the targeted UE subscription data from the UDM to authorize the request. If needed, the AMF is responsible to check the per UE subscription data when it controls 5G-AN to provide 5G access stratum timing information.

- A trusted AF can request a stringent/resilient time synchronization service for targeted UEs or DS-TTs if the UEs subscription supports.

- Time service parameters can be included in the UE subscription data:

a) Authorized time synchronization method: access stratum, gPTP, or both;

b) One or multiple authorized Uu error budget: e.g. 1us, 250ns, or other values. Multiple authorized Uu error budgets allows 5G network to select a certain Uu error budget, based on AF request. The enforced Uu error budget should not exceed the most stringent value.

### 6.19.3 Procedures

Below is the flow chart for AF requesting time synchronization service for targeted UE.

#### 6.19.3.1 AF requesting time synchronization service for targeted UE

Procedures of AF requesting time synchronization service for targeted UE are shown:



Figure 6.19.3-1: AF requesting time synchronization service based on subscription

0. UDM subscription data may include a new subscription type for time synchronization service or timing resiliency service. The subscription data indicates whether or not the UE support time synchronization service or timing resiliency services. The subscription data may also include 5GS clock properties, e.g. clock class, accuracy, etc. to reflect the possible selection of clock source e.g. during GNSS unavailability.

1. AF request for time synchronization service for the UE.

2. When receiving the time synchronization request for the UE, the TSCTSF will check with UDM, whether and what information the UE has the subscription for time synchronization service. The time service parameter of UE subscription data refers to the above description.

3. TSCTSF determinates a suitable time source to provide time synchronization service for the UE if the subscription data is satisfied.

4. TSCTSF may sends the determinate information (with 5GS clock properties including e.g. clock class, accuracy information) to UPF for time synchronization service, UPF initiates PTP or gPTP based distribution to the UE to provide timing synchronization. Or TSCTSF may send the determinate information to RAN for time synchronization service, RAN initiates access stratum distribution to the UE to provide timing synchronization.

### 6.19.4 Impacts on services, entities and interfaces

TSCTSF:

- Update the 5G time distribution indication based on UE subscription.

- Authorize time synchronization service request based on UE subscription.

- Providing time synchronization service based on UE subscription.

- Determining a suitable 5G timing source to provide time synchronization service for the UE.

AMF:

- Support to forward UE time synchronization service to targeted TSCTSF.

UDM:

- Support to perform the storage of UE Subscription data including time synchronization parameters or timing resiliency parameters.

## 6.20 Solution #20: NG-RAN acting as CUC towards CNC of the N3 transport network

### 6.20.1 Introduction

Key idea of this solution is that NG-RAN acts as CUC towards the CNC of the N3 transport network.

### 6.20.2 Functional Description

The solution is based on the architecture in Figure 6.20.2-1:



Figure 6.20.2-1: NG-RAN acting as CUC towards CNC of the N3 transport network

Editor's note: The consequence of collocating CUC with a single gNB is FFS.

The solution is based on the following principles:

- If NG-RAN receives a QoS Flow description from the SMF, which includes a TSCAI:

NG-RAN derives a stream identification description based on the NG-RAN and UPF tunnel end point addresses and ports and traffic requirements/characteristics based on the QoS profile, TSCAI information and the CN PDB.

- RAN (acting as a CUC), provides the stream identification/requirements to the transport network CNC.

- If the QoS flow description with TSCAI is removed by the SMF or if the UE context is removed in the RAN (e.g. when the UE enters Idle or when the UE relocates to a different RAN node), then RAN (acting as CUC) removes the previously provided stream identification/requirements from the transport network's CNC.

NOTE 1: To enable the transport network to distinguish QoS flows, this solution assumes that separate tunnel end-point addresses are used for the N3 tunnels for QoS flows, which include a TSCAI (SMF can instruct RAN and UPF to do so). Use of IPv6 addresses can ensure that sufficient addresses are available.

NOTE 2: This solution does not assume support of talker/listener functionality to be supported by RAN and UPF.

NOTE 3: Whether the above needs to be standardized or can be left as an option for RAN implementation can be determined in coordination with RAN WG3.

### 6.20.3 Procedures

Existing procedures are reused.

### 6.20.4 Impacts on services, entities and interfaces

NG-RAN:

- For QoS flows for which SMF provides TSCAI, derive a stream identification based on NG-RAN/UPF tunnel end point addresses and ports and traffic requirements/characteristics based on the QoS profile, TSCAI information and the CN PDB.

- Provide stream requirements to transport network CNC.

- Allocate separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels (existing functionality).

UPF:

- Allocate separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels (existing functionality).

SMF:

- Instruct the NG-RAN and UPF to allocate separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels using existing NGAP and existing N4 signalling.

## 6.21 Solution #21: BAT adjustment by TSNCF to TSN in the transport network

### 6.21.1 Introduction

This solution enables the 5GS to adapt downstream scheduling in order for 5GS to meet really low latency (e.g. 2ms) requirement. This solution also can be used for the UL stream scheduling.

This solution makes the following assumptions:

- There is TSN deployed in the transport network.

- This solution builds on the top of solution 11.

### 6.21.2 Functional Description

The solution is based on the architecture in Figure 6.11.2-1 of solution 11.

The solution is based on the following principles:

- When the NG-RAN receives the TSCAI during Qos flow establishment/modification, it detects there is a need for adjustment to the Burst Arrival Time (i.e. offset to the BAT).

- The NG-RAN indicate the BAT offset to TSNCF/CUC in the response.

- The TSNCF calculate the Talker/Listener status according to the BAT offset and stream information. The TSNCF uses the procedures described in Solution 11 to communicate with the NG-TT, TNW-TT and CNC.

NOTE: Whether TSNCF can enforce a negative BAT offset depends on whether the TSN in the transport network can achieve the delay, i.e. CN-PDB – BAT offset

- After the TSNCF/CUC receives the configuration from CNC, the TSNCF update the TSCAC and send it to SMF.

- The SMF update the TSCAI and send to NG-RAN/UPF.

### 6.21.3 Procedures

The procedure in Figure 6.11.3-1 is re-used with following enhancement:



Figure 6.21.3-1: (Figure 6.11.3-1)

8. NG-RAN detect the offset to the BAT is needed. The NG-RAN send the offset and stream information to AMF.

9-12. The BAT offset is sent to TSNCF.

13. The TSNCF calculate the Talker/Listener status according to the BAT offset and stream information.

14-15. TSNCF/CUC receives the configuration from CNC, the TSNCF sends the stream configuration to NG-TT and TNW-TT in the PMIC/UMIC as described in Solution 11 and updates the TSCAC and sends it to SMF with the configuration.

NOTE: Update the TSCAC is to make TSCAI is align with the stream configuration from TSN CNC in the NG-RAN.

Editor's note: It is FFS whether updating the TSCAC is necessary because the stream configuration that is sent to NG-TT via PMIC contains the same timing information.

17-18. The SMF updates the TSCAI. And send the TSCAI and configuration to the NG-RAN.

### 6.21.4 Impacts on services, entities and interfaces

In addition to the impacts in sol#11, the following impacts are caused by this solution:

NG-RAN:

- Determines a BAT offset for UL/DL traffic according to TSCAI.

- Provides the BAT offset values to the TSNCF in a response to the QoS Flow establishment or modification request.

TSNCF:

- The TSNCF calculate the Talker/Listener status according to the BAT offset and stream information.

- After the TSNCF/CUC receives the configuration from CNC, the TSNCF update the TSCAC and send it to SMF.

## 6.22 Solution #22: Transmission opportunities exposure

### 6.22.1 Introduction

This solution enables the RAN to provide to an AF some details on DL transmission opportunities, so that the AF can adapt its transmissions times to minimise end-to end delays.

The solution addresses the following scenario: Adapting downstream scheduling based on RAN feedback for low latency communication.

The solution addresses also the enhancement of transmissions delays in the uplink.

In TDD transmissions, the frame structure has an impact on transmission delays. Indeed, a DL packet has to wait for a DL part of the frame before being actually transmitted, and similarly an UL packet will have to wait for an UL part in the frame.

In NR, the TDD frame structure is very flexible, and can be composed of several UL and DL chunks. We call "transmission opportunity" one of this DL or UL chunk.

The principle of this solution is to provide to an application function information about the transmission opportunities. It is then up to the application to adapt its sending times accordingly to minimise transmission delays. In case of 5GS integration in a TSN network, this information can be used to minimise the independent delays provided to the CNC.

### 6.22.2 Functional Description

The application function is assumed to be able to adapt its sending times. In case of UL streams, the application client is assumed to be able to adapt its transmission times. This is typically the case when the 5G system is acting as a TSN bridge in a TSN.

The solution is based on the following principle:

The AF indicates to the PCF that it is interested in getting transmission opportunities information, directly in case of a TSN-AF or through NEF/TSCTSF otherwise.

The transmission opportunities information request is forwarded to RAN by reusing PDU session modification procedure.

The RAN builds the transmission opportunities information. This information may be composed of:

- A start of frame reference time.

- A list of offsets for DL opportunities.

- A list of offsets for UL opportunities.

- A periodicity.

An example of the mapping between a RAN frame structure and the transmission opportunities information is provided in Figure 6.22.2-1.



Figure 6.22.2-1: Example of transmission opportunities information

The RAN forwards the transmission opportunities information to the SMF.

The SMF translates the reference time from 5G clock to external clock, taking into account CN delay and clock drift.

SMF sends the translated transmission opportunities information back to the AF via PCF/TSCTSF/NEF or directly via the PCF in case of TSN-AF.

Editor's note: Clock time difference management has to be clarified.

### 6.22.3 Procedures

Figure 6.22.3-1 describe the procedure for this solution.



Figure 6.22.3-1: Procedure for transmission opportunities exposure

1. AF indicates to the PCF a request for getting transmission opportunities information. Signalling AF session with requested QoS procedure (clause 4.15.6.6 in TS 23.502 [3]) is used.

2. The transmission opportunities information is forwarded to RAN by reusing PDU session modification procedure:

- RAN gets frame format it uses for that PDU session and derives the transmission opportunities parameters.

- SMF translates the start of frame indication from 5G internal clock reference to external clock reference.

3. PCF provides the transmission opportunities information to the AF using the notification procedures.

In case of TSN-AF, the transmission opportunities information can be useful for computing the delays to be advertised to the CNC, i.e. the TSN-AF shall have the option of getting the transmission opportunity information before requesting any data flow. In this case, the TSN-AF triggers the transmission opportunities information request in Npcf\_PolicyAuthorization\_Update without including a stream request.

Editor's note: To be checked whether the QoS request procedure is the right procedure to use in case the AF does not include a stream request.

After having received the transmission opportunities information, the AF may trigger another AF session with requested QoS procedure including flow BAT and periodicity that take into account transmission opportunities information.

### 6.22.4 Impacts on services, entities and interfaces

AF:

- Transmission opportunities information request.

- Computing the delays to be advertised to the CNC taking into account transmission opportunities information (TSN-AF).

- Burst sending schedule adaptation according to the received transmission opportunities information.

SMF:

- Support of signalling transmission opportunities request / transmission opportunities information.

- Translates the start of frame indication from 5G clock to external clock.

NG-RAN:

- Reception of transmission opportunities information request.

- Provides transmission opportunities information.

PCF/TSCTSF/NEF:

- Support of signalling transmission opportunities request / transmission opportunities information.

# 7 Evaluation

## 7.1 Key Issue #3: Support for controlling 5G time synchronization service based on subscription

There are 2 solutions (Sol#18, Sol#19) for KI#3. The following technical issues are studied:

1. How to authorize time synchronization service based on UE subscription:

- TSCTSF performs time synchronization service configuration (i.e. ASTI and/or (g)PTP time distribution) based on UE's Time Synchronization Subscription Data. (Sol#18, Sol#19).

- AMF performs time synchronization service configuration for ASTI if the Access Stratum Time Synchronization Service Authorization is available at the UDM and the UE is authorized. (Sol#18).

- Applicability of time sync subscription for time sync service activation with or without AF request. (Sol#18).

- TSCTSF authorizes time synchronization service request based on UE subscription. (Sol#19).

2. How to enforce time synchronization service on a per UE basis based on subscription:

- TSCTSF performs time synchronization service configuration (i.e. ASTI and/or (g)PTP time distribution) based on UE's Time Synchronization Subscription Data with or without AF request. (Sol#18).

- AMF performs time synchronization service configuration for ASTI if the Access Stratum Time Synchronization Service Authorization is available at the UDM and the UE is authorized. (Sol#18).

- TSCTSF updates the 5G time distribution indication based on UE subscription. (Sol#19).

- TSCTSF subscribes to Time Synchronization Subscription Data at the UDM. (Sol#18, Sol#19).

- TSCTSF determines a suitable 5G timing source to provide time synchronization service for the UE. (Sol#19).

3. What parts of time synchronization service require a separate UE subscription (and authorization), if any:

- UDM stores Time Synchronization Subscription Data and Access Stratum Time Synchronization Service Authorization fields management with or without AF request. (Sol#18).

- UDM stores Subscription data including time synchronization parameters or timing resiliency parameters. (Sol#19).

## 7.2 Key Issue #5: Interworking with TSN network deployed in the transport network

There are 4 solutions (Sol#9, Sol#10, Sol#11, Sol#20) for KI#5. The solution #10 has been merged into Solution #9, therefore it is not considered here. The following technical issues are studied:

a) The architecture enhancement to support the interworking between 5GS and TSN networks deployed in the transport network.

- NG-RAN/NG-TT and UPF/TNW-TT support LLDP to report the topology to CNC in TSN Transport Network. It supports the container to communicate with TSNCF. TSNCF collects the Talker/Listener stream requirement as specified in IEEE Std 802.1Qcc [6] from NG-TT and TNW-TT via PMIC/UMIC. It provides the Talker/Listener status to CNC and receives the status of stream configuration from CNC. It provides the Talker/Listener configuration status to NG-TT and TNW-TT via PMIC/UMIC. (Sol#11).

- SMF allows information access with the collocated TN CUC to support UNI as described in IEEE P802.1Qdj [10]. SMF determines the traffic requirements for a QoS Flow and initiates that CUC translates them to merged stream requirements which are then passed to the CNC in TSN Transport Network. (Sol#9).

- TSNCF (co-located with TSCCF/TSN AF) act as 5G CUC to support UNI as described in IEEE P802.1Qdj [10]. TSNCF determines the traffic requirements and translates them to merged stream requirements which are then passed to the CNC in TSN Transport Network. (Sol#11).

- NG-RAN and UPF may support Listener/Talker and Stream Transformation as described in IEEE P802.1Qdj [10]. (sol#9 and sol#11) If the Stream Transformation in NG-RAN and UPF is not supported, two options for identifying the traffic on QoS Flow basis in the TN: 1) SMF instructs UPF and RAN to assign a separate CN tunnel end point address for each QFI or 2) the interface between the CUC and CNC in the TN allows the SMF and CUC to indicate the TEID and QFI of the given QoS Flow to the CNC in the TN (Sol#9).

- SMF may transfer received merged end station communication-configuration from the TN CNC to the Talker/Listener accordingly. (Sol#9).

- TSNCF (co-located with TSCCF/TSN AF) may transfer received merged end station communication-configuration from the TN CNC to the Talker/Listener accordingly. (Sol#11).

- NG-RAN and UPF may support the functionality of Listener/Talker as described above. (Sol#9, sol#11).

- NG-RAN provides stream requirements to transport network CNC, and allocates separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels (existing functionality). (Sol#20).

- SMF instructs the NG-RAN and UPF to allocate separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels using existing NGAP and existing N4 signalling. (Sol#20).

- NG-RAN provides stream identification to transport network CNC. (Sol#20).

b) What information are needed and how to collect the information from 5GS (e.g. NG-RAN, 5GC NF), so that the 5GS can interact with TSN network. Also, determine which 5GS entity is responsible to provide it to the TSN network deployed in the transport network.

- TSNCF collects the Talker/Listener stream requirement as specified in IEEE Std 802.1Qcc [6] from NG-TT and TNW-TT via PMIC/UMIC. It provides the Talker/Listener status to CNC and receives the status of stream configuration from CNC. It provides the Talker/Listener configuration status to NG-TT and TNW-TT via PMIC/UMIC. (Sol#11).

- SMF allows information access with the collocated CUC to support UNI as described in IEEE P802.1Qdj [10]. SMF determines the traffic requirements for a QoS Flow and initiates that CUC translates them to merged stream requirements which are then passed to the CNC in Transport Network. (Sol#9).

- NG-RAN provides stream requirements to transport network CNC, and allocates separate tunnel end-point destination addresses per QoS Flow (for QoS flows with TSCAI) used for the N3 tunnels (existing functionality). (Sol#20).

- NG-RAN may determine a dynamic value of 5G-AN PDB in UL direction at the gNB egress. The NG-RAN provides the dynamic value of 5G-AN PDB value to the SMF in a response to the QoS Flow establishment or modification request. This is used as more accurate value for AN-PDB when the SMF determines the traffic requirements for a QoS Flow towards the TN CNC (Sol#9).

## 7.3 Evaluation for KI #6: Adapting downstream scheduling based on RAN feedback for low latency communication

There are currently 7 solutions in the TR for Key Issue#6: Solution#2, Solution#12, Solution#13, Solution#15, Solution#16, Solution#21 and Solution#22. Solution#16 has been merged with Solution#12, so it is not considered further. Rest of the solutions are summarized below.

The solutions can be divided into two categories:

1) NG-RAN determines the timing feedback based on the reception time of the packets in user plane (**Solutions 2 and 15**).

The 5GS notifies the AF for the Burst Arrival Time offset; that is expressed in reference to the actual reception timing of the packets as experienced by the NG-RAN in User Plane; Burst Arrival Time offset can take positive or negative values. The solution#2 is applicable only for traffic in DL direction. Solution #15 is an enhancement of Solution#2 to make it applicable also for traffic in UL direction, but this impacts to the UE. The solutions do not require that the application is time-synchronized with the 5GS, i.e. BAT in TSCAI is optional.

The solution can only adjust the sending time after the traffic has started. In practice it requires several packets until the application receives the feedback and required latency can be met.

2) 5GS and AF negotiate the Burst Arrival Time in control plane (**Solutions 12, 13, 21, 22**).

These solutions require that the application is time-synchronized with the 5GS, i.e. BAT in TSCAI is mandatory.

In Solution#12 the AF provides a "BAT window" to 5GC and to NG-RAN; it consists of earliest and latest arrival time of the traffic. The NG-RAN responds with a "BAT offset" that is relative to the earliest arrival time in the BAT window and is less or equal to the subtract of the latest and earliest arrival times of the BAT window. The BAT offset can be provided separately for UL and DL directions.

In Solution#21 the feedback from the NG-RAN is only used to indicate the timing of the burst to the Transport Network (via TN CNC), thus the solution requires that integration with TSN in the Transport Network is supported as described in Solution#11 for KI#5. In addition, since the feedback is not sent to the AF, the application cannot adjust the timing based on the feedback, thus the bridges in the Transport Network will buffer the bursts.

In Solution#13 the NG-RAN provides a Burst Arrival Window (BAW) in absolute time and burst periodicity preference to 5GC (separately for UL and DL). The BAW and periodicity preference are then to be provided to the AF; the AF provides a BAT to the NG-RAN that is within the Burst Arrival Window.

Solution#22 is similar to Solution#13, but instead of providing Burst Arrival Window and periodicity preference, the NG-RAN provides "transmission opportunities" to the AF, that consists of start of frame reference time, a list of offsets for DL opportunities, a list of offsets for UL opportunities, and periodicity. The AF is then supposed to update the QoS-request accordingly. The solution also contains a procedure for the AF to query the "transmission opportunities" from the NG-RAN, before the AF has invoked the actual QoS-request for a stream.

# 8 Conclusions

## 8.1 Conclusion for KI #4: AF Request of PER for QoS and Alt-QoS

It is agreed to adopt Solution #8: "AF Request of PER for QoS and Alt-QoS" for normative work.

## 8.2 Key Issue #2: Time synchronization service enhancements

The following bullet points summarize the principles for the way forward:

- To request a Requested Coverage Area for time synchronization services, AFs within the operator's domain formulates a spatial validity condition using a list of Tracking Area identities, but AFs outside the operator's domain use a geographical area (e.g. a civic address or shapes) instead, while NEF transforms this information into a list of Tracking Area identities.

- The AF provides the Requested Coverage Area for time synchronization services, UE list and time synchronization services (ASTI or (g)PTP based) to TSCTSF, optional via NEF.

NOTE: The Requested Coverage Area is restricted to TA level granularity.

- In order to track the UE moving in and out of Time Synchronization coverage area at a TA granularity, the Registration Area (RA) shall only include TAs either inside or outside of the Requested Coverage Area the AF requested for Time Synchronization. This ensures the UE performs Registration update with the network when the UE moves in and out of Requested Coverage Area.

- The TSCTSF need to query with UDM to check whether ASTI or (g)PTP based time synchronization is allowed to be requested by AF for the UE.

- The TSCTSF is responsible of activate/deactivate time synchronization services (ASTI or (g)PTP based) considering the spatial validity condition provided by the AF.

- The TSCTSF discovers the AMF(s) serving the list of TA(s) that comprise the spatial validity condition using the NRF.

- The TSCTSF subscribes to UE’s location or UE's presence in Area of Interest at the discovered AMF(s).

- The TSCTSF may optionally provide the the Location Reporting Type indication to the AMF when the TSCTSF subscribes to UE’s location or presence in AoI. Otherwise, the AMF determines the Location Reporting Type indication.

- The determination of the Location Reporting Type indication and Location Report Level can be based on AoI requested, other location reporting processes the UE may have active with the AMF, and the UE’s current RRC state (if known). Alternatively, the UE’s presence in the AoI event type may be used unless specified otherwise.

- The Location Report Level shall be set in accordance with the Requested Coverage Area.

- The TSCTSF determines (based on notifications from the discovered AMF(s)) whether the targeted UE(s) are inside or outside the AF Requested Coverage Area.

- The TSCTSF activates time synchronization services for UE(s) that are inside the Requested Coverage Area. If the AF has requested (g)PTP based time distribution, then TSCTSF creates the PTP port in DS-TT and adds it to the PTP instance as described in clause 4.15.9.3.2 in TS 23.502 [3].

- TSCTSF notifies the AF with the indication of 5G access stratum time distribution (enabled, disabled) for the targeted UE(s) for which the AF has requested ASTI-based time distribution that are inside or move inside or outside of the Requested Coverage Area.

- If the TSCTSF has determined (e.g. notified) that the UE has moved outside the AF Requested Coverage Area for which the AF has requested (g)PTP based time distribution, then TSCTSF temporarily removes the UE/DS-TT from the PTP instance:

- If the DS-TT is configured to send Sync, Follow\_Up and Announce messages for the related PTP instance, then TSCTSF deactivates the Grandmaster functionality in the DS-TT using PMIC (see also clause K.2.2.4 of TS 23.501 [2]) and removes the DS-TT from the PTP instance (see also clause K.2.2.1 of TS 23.501 [2]).

- If NW-TT is configured to send Sync, Follow\_Up and Announce messages on behalf of the DS-TT, then TSCTSF deactivates the Grandmaster functionality on behalf of the DS-TT in NW-TT using UMIC (see also clause K.2.2.4 of TS 23.501 [2]) and removes the DS-TT from the PTP instance (see also clause K.2.2.1 of TS 23.501 [2]).

- The TSCTSF informs the AF for the impacted UE by indicating the PTP port state as Inactive for the related DS-TT PTP port.

- If TSCTSF has determined (e.g. notified) that the UE has moved inside the AF Requested Coverage Area for which the AF has requested (g)PTP based time distribution, then TSCTSF adds the DS-TT PTP port to the PTP instance and also (re-)activates the Grandmaster functionality. The TSCTSF informs the AF for the impacted UE by indicating the PTP port state as Active for the related DS-TT PTP port.

- If the TSCTSF has determined (e.g. notified) that the UE has moved outside the AF Requested Coverage Area for which the AF has requested ASTI based time distribution, then TSCTSF temporarily deactivate ASTI time synchronization service by disabling the indication of 5G access stratum time distribution for the targeted UE(s).

- If TSCTSF has determined (e.g. notified) that the UE has moved inside the AF Requested Coverage Area for which the AF has requested ASTI based time distribution, then TSCTSF enables the indication of 5G access stratum time distribution for the targeted UE(s) based on the AF-requested requirement of time synchronization service.

## 8.3 Conclusion for KI #5: Interworking with TSN network deployed in the transport network

The following bullet is the interim conclusion for KI#5:

- There is 5G CUC to interact with TN CNC on exchanging Talker/Listener or Status Groups information. The 5G CUC is collocated with the SMF(s).

- The 5G CUC will map the QoS Flow related parameters into Talker/Listener Group in IEEE 802.1Qcc. The detailed handling of the parameters in Talker/Listener or Status Groups information is described in clause 6.9.2.

- The RAN and UPF may support the functionality of Listener/Talker for the following:

- hold and buffer functionality in a case when the TSCAI contains a BAT in UL and/or DL direction. In this case the TimeAwareOffset is sent to the Talker in RAN/UPF in a Transparent Container, and the Talker in RAN/UPF must buffer the data burst until the time indicated in the TimeAwareOffset is reached.

- for support of stream transformation, the Talker/Listener does not provide the DataFrameSpecification. In this case the 5G CUC transfers the InterfaceConfiguration received from the TN CNC to Talker in a Transparent Container, and the Talker in RAN/UPF must use the indicated MAC address, VLAN ID or IP-tuples for the data stream.

- for 5G CUC to retrieve the InterfaceCapabilities and/or EndStationInterfaces from the Talker/Listener via Transparent Container. Otherwise, this information must be preconfigured or determined by 5G CUC.

- NG-RAN and UPF may support u-plane LLDP functionality. When LLDP is supported, the u-plane is performing the LLDP functionality without the need for c-plane interaction with CNC of the transport network for the purpose of LLDP as specified in the 6.11.2.

- It is assumed that RAN, 5GC and Transport Network are time synchronized with each other in 5G internal system clock.

## 8.4 Key issue #6: Adapting downstream scheduling based on RAN feedback for low latency communication

The following bullet points summarize the principles for the way forward:

- Proactive feedback requires that 5GS and the AF receive time information from the same master clock. Since this assumption cannot hold in all deployment, both pro-active and reactive feedback mode shall be supported. The feedback is in order to align the burst arrive time and the next transmission opportunity on the respective direction (i.e. both UL and DL) of the traffic to reduce the potential buffering delay.

- When the AF gets the feedback (in both mode), and the AF is capable of BAT adaptation, the AF adjusts the burst sending time accordingly.

NOTE: For UL, the AF adjusts the burst sending time by using application layer mechanism, e.g. to notify the application in device side.

- The AF provides adaptation capability information of the application to 5GS.

Principles for Proactive feedback:

- If the AF indicates its capability for BAT adaptation or a BAT window along with the BAT as specified in Rel-17. And the PCF receives a policy authorization request from the AF/NEF/TSCTSF that indicates that capability or a BAT window:

- the PCF sets a trigger to be notified for the "BAT offset" event for the corresponding PCC Rule via the SM policy control service to the SMF.

- If the SMF receives an indication for a BAT adaptation capability or a BAT window, in a TSCAC, the SMF includes that indication or a BAT window into TSCAI along with the QoS Flow establishment request. This indicates to the NG-RAN that the NG-RAN may provide a BAT offset in an N2 SM information as a response to the SMF.

- As a response to the QoS Flow establishment request, the NG-RAN may provide a "BAT offset" that is within the BAT window, if available value. The BAT offset is provided from NG-RAN to SMF, eventually forwarded via PCF/TSCTSF/NEF to AF.

- If the AF does not receive the BAT offset (e.g. NG-RAN did not provide it), the AF assumes that the BAT value is used as a Burst Arrival Time in 5GS.

- The SMF configures the UPF for clock drifting reports as specified in TS 23.502 [3]. In a case the SMF receives a clock drifting report from UPF, the SMF adjusts the BAT offset based on the existing procedures in TS 23.502 [3] and provides the updated BAT offset to the AF via PCF/TSCTSF/NEF.

- The AF may also indicate its capability for periodicity adaptation or a Periodicity Range in the AF Request together with the parameter for BAT adaption mentioned above.

- The RAN may provide a periodicity feedback together with a BAT offset mentioned above. The periodicity feedback shall be within the Periodicity Range (if available). If RAN provides feedback with only one periodicity, the feedback for BAT is accepted based on proposed periodicity. If RAN provides feedback only for BAT, the assumed periodicity is accepted and the signaling continues as described already.

- If AF can accept the changed periodicity and changed BAT, it applies those to the traffic. If AF can only accept the changed periodicity but cannot support proposed BAT, then it provides the BAT (or BAT window) and the signaling continues as described already.

- If the AF accept the periodicity and BAT, it needs to send a confirmation to the 5GS in order to notify SMF/CUC the periodicity or BAT which shall be used in integration with TSN transport network as described in clause 8.3.

Editor's note: Whether periodicity values are provided will be determined in a future meeting based on SA1 feedback.

Principles for Reactive feedback:

- The AF may request the 5GS to report the BAT offset; that is a time offset to the observed timing of the packet reception in the user plane in the NG-RAN. In this case the AF subscribes for the QoS notifications as described in the QoS notification control procedure in TS 23.501 [2] and includes an indication of "burst arrival time adaptation" in the QoS-request to the 5GC.

- If the PCF receives indication for " burst arrival time adaptation" along a subscription for QoS notifications in policy authorization request from AF/NEF/TSCTSF, the PCF sets the QoS notification control parameter as described in TS 23.501 [2] and in addition sets a trigger to be notified for the "BAT offset" event for the corresponding PCC Rule via the SM policy control service to the SMF. The SMF provides the notification control parameter to the NG-RAN as described in TS 23.501, and in addition includes the indication of " burst arrival time adaptation" to the QoS profile.

- If the Notification control is enabled and indication of " burst arrival time adaptation" is set in theTSCAI, and the NG-RAN determines that the PDB can no longer be guaranteed for a QoS Flow, the NG-RAN notifies the SMF as described in TS 23.501 [2] and in addition may include a BAT offset to the N2 SM information that is sent to SMF, eventually forwarded via PCF/TSCTSF/NEF to AF.

- If the NG-RAN receives the indication for "burst arrival time adaptation", the NG-RAN indicates the parameter to the UE via RRC signalling. The NG-RAN indicates a threshold for the BAT offset reports to the UE.

- If the UE receives the indication for "burst arrival time adaptation" from NG-RAN, the UE determines a relative BAT offset value in reference to the current Burst Arrival Time experienced by UE (i.e. in reference to when UE currently receives bursts) and the scheduling UL time slot at UE (e.g. in Configured Grants, as defined in TS 38.321 [11]). The UE sends the BAT offset to RAN when the time offset value reaches the configured threshold, and NG-RAN sends the BAT offset value to SMF.

Editor's note: The need for UL BAT adaptation and the associated RRC signalling as described above is to be confirmed by RAN WG2.

## 8.5 Conclusion for KI #1: 5GS network timing synchronization status and reporting

The following bullet points summarize the principles for the way forward:

- Detecting and reporting RAN and UPF timing synchronization status to TSCTSF

Editor’s note: What the RAN and UPF timing synchronization status consists of is FFS.

- NG-RAN and UPF/NW-TT can detect timing synchronization degradation/failure/improvement locally.

NOTE: The detection is performed based on information provided by time synchronization protocols used in the transport network for both RAN and UPF, or, in the case of NG-RAN, using information provided by a local GNSS receiver. However, in any case, the details on how exactly NG-RAN/UPF detects timing synchronization degradation/failure/improvement locally are beyond the scope of 3GPP.

- TSCTSF may receive network timing synchronization status information of RAN and UPF/NW-TT directly from OAM.

- Alternatively, TSCTSF may receive network timing synchronization status information of RAN and UPF/NW-TT using control plane signaling at node level. For UPF/NW-TT case the TSCTSF may use UMIC. For NG-RAN case the TSCTSF may obtain NG-RAN information via the AMF (i.e. AMF uses NGAP signaling to configure the NG-RAN reporting).

Editor’s note: How to support additional methods (NGAP, control plane signalling, etc.) to obtain timing synchronization status from NG-RAN requires RAN feedback.

- UE determining that the RAN timing synchronization status changed using:

- SIB broadcast information to enable UEs in RRC\_IDLE and RRC\_INACTIVE and in case of RRC\_CONNECTED UEs, dedicated RRC signaling, to enable UEs to determine that:

- the timing synchronization status of the cell that the UE is camping on has changed;

- the timing synchronization status of the new cell the UE is camping on after cell reselection is different compared to the timing synchronization status of the cell that the UE was previously camping on.

- If the UE has determined that the RAN timing synchronization status has changed and the UE has been requested by the TSCTSF to connect to the network in case the RAN timing synchronization status changes, the UE performs a registration (if the UE is in RRC\_IDLE) or the UE Triggered Connection Resume in RRC Inactive procedure (if the UE is in RRC\_INACTIVE).

Editor’s note: Whether the UE performs a Registration also in Inactive is FFS.

Editor’s note: The details of which existing/new SIB information the UE uses to determine that the RAN timing synchronization status has changed is FFS and will be coordinated with RAN WGs.

Editor’s note: How to provide RAN timing synchronization status information to the UE is FFS and will be coordinated with RAN WGs. Details of which RAN timing synchronization status information to provide to the UE will be determined based on feedback from ITU-T.

- Determining UEs impacted by RAN timing synchronization status degradation/improvement:

- TSCTSF subscribes to receive location information (RAN node granularity) from AMF for UEs that AF requested time synchronization for or which are configured for (g)PTP-based time synchronization based on subscription.

- When activating time synchronization for a UE, TSCTSF requests the UE to connect to the network via AMF (i.e., to perform a registration if the UE is in RRC\_IDLE or the UE Triggered Connection Resume in RRC Inactive (if the UE is in RRC\_INACTIVE) in case when the UE later detects that the RAN timing synchronization status has changed while the UE is in RRC\_IDLE or RRC\_INACTIVE.

- TSCTSF correlates information about impacted RAN nodes and the UE location information received from AMF to determine the UEs impacted by RAN timing status degradation/failure/improvement.

Editor's note: Whether alternatively NG-RAN can be responsible for determining the impacted UE(s) and sending the NG-RAN timing synchronization status reports to the AMF via NG-AP signalling, together with the impacted UE(s) is FFS.

- Determining UEs impacted by UPF timing synchronization status degradation or improvement (only for the case when UPF/NW-TT is involved in providing time information to DS-TT):

- TSCTSF determines the UEs for which an impacted UPF/NW-TT is configured to send (g)PTP messages.

- Informing AFs about network timing synchronization status degradation or improvement:

- If TSCTSF has determined UEs impacted by RAN or UPF timing synchronization status degradation or improvement or failure then TSCTSF informs the AF about the timing synchronization status for those UEs if the AF was the requester of the time synchronization service.

- The AF may subscribe to time synchronization service status for a UE (or group of UEs) for which the AF requests or has requested time synchronization service (for ASTI or (g)PTP services).

- For the subscribed AFs the TSCTSF provides time synchronization service status.

Editor’s note: Which information to provide to AF is FFS.

Editor’s note: Whether both UE and AF need to be informed about time synchronization status details simultaneously, and in which cases only UE or only AF may receive it is FFS.

- Deactivating/reactivating/updating time sychronization services based on RAN/UPF timing synchronization status changes:

- PTP case: For UEs that are part of a PTP instance and which are impacted by RAN or UPF time synchronization status degradation or improvement:

- If TSCTSF determines that the Time synchronization error budget provided by AF can still be met, then TSCTSF may update the clockQuality information sent in Announce messages (see IEEE 1588 [8] clause 7.6.2) for the PTP instance using existing procedures and existing PMIC/UMIC information. The handling of Announce messages follows existing procedures as described in TS 23.501 [2].

- If TSCTSF determines that the Time synchronization error budget provided by AF cannot be met (see above) then TSCTSF temporarily removes the UE/DS-TT from the PTP instance using existing procedures in clause K.2.2.1 and clause K.2.2.4 of TS 23.501 [2]).

- If TSCTSF determines that the Time synchronization error budget provided by AF can be met again then TSCTSF adds the DS-TT PTP port to the PTP instance again and also re-activates the Grandmaster functionality.

- ASTI case: TSCTSF updates the access stratum time distribution indication to "enable" or "disable" and forwards the attribute to the serving NG-RAN nodes for the impacted UEs via AMF depending on whether the Time synchronization error budget can or cannot be met (following Rel-17 operations as described in clause 4.15.9.4 of TS 23.502 [3]).

Editor’s note: It is FFS whether AF can also decide to deactivate/reactivate/update time sychronization services based on RAN or UPF timing synchronization status degradation or improvement.

## 8.6 Conclusion for KI#3: Support for controlling 5G time synchronization service based on subscription

The following principles summarize the solution baseline:

- UE subscription data types stored in the UDM are extended to include two new data structures related to time synchronization service:

1) The "Access and Mobility Subscription data" is extended with the following fields:

- “Access Stratum Time Synchronization Service Authorization” which indicate whether the UE is provisioned to receive RTI reception.

- (Optionally) the Uu time synchronization error budget.

- (Optionally) One or more periods of Start and stop times defining active times of Access Stratum Time Synchronization Service for the UE.

- (Optionally) Coverage Area: defining a list of TAs where the ASTI-based time synchronization is available for the UE. .

2) A new subscription data "Time Synchronization Subscription data":

- the “AF request Authorization”, indicating whether the UE is authorized for an AF-requested time synchronization services:

- "allowed" or "not allowed" for (g)PTP based time synchronization service (per DNN/S-NSSAÍ and UE identity),

- "allowed" or "not allowed" for ASTI based time synchronization services (per UE identity).

- optionally a list of TA(s) which restricts the area in which an AF may request time synchronization services

Editor's Note: How to enable an AF to request ASTI service if there is also an ASTI subscription in the Access and Mobility Subscription data is FFS.

- one or more “Subscribed time synchronization service ID(s)”, each containing the DNN/S-NSSAI and a reference to a PTP instance configuration pre-configured at the TSCTSF (e.g. PTP profile, PTP domain, etc).

- (Optionally) For each PTP instance configuration, one or more periods of Start and stop times defining active times of Time Synchronization Service for the PTP instance.

- (Optionally) For each PTP instance configuration, Coverage Area defining a list of TAs where the (g)PTP-based time synchronization is available for the UEs in the PTP instance.

- (Optionally) Uu time synchronization error budget.

- The AMF uses the "Access and Mobility Subscription data" in the following way:

- The AMF retrieves the "Access and Mobility Subscription data" stored at the UDM during the registration procedure.

- If the AMF receives Access Stratum Time Synchronization Service Authorization from UDM, it provides 5G access stratum time distribution indication and Uu time synchronization error budget (if part of the Access Stratum Time Synchronization Service Authorization received from the UDM) to NG-RAN.

- The AF is not allowed to modify the 5GS access stratum time distribution parameters if “Access Stratum Time Synchronization Service Authorization” indicates that the UE is provisioned to receive RTI reception. This may be enforced by the AMF.

NOTE: If there is "Access Stratum Time Synchronization Service Authorization" in the "Access and Mobility Subscription data", the "AF request Authorization" for ASTI based in the "Time Synchronization Subscription data" should be set to "not allowed".

- If the Access Stratum Time Synchronization Service Authorization contains Start and stop times, the AMF enables and disables the 5G access stratum time distribution indication to the NG-RAN according to the expiry of start and stop times if the UE is in CM\_Connected. If the UE is in CM\_Idle when a Start time condition is met, AMF pages the UE and provides the 5G access stratum time distribution indication to NG-RAN as part of the subsequent service request procedure initiated by the UE in response to the paging.

- If the Access Stratum Time Synchronization Service Authorization contains Coverage Area, the AMF enables and disables the 5G access stratum time distribution indication to the NG-RAN when the UE moves inside or outside of the Coverage Area, respectively.

- The TSCTSF uses the Time Synchronization Subscription data in the following way:

- The TSCTSF retrieves the Time Synchronization Subscription data from the UDM when the TSCTSF receives an AF request for the time synchronization service (either ASTI or (g)PTP). According to the “AF request Authorization” in the Subscription data, the TSCTSF determines whether the UE is authorized for an AF-requested time synchronization service. If the UE is authorized, the TSCTSF proceeds as specified in TS 23.502 [3].

- The TSCTSF retrieves the Time Synchronization Subscription data from the UDM when the TSCTSF receives notification from the PCF that a UE has established a PDU Session that is potentially impacted by (g)PTP-based time synchronization service. The TSCTSF retrieves the PTP instance configurations referenced from the Subscribed time synchronization service ID(s). The PTP instance configurations are stored locally in the TSCTSF.

- The TSCTSF determines if one or more of the PTP instance configurations match with the DNN/S-NSSAI of the given PDU Session. If no PTP instance exists for the given PTP instance configuration, the TSCTSF initializes the PTP instance in 5GS as described in clause K.2.2 of TS 23.501 [2]. The TSCTSF configures a PTP port in DS-TT and adds it to the corresponding PTP instance in NW-TT as described in clause K.2.2 of TS 23.501 [2].

- If the PTP instance configuration referenced by the Time Synchronization Subscription data for the UE contains start and stop times, the TSCTSF, upon expiry of start time, creates the PTP instance and adds the PTP port in DS-TT to the PTP instance. Upon expiry of stop time, if this is the last period of start and stop times in the PTP instance configuration, the TSCTSF deletes the PTP instance, otherwise the TSCTSF temporarily disables the PTP instance.

- If the PTP instance configuration referenced by the Time Synchronization Subscription data for the UE contains Coverage Area, the TSCTSF subscribes to UE's presence in Area of Interest at the discovered AMF(s) in similar manner as concluded for KI#2. When the TSCTSF determines that the UE has moved inside or outside of the Coverage Area, the TSCTSF adds or temporarily removes the PTP port in DS-TT from the corresponding PTP instance, in similar manner as concluded for KI#2.

Annex A: KI#1 related additional analysis

## Annex A.1 Methods to notify RAN Time Synchronization Status towards the UE

### A.1.1 Alternative 1: gNB provides a reference report ID within SIB

In this alternative when there is a new RAN timing synchronization status report available at the gNB, the gNB includes in the SIB a status report ID as a notification for the UEs reading the SIB. The report ID can be an optional integer information element. This report ID enables the UE to know there is new information available. There are two options for the UE to determine RAN timing synchronization status information with the Report ID:

1. The UE can actively retrieve the RAN timing synchronization status information from the network by entering RRC\_Connected.
2. Report ID is an index that maps to a pre-defined and/or standardized time synchronization characteristics thus the UE can automatically determine this without having to move to RRC\_CONNECTED state.

An overall procedure for SIB including a reference report ID is illustrated in Figure A.1.1-1.



Figure A.1.1-1: Procedure for gNB provisioning status report ID in SIB

1. The UE has received reference time information using unicast RRC or via SIB9. The RAN releases the UE to RRC Inactive or RRC Idle state.

2. The NG-RAN node detects a primary source event (e.g., degradation, failure, recovery).

3. The NG-RAN generates a RAN timing synchronization status report and an associated status report ID.

4-5. The NG-RAN node broadcasts a status report ID in the cell using SIB to notify the primary source event to the UEs camping in the cell.

6. The UE reads SIB and the status report ID and:

- Alternative a), the UE determines there is a new RAN timing synchronization status report available at the NG-RAN which should be retrieved following steps 7-9.; or

- Alternative b), the UE uses the status report ID as an index to map to the pre-defined and/or standardized characteristics. Steps 7-9 are skipped.

7. In case of alternative a), the UE enters RRC\_Connected..

8. In case of alternative a) after UE moves to RRC\_CONNECTED mode, the NG-RAN determines the UE is subscribed to RAN timing synchronization status (e.g., based on configuration provided by the TSCTSF via AMF).

9. In case of alternative a) the NG-RAN node sends the last available RAN timing synchronization status report with its associated status report ID to the UE via dedicated RRC signaling.

10. In case of alternative b) the UE uses the report ID as an index to map to the pre-defined and/or standardized characteristics that describe the RAN timing synchronization status.

A.1.2 Alternative 2:

This alternative covers a case when a time synchronization status needs to be reported to UEs in RRC\_IDLE and RRC\_Inactive states where applications need such information. For this purpose, it is proposed to use a SIB9 message to transmit a flag and a timestamp so that UEs in RRC\_IDLE and RRC\_Inactive state get information/trigger about a new time synchronization status report available. Then, UEs, providing a specific time synchronization service, need now to move to RRC\_CONNECTED state so that the report could be delivered to them via dedicated RRC signalling. An overall procedure shall include at least the following steps:

1. The UE has a time synchronization service configured. During the ongoing service, the UE moves to RRC\_IDLE or RRC\_Inactive state (which could happen due to different reasons). While the UEs in RRC\_IDLE or and RRC\_Inactive state, the NG-RAN detects an event related to a primary time source (e.g., degradation, improvement, failure…). This event triggers a time synchronization status report, and now this report needs to be sent from the NG-RAN node to the UE.
2. A new field, acting as a flag, is included in SIB9 to indicate to UEs in RRC\_IDLE state that a time synchronization status report is available. Consequently, the UEs need to move to RRC\_CONNECTED state to receive the report, if it has an ongoing time synchronization service.

In addition to a flag, another field (e.g., *flagSetTimeUTC*) is included in SIB9 to reflect a time (actual *timeInfoUTC* value) when the flag was set/changed, which is required so that UEs are aware which report the flag is referring to since every report can be linked to unique time.

NOTE: UEs supporting the feature and when the time sync service is active (e.g., configured by upper layers) in the UE, such UE will be mandated to ensure that they always have a valid version of SIB9 stored, which is required for this reporting procedure to work. Otherwise, UEs are not mandated to re-acquire a SIB9 message unless a SI update notification is received, i.e., no new requirements on UEs with respect to SIB acquisition are pursued.

The flag and *flagSetTimeUTC* fields (this two information may be reflected by one field) shall be updated by the NG-RAN node only when there is a change in a time synchronization status.

1. If there is a new report, NG-RAN updates SIB9. The UEs re-acquires SIB9 and reads the flag and *flagSetTimeUTC* fields in the received SIB9 message. Based on the information in these fields, the UE determines whether there is a new time synchronization report available at the NG-RAN.
2. If the UE determines there is a new time synchronization status report available, the UE initiates the relevant legacy procedure to enter the RRC\_CONNECTED state. The procedure of RRC state transition is not affected.
3. After completing the transition to RRC\_CONNECTED state, the NG-RAN determines (based on the information provided by the AMF via the TSCTSF)) that the latest time synchronization status report needs to be sent to this UE.

Steps at RRC\_CONNECTED state is common to all variants.

1. The NG-RAN sends the latest time synchronization status report to the UE via dedicated RRC signalling. If a time synchronization status changes and a new report is available after the UE has gone to RRC\_IDLE or RRC\_Inactive state again, then the process with an update of the flag and the *flagSetTimeUTC* fields repeats.

### A.1.3 Alternative 3: Broadcast the time change status in SIB

This alternative is related to the conclusion for KI#1 on:

* the NG-RAN informs UEs that receive 5G access stratum time about the time synchronization status by providing additional time synchronization status information (e.g. synchronization state, primary source description (e.g. type, quality, lock state), clock class and information about traceability to UTC, clock accuracy and stability) to UEs

The idea of this alternative is to provide RAN Time Synchronization Status in SIB. According to the status information, the UE know the time status has be changed. In this alternative, there is no inter-RAN node cooperation.

The ReferenceTimeinfo (RTI) is extended with:

* Time quality (e.g. quality, clock class)
* Latest time status change time
* Time source

NOTE: The detail of time quality will depend on the ITU-T feedback.

#### A.1.3.1 Procedures

##### A.1.3.1.1 Broadcast the time change status



Figure A.1.3.1.1-1: Broadcasting RAN Time Synchronization Status

1. The AF has requested 5G access stratum time distribution for the UE and NG-RAN know it need to notify the time status to UE if there is primary time source event (e.g. changed, degradation, etc).

NOTE 1: This step can be optional or depend on the existing solution in this TR.

2. The NG-RAN provides the referencetimeinfo to UE via SIB9 or dedicated RRC:

3. There is a primary time source event that occurs (e.g degradation, switch, failure, recovery).

4. The NG-RAN provides the enhanced referencetimeinfo to UE via SIB9 or dedicated RRC. According to the Latest time status change time in the RTI, the UE know whether this is primary time source event occurs.

NOTE 2: The UE may store the RAN id and Latest time status change time to make the comparision. This is up to UE implementation.

### A.1.4 Alternative 4: Ciphered RAN Time Synchronization Status in SIB

Key idea of this alternative is to provide RAN Time Synchronization Status in SIB. RAN Time Synchronization Status may optionally be ciphered. Ciphering keys are only provided to UEs, which are subscribed for time synchronization or for which an AF has successfully requested time synchronization.

Ciphering RAN Time Synchronization Status in SIB ensures that RAN Time Synchronization Status can only be read by UEs that are privy to this information.

To enable ciphering of the Ciphering RAN Time Synchronization Status, TSCTSF obtains the RAN Time Synchronization Status from NG-RAN nodes and provides the ciphered RAN Time Synchronization Status to NG-RAN nodes via AMF (see clause A.1.4.1 for details).

NOTE 1: Details of how to obtain RAN Time Synchronization Status are discussed in the solutions documented in clause 6 of this TR.

This means that the same ciphered RAN Time Synchronization Status information is provided to all UEs that have received the ciphering keys.

This alternative is based on the existing solution for Broadcast of Assistance Data for location services (see TS 23.273 clause 6.14 and TS 37.355 clause 7 for details on Broadcast of Assistance Data).

Editor's note: Feasibility of this solution depends on feedback from RAN2/3 and SA3.

#### A.1.4.1 Procedures

##### A.1.4.1.1 Broadcast of RAN Time Synchronization Status



Figure A.1.4.1.1-1: Broadcasting RAN Time Synchronization Status

1. TSCTSF obtains RAN Time Synchronization Status

NOTE 1: Details of how to obtain RAN Time Synchronization Status are discussed in the solutions documented in clause 6 of this TR.

2. TSCTSF may optionally cipher RAN Time Synchronization Status using a common key for all RAN nodes across one or multiple tracking areas.

3. TSCTSF invokes the Namf\_Communication\_NonUeN2MessageTransfer service operation towards the AMF to request the transfer of RAN Time Synchronization Status to an NG-RAN node. TSCTSF includes the Network RAN Time Synchronization Status and the target NG-RAN node identity

4. AMF provides RAN Time Synchronization Status to the NG-RAN node indicated by TSCTSF.

5. RAN broadcasts the RAN Time Synchronization Status.

6.- UEs receive the RAN Time Synchronization Status provided in SIB. If the reference time quality information is ciphered and the UE has been provided with the ciphering key (see clause A.X.2.2), the UE deciphers the reference time quality information.

NOTE 2 Similar as for the existing broadcast of assistance data for location services, it is assumed that UEs, which support receiving RAN Time Synchronization Status will be mandated, e.g., configured by upper layers, to ensure having a valid version of the SIB that will contain RAN Time Synchronization Status in RRC\_IDLE and RRC\_INACTIVE. (See also TS 38.331 clause 5.2.2.1 for further details on SIB handling by the UE for broadcast of assistance data for location services.)

##### A.1.4.1.2 Delivery of ciphering keys to UEs for broadcast of RAN Time Synchronization Status

This procedure is used by the TSCTSF and the AMF to distribute ciphering keys to UEs to enable UEs to decipher RAN Time Synchronization Status ciphered by TSCTSF.



Figure A.1.4.1.2-1: Delivery of Ciphering Keys to UEs for broadcast of RAN Time Synchronization Status

1. TSCTSF provides AMF with one or more ciphering keys used to cipher RAN Time Synchronization Status information according to the procedure in clause A.1.4.1.1.1. For each ciphering key, TSCTSF includes a ciphering key value, a ciphering key identifier, a validity period, and a set of applicable tracking areas.

2. The AMF stores the ciphering keys including the validity periods and applicable tracking areas.

3. A UE sends a Registration Request. The Registration Request may be sent as part of normal mobility management, a Registration Request may also be sent specifically to request and obtain ciphering keys. The UE includes in the Registration Request an indication that ciphering keys are requested.

4. The AMF returns a Registration Accept to the UE as defined in TS 23.502. If the Registration Request includes the indication that ciphering keys are requested and the UE is subscribed for time synchronization services or AMF has received a request from TSCTSF to activate access stratum time synchronization for the UE, then AMF includes in the Registration Accept one or more ciphering keys applicable to the UE's current tracking area. AMF also includes for each ciphering key the ciphering key value, the ciphering key identifier, the validity period and the set of applicable tracking areas.

Annex B:  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2022-02 | SA2#149E | S2-2201055 | - | - | - | Proposed skeleton agreed at S2#149E | 0.0.0 |
| 2022-02 | SA2#149E | - | - | - | - | Implemented agreed P-CRs at S2#149E – S2-2201759, S2-2201760, S2-2201761, S2-2201762, S2-2201763, S2-2201764, S2-2201765, S2-2201766, S2-2201768, S2-2201769, S2-2201770. | 0.1.0 |
| 2022-04 | SA2#150E | - | - | - | - | Implemented agreed P-CRs at S2#150E - S2-2203462, S2-2203463, S2-2203464, S2-2203465, S2-2203466, S2-2203467, S2-2203468,  S2-2203469, S2-2203470, S2-2203471, S2-2203472, S2-2203473, S2-2203474, S2-2203475, S2-2203476, S2-2203477, S2-2203478. | 0.2.0 |
| 2022-05 | SA2#151E | - | - | - | - | Implemented agreed P-CRs at S2#151E - S2-2205159, S2-2205160, S2-2205161, S2-2205162, S2-2205163, S2-2205164, S2-2205165, S2-2205166, S2-2205167, S2-2205168, S2-2205169, S2-2205170, S2-2204421, S2-2205171, S2-2205172, S2-2205173, S2-2204591, S2-2205174, S2-2205175, S2-2205176, S2-2205177, S2-2205178, S2-2205179, S2-2205180, S2-2205181, S2-2205182, S2-2205183 | 0.3.0 |
| 2022-08 | SA2#152E | - | - | - | - | Implemented agreed P-CRs at SA2#152E - S2-2207723, S2-2207724, S2-2207725, S2-2207726, S2-2207727,  S2-2207728, S2-2207729, S2-2207730, S2-2207731, S2-2207732,  S2-2207733, S2-2207734, S2-2205934, S2-2206610, S2-2207735,  S2-2207736, S2-2207737, S2-2206593, S2-2205933 | 0.4.0 |
| 2022-09 | SA#97-e | SP-220818 | - | - | - | MCC editorial update for presentation to TSG SA for information` | 1.0.0 |
| 2022-10 | SA2#153E | - | - | - | - | Implemented agreed P-CRs at SA2#153E - S2-2209871, S2-2209872, S2-2209873, S2-2209874, S2-2209875, S2-2209876, S2-2209877, S2-2209878, S2-2208187, S2-2209880, S2-2209881 | 1.1.0 |