**3GPP TSG- Meeting #**

**Wuhan, China, April 7 – April 11, 2025**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *CR-Form-v12.3* | | | | | | | | |
| **CHANGE REQUEST** | | | | | | | | |
|  | | | | | | | | |
|  |  | **CR** |  | **rev** | **-** | **Current version:** |  |  |
|  | | | | | | | | |
| *For* [***HE******LP***](http://www.3gpp.org/3G_Specs/CRs.htm#_blank)*on using this form: comprehensive instructions can be found at* [*http://www.3gpp.org/Change-Requests*](http://www.3gpp.org/Change-Requests)*.* | | | | | | | | |
|  | | | | | | | | |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Proposed change affects:*** | UICC apps |  | ME | **X** | Radio Access Network | **X** | Core Network |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | | | | | |
| ***Title:*** |  | | | | | | | | | |
|  |  | | | | | | | | | |
| ***Source to WG:*** |  | | | | | | | | | |
| ***Source to TSG:*** | R2 | | | | | | | | | |
|  |  | | | | | | | | | |
| ***Work item code:*** |  | | | | |  | ***Date:*** | | |  |
|  |  | | | |  | |  | | |  |
| ***Category:*** | **B** |  | | | | | ***Release:*** | | |  |
|  | *Use one of the following categories:* ***F*** *(correction)* ***A*** *(mirror corresponding to a change in an earlier release)* ***B*** *(addition of feature),* ***C*** *(functional modification of feature)* ***D*** *(editorial modification)*  Detailed explanations of the above categories can be found in 3GPP [TR 21.900](http://www.3gpp.org/ftp/Specs/html-info/21900.htm). | | | | | | | | *Use one of the following releases: Rel-8 (Release 8) Rel-9 (Release 9) Rel-10 (Release 10) Rel-11 (Release 11) … Rel-17 (Release 17) Rel-18 (Release 18) Rel-19 (Release 19)  Rel-20 (Release 20)* | |
|  |  | | | | | | | | | |
| ***Reason for change:*** | | Introduction of Release-19 Network Energy Savings Enhancements. | | | | | | | | |
|  | |  | | | | | | | | |
| ***Summary of change:*** | | This CR introduces Release-19 Network Energy Savings Enhancements for NR in TS 38.300. | | | | | | | | |
|  | |  | | | | | | | | |
| ***Consequences if not approved:*** | | No support for Release-19 Network Energy Savings Enhancements. | | | | | | | | |
|  | |  | | | | | | | | |
| ***Clauses affected:*** | | 3.1, 3.2, 5.2.4, 5.2.5.5, 7.3.1, 7.3.2, 9.2.1.2, 9.2.5, 9.2.6, 9.2.7, 15.4.2.5, 15.4.2 | | | | | | | | |
|  | |  | | | | | | | | |
|  | | **Y** | **N** |  | | | |  | | |
| ***Other specs*** | |  | **X** | Other core specifications | | | | TS/TR ... CR ... | | |
| ***affected:*** | |  | **X** | Test specifications | | | | TS/TR ... CR ... | | |
| ***(show related CRs)*** | |  | **X** | O&M Specifications | | | | TS/TR ... CR ... | | |
|  | |  | | | | | | | | |
| ***Other comments:*** | |  | | | | | | | | |
|  | |  | | | | | | | | |
| ***This CR's revision history:*** | |  | | | | | | | | |

*Start of changes*

# 3 Abbreviations and Definitions

## 3.1 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1], in TS 36.300 [2] 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] and TS 36.300 [2].

5GC 5G Core Network

5GS 5G System

5QI 5G QoS Identifier

A2X Aircraft-to-Everything

A-CSI Aperiodic CSI

AGC Automatic Gain Control

AI Artificial Intelligence

AKA Authentication and Key Agreement

AMBR Aggregate Maximum Bit Rate

AMC Adaptive Modulation and Coding

AMF Access and Mobility Management Function

AR Augmented Reality

ARP Allocation and Retention Priority

ATG Air to Ground

BA Bandwidth Adaptation

BCCH Broadcast Control Channel

BCH Broadcast Channel

BFD Beam Failure Detection

BH Backhaul

BL Bandwidth reduced Low complexity

BPSK Binary Phase Shift Keying

BRID Broadcast Remote Identification

C-RNTI Cell RNTI

CAG Closed Access Group

CAPC Channel Access Priority Class

CBRA Contention Based Random Access

CCE Control Channel Element

CD-SSB Cell Defining SSB

cellDTRX-RNTI Cell Discontinuous Transmission and Reception RNTI

CFR Common Frequency Resource

CFRA Contention Free Random Access

CG Configured Grant

CHO Conditional Handover

CIoT Cellular Internet of Things

CLI Cross Link interference

CMAS Commercial Mobile Alert Service

CORESET Control Resource Set

CP Cyclic Prefix

CPA Conditional PSCell Addition

CPC Conditional PSCell Change

DAA Detect And Avoid

DAG Directed Acyclic Graph

DAPS Dual Active Protocol Stack

DFT Discrete Fourier Transform

DCI Downlink Control Information

DCP DCI with CRC scrambled by PS-RNTI

DCR Direct Communication Request

DL-AoD Downlink Angle-of-Departure

DL-SCH Downlink Shared Channel

DL-TDOA Downlink Time Difference Of Arrival

DMRS Demodulation Reference Signal

DRX Discontinuous Reception

DSR Delay Status Report

DTX Discontinuous Transmission

E-CID Enhanced Cell-ID (positioning method)

EC Energy Cost

EHC Ethernet Header Compression

ePWS enhancements of Public Warning System

ETWS Earthquake and Tsunami Warning System

FS Feature Set

FSA ID Frequency Selection Area Identity

G-CS-RNTI Group Configured Scheduling RNTI

G-RNTI Group RNTI

GFBR Guaranteed Flow Bit Rate

GIN Group ID for Network selection

GNSS Global Navigation Satellite System

GSO Geosynchronous Orbit

H-SFN Hyper System Frame Number

HAPS High Altitude Platform Station

HRNN Human-Readable Network Name

IAB Integrated Access and Backhaul

IFRI Intra Frequency Reselection Indication

I-RNTI Inactive RNTI

INT-RNTI Interruption RNTI

KPAS Korean Public Alarm System

L2 Layer-2

L3 Layer-3

LBT Listen Before Talk

LDPC Low Density Parity Check

LEO Low Earth Orbit

LTM L1/L2 Triggered Mobility

MBS Multicast/Broadcast Services

MCE Measurement Collection Entity

MCCH MBS Control Channel

MDBV Maximum Data Burst Volume

MEO Medium Earth Orbit

MIB Master Information Block

MICO Mobile Initiated Connection Only

MFBR Maximum Flow Bit Rate

ML Machine Learning

MMTEL Multimedia telephony

MNO Mobile Network Operator

MO-SDT Mobile Originated SDT

MP Multi-Path

MPE Maximum Permissible Exposure

MRB MBS Radio Bearer

MT Mobile Termination

MT-SDT Mobile Terminated SDT

MTCH MBS Traffic Channel

MTSI Multimedia Telephony Service for IMS

MU-MIMO Multi User MIMO

Multi-RTT Multi-Round Trip Time

MUSIM Multi-Universal Subscriber Identity Module

N3C Non-3GPP Connection

NB-IoT Narrow Band Internet of Things

NCD-SSB Non Cell Defining SSB

NCGI NR Cell Global Identifier

NCL Neighbour Cell List

NCR Neighbour Cell Relation

NCRT Neighbour Cell Relation Table

NES Network Energy Savings

NGAP NG Application Protocol

NGSO Non-Geosynchronous Orbit

NID Network Identifier

NPN Non-Public Network

NR NR Radio Access

NSAG Network Slice AS Group

NTN Non-Terrestrial Network

OD-SIB1 On-demand SIB1

OD-SSB On-demand SSB

P-MPR Power Management Maximum Power Reduction

P-RNTI Paging RNTI

PCH Paging Channel

PCI Physical Cell Identifier

PDB Packet Delay Budget

PDC Propagation Delay Compensation

PDCCH Physical Downlink Control Channel

PDSCH Physical Downlink Shared Channel

PEI Paging Early Indication

PER Packet Error Rate

PH Paging Hyperframe

PLMN Public Land Mobile Network

PNI-NPN Public Network Integrated NPN

PF Paging Frame

PO Paging Occasion

PQI PC5 5QI

PRACH Physical Random Access Channel

PRB Physical Resource Block

PRG Precoding Resource block Group

PRS Positioning Reference Signal

PS-RNTI Power Saving RNTI

PSDB PDU Set Delay Budget

PSER PDU Set Error Rate

PSI PDU Set Importance

PSIHI PDU Set Integrated Handling Information

PSS Primary Synchronisation Signal

PTM Point to Multipoint

PTP Point to Point

PTW Paging Time Window

PUCCH Physical Uplink Control Channel

PUSCH Physical Uplink Shared Channel

PWS Public Warning System

QAM Quadrature Amplitude Modulation

QFI QoS Flow ID

QMC QoE Measurement Collection

QoE Quality of Experience

QPSK Quadrature Phase Shift Keying

RA Random Access

RA-RNTI Random Access RNTI

RACH Random Access Channel

RANAC RAN-based Notification Area Code

REG Resource Element Group

RIM Remote Interference Management

RLM Radio Link Monitoring

RMSI Remaining Minimum SI

RNA RAN-based Notification Area

RNAU RAN-based Notification Area Update

RNTI Radio Network Temporary Identifier

RQA Reflective QoS Attribute

RQoS Reflective Quality of Service

RS Reference Signal

RSRP Reference Signal Received Power

RSRQ Reference Signal Received Quality

RSSI Received Signal Strength Indicator

RSTD Reference Signal Time Difference

RTT Round Trip Time

RVQoE RAN visible QoE

SCS SubCarrier Spacing

SD Slice Differentiator

SDAP Service Data Adaptation Protocol

SDT Small Data Transmission

SD-RSRP Sidelink Discovery RSRP

SFI-RNTI Slot Format Indication RNTI

SHR Successful Handover Report

SIB System Information Block

SI-RNTI System Information RNTI

SLA Service Level Agreement

SL-PRS Sidelink Positioning Reference Signal

SL-RSRP Sidelink RSRP

SMC Security Mode Command

SMF Session Management Function

SMTC SS/PBCH block Measurement Timing Configuration

S-NSSAI Single Network Slice Selection Assistance Information

SNPN Stand-alone Non-Public Network

SNPN ID Stand-alone Non-Public Network Identity

SPR Successful PSCell Addition/Change Report

SPS Semi-Persistent Scheduling

SR Scheduling Request

SRAP Sidelink Relay Adaptation Protocol

SRS Sounding Reference Signal

SRVCC Single Radio Voice Call Continuity

SS Synchronization Signal

SSB SS/PBCH block

SSS Secondary Synchronisation Signal

SSSG Search Space Set Group

SST Slice/Service Type

SU-MIMO Single User MIMO

SUL Supplementary Uplink

TA Timing Advance

TB Transport Block

TCE Trace Collection Entity

TNL Transport Network Layer

TPC Transmit Power Control

TRP Transmit/Receive Point

TRS Tracking Reference Signal

TSS Timing Synchronization Status

U2N UE-to-Network

U2U UE-to-UE

UAV Uncrewed Aerial Vehicle

UCI Uplink Control Information

UDC Uplink Data Compression

UDM Unified Data Management

UE-Slice-MBR UE Slice Maximum Bit Rate

UL-AoA Uplink Angles of Arrival

UL-RTOA Uplink Relative Time of Arrival

UL-SCH Uplink Shared Channel

UL-WUS Uplink Wake-Up Signal

UPF User Plane Function

URLLC Ultra-Reliable and Low Latency Communications

VR Virtual Reality

V2X Vehicle-to-Everything

Xn-C Xn-Control plane

Xn-U Xn-User plane

XnAP Xn Application Protocol

XR eXtended Reality

## 3.2 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1], in TS 36.300 [2] 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] and TS 36.300 [2].

**2Rx XR UE**: two antenna port XR UE as specified in TS 38.101-1 [18].

**A2X communication**: A communication to support A2X services leveraging PC5 reference points. A2X services are realized by various types of A2X applications, i.e. BRID or DAA.

**Aerial UE communication:** functionality enabling Aerial UE function, as defined in 16.18.

**Air to Ground network:** An NG-RAN consisting of ground-based gNBs, which provide cell towers that send signals up to an aircraft's antenna(s) of onboard ATG terminal, with typical vertical altitude of around 10,000m and take-off/landing altitudes down to 3000m.

**BH RLC channel**: an RLC channel between two nodes, which is used to transport backhaul packets**.**

**Boundary IAB-node:** as defined in TS 38.401 [4].

**Broadcast MRB**:A radio bearer configured for MBS broadcast delivery.

**CAG Cell**:a PLMN cell broadcasting at least one Closed Access Group identity.

**CAG Member Cell**:for a UE, a CAG cell broadcasting the identity of the selected PLMN, registered PLMN or equivalent PLMN, and for that PLMN, a CAG identifier belonging to the Allowed CAG list of the UE for that PLMN.

**CAG-only cell**: a CAG cell that is only available for normal service for CAG UEs.

**Cell-Defining SSB**: an SSB with an RMSI associated.

**Child node**: IAB-DU's and IAB-donor-DU's next hop neighbour node; the child node is also an IAB-node.

**Conditional Handover (CHO**): a handover procedure that is executed only when execution condition(s) are met.

**CORESET#0**: the control resource set for at least SIB1 scheduling, can be configured either via MIB or via dedicated RRC signalling.

**DAPS Handover**: a handover procedure that maintains the source gNB connection after reception of RRC message for handover and until releasing the source cell after successful random access to the target gNB.

**Data Burst:** A set of multiple PDUs generated and sent by the application in a short period of time, as defined in TS 23.501 [3].

**Direct Path**: a type of UE-to-Network transmission path, where data is transmitted between a UE and the network without sidelink relaying.

**Downstream**: direction toward child node or UE in IAB-topology.

**Early Data Forwarding**: data forwarding that is initiated before the UE executes the handover.

**Earth-centered, earth-fixed**: a global geodetic reference system for the Earth intended for practical applications of mapping, charting, geopositioning and navigation, as specified in NIMA TR 8350.2 [51].

**eRedCap UE**: a UE with enhanced reduced capabilities as specified in clause 4.2.22.1 in TS 38.306 [11].

**Feeder link**: wireless link between the NTN Gateway and the NTN payload.

**Geosynchronous Orbit**: earth-centered orbit at approximately 35786 kilometres above Earth's surface and synchronised with Earth's rotation. A geostationary orbit is a non-inclined geosynchronous orbit, i.e. in the Earth's equator plane.

**Group ID for Network Selection**: an identifier used during SNPN selection to enhance the likelihood of selecting a preferred SNPN that supports a Default Credentials Server or a Credentials Holder, as specified in TS 23.501 [3].

**gNB**: node providing NR user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.

**High Altitude Platform Station**: airborne vehicle embarking the NTN payload placed at an altitude between 8 and 50 km.

**IAB-donor**:gNB that provides network access to UEs via a network of backhaul and access links.

**IAB-donor-CU**: as defined in TS 38.401 [4].

**IAB-donor-DU**:as defined in TS 38.401 [4].

**IAB-DU**: gNB-DU functionality supported by the IAB-node to terminate the NR access interface to UEs and next-hop IAB-nodes, and to terminate the F1 protocol to the gNB-CU functionality, as defined in TS 38.401 [4], on the IAB-donor.

**IAB-MT**: IAB-node function that terminates the Uu interface to the parent node using the procedures and behaviours specified for UEs unless stated otherwise. IAB-MT function used in 38-series of 3GPP Specifications corresponds to IAB-UE function defined in TS 23.501 [3].

**IAB-node**: RAN node that supports NR access links to UEs and NR backhaul links to parent nodes and child nodes. The IAB-node does not support backhauling via LTE.

**IAB topology**: the unison of all IAB-nodes and IAB-donor-DUs whose F1 and/or RRC connections are terminated at the same IAB-donor-CU.

**Indirect Path**: a type of UE-to-Network transmission path, where data is forwarded via a U2N Relay UE between a U2N Remote UE and the network.

**Inter-donor partial migration:** migration of an IAB-MT to a parent node underneath a different IAB-donor-CU while the collocated IAB-DU and its descendant IAB-node(s), if any, are terminated at the initial IAB-donor-CU. The procedure renders the said IAB-node as a boundary IAB-node.

**Intra-system Handover**:handover that does not involve a CN change (EPC or 5GC).

**Inter-system Handover**:handover that involves a CN change (EPC or 5GC).

**Late Data Forwarding**: data forwarding that is initiated after the source NG-RAN node knows that the UE has successfully accessed a target NG-RAN node.

**L1/L2 Triggered Mobility**: a cell switch procedure that the network triggers via MAC CE based on L1 or L3 measurement report.

**Mapped Cell ID**: in NTN, it corresponds to a fixed geographical area.

**MBS Radio Bearer**: A radio bearer configured for MBS delivery.

**Mobile-IAB cell**: a cell of a mobile IAB-DU.

**Mobile IAB-DU**: gNB-DU functionality supported by the mobile IAB-node to terminate the NR access interface to UEs, and to terminate the F1 protocol to the gNB-CU functionality on the IAB-donor, as defined in TS 38.401 [4].

**Mobile IAB-DU migration**: procedure for a mobile IAB-node as defined in TS 38.401 [4].

**Mobile IAB-MT**: mobile IAB-node function that terminates the Uu interface to the parent node using the procedures and behaviours specified for UEs unless stated otherwise.

**Mobile IAB-MT migration**: procedure for a mobile IAB-MT as defined in TS 38.401 [4].

**Mobile IAB-node**: RAN node that supports NR access links to UEs and an NR backhaul link to a parent node, and that can conduct physical mobility across the RAN area. The mobile IAB-node function used in 38-series of 3GPP Specifications corresponds to the MBSR function defined in TS 23.501 [3].

**MP Relay UE**: a UE that provides functionality to support connectivity to the network for MP Remote UE(s).

**MP Remote UE**: a UE that communicates with the network via a direct Uu link and a MP Relay UE.

**MSG1**: preamble transmission of the random access procedure for 4-step random access (RA) type.

**MSG3**: first scheduled transmission of the random access procedure.

**MSGA**:preamble and payload transmissions of the random access procedure for 2-step RA type.

**MSGB**:response to MSGA in the 2-step random access procedure. MSGB may consist of response(s) for contention resolution, fallback indication(s), and backoff indication.

**Multicast/Broadcast Service**: A point-to-multipoint service as defined in TS 23.247 [45].

**Multicast MRB**:A radio bearer configured for MBS multicast delivery.

**Multi-hop backhauling**: using a chain of NR backhaul links between an IAB-node and an IAB-donor.

**NCR-Fwd**: Network-Controlled Repeater node function, which performs amplifying-and-forwarding of UL/DL RF signals between gNB and UE. The behaviour of the NCR-Fwd is controlled according to the side control information received by the NCR-MT from a gNB.

**NCR-Fwd access link**: link used for transmissions between the NCR-Fwd and UEs.

**NCR-Fwd backhaul link**: link used for backhauling between the NCR-Fwd and gNB.

**NCR-MT**: NCR-node entity which communicates with a gNB via a control link to receive side control information. The control link is based on NR Uu interface.

**NCR-node**: RAN node comprising NCR-MT and NCR-Fwd.

**ng-eNB**: node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.

**NG-C**: control plane interface between NG-RAN and 5GC.

**NG-U**: user plane interface between NG-RAN and 5GC.

**NG-RAN node**: either a gNB or an ng-eNB.

**Non-CAG Cell**: a PLMN cell which does not broadcast any Closed Access Group identity.

**Non-Cell Defining SSB**: an SSB without an RMSI associated.

**Non-Geosynchronous orbit**: earth-centered orbit with an orbital period that does not match Earth's rotation on its axis. This includes Low and Medium Earth Orbit (LEO and MEO). LEO operates at altitudes between 300 km and 1500 km and MEO at altitudes between 7000 km and 25000 km, approximately.

**Non-terrestrial network**: an NG-RAN consisting of gNBs, which provide non-terrestrial NR access to UEs by means of an NTN payload embarked on an airborne or space-borne NTN vehicle and an NTN Gateway.

**NR backhaul link**: NR link used for backhauling between an IAB-node and an IAB-donor, and between IAB-nodes in case of a multi-hop backhauling.

**NR sidelink communication**: AS functionality enabling at least V2X communication as defined in TS 23.287 [40] and/or A2X communication as defined in TS 23.256 [60] and/or the ProSe communication (including ProSe non-Relay and UE-to-Network Relay communication) as defined in TS 23.304 [48], between two or more nearby UEs, using NR technology but not traversing any network node.

**NR sidelink discovery**: AS functionality enabling ProSe non-Relay Discovery and ProSe UE-to-Network Relay discovery for Proximity based Services as defined in TS 23.304 [48] between two or more nearby UEs, using NR technology but not traversing any network node.

**NTN Gateway**: an earth station located at the surface of the earth, providing connectivity to the NTN payload using the feeder link. An NTN Gateway is a TNL node.

**NTN payload**: a network node, embarked on board a satellite or high altitude platform station, providing connectivity functions, between the service link and the feeder link. In the current version of this specification, the NTN payload is a TNL node.

**Numerology**: corresponds to one subcarrier spacing in the frequency domain. By scaling a reference subcarrier spacing by an integer *N*, different numerologies can be defined.

**Parent node**: IAB-MT's or mobile IAB-MT's next hop neighbour node; the parent node can be an IAB-node or IAB-donor-DU

**PC5 Relay RLC channel**: an RLC channel between L2 U2N Remote UE and L2 U2N Relay UE, or between L2 U2U Remote UE and L2 U2U Relay UE, which is used to transport packets over PC5 for L2 UE-to-Network/UE-to-UE Relay**.**

**PDU Set**: one or more PDUs carrying the payload of one unit of information generated at the application level (e.g. frame(s) or video slice(s) for XR Services), as defined in TS 23.501 [3].

**PLMN Cell**: a cell of the PLMN.

**RACH-less LTM**: an LTM cell switch procedure where UE skips the random access procedure.

**RedCap UE**: a UE with reduced capabilities as specified in clause 4.2.21.1 in TS 38.306 [11].

**Relay discovery**: AS functionality enabling 5G ProSe UE-to-Network Relay Discovery as defined in TS 23.304 [48], using NR technology but not traversing any network node.

**Satellite**:a space-borne vehicle orbiting the Earth embarking the NTN payload.

**Service link**:wireless link between the NTN payload and UE.

**Sidelink Discovery RSRP:** RSRP measurements on PC5 link related to NR sidelink discovery.

**Sidelink RSRP:** RSRP measurements on PC5 link related to NR sidelink communication.

**SNPN Access Mode**: mode of operation whereby a UE only accesses SNPNs.

**SNPN-only cell**: a cell that is only available for normal service for SNPN subscribers.

**SNPN Identity**: the identity of Stand-alone NPN defined by the pair (PLMN ID, NID).

**Transmit/Receive Point**:part of the gNB transmitting and receiving radio signals to/from UE according to physical layer properties and parameters inherent to that element.

**U2N Relay UE**: a UE that provides functionality to support connectivity to the network for U2N Remote UE(s).

**U2N Remote UE**: a UE that communicates with the network via a U2N Relay UE.

**U2U Relay UE**: a UE that provides functionality to support connectivity between two U2U Remote UEs.

**U2U Remote UE**: a UE that communicates with other UE(s) via a U2U Relay UE.

**UL-WUS**: Uplink Wake-Up Signal used to trigger OD-SIB1 transmission.

**Upstream**: direction toward parent node in IAB-topology.

**Uu Relay RLC channel**: an RLC channel between L2 U2N Relay UE or MP Relay UE and gNB, which is used to transport packets over Uu for L2 UE-to-Network Relay or for indirect path in case of MP.

**V2X sidelink communication**: AS functionality enabling V2X communication as defined in TS 23.285 [41], between nearby UEs, using E-UTRA technology but not traversing any network node.

**Xn**: network interface between NG-RAN nodes.

# 4 Overall Architecture and Functional Split

## 4.1 Overall Architecture

An NG-RAN node is either:

- a gNB, providing NR user plane and control plane protocol terminations towards the UE; or

- an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE.

The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]).

NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4].

The NG-RAN architecture is illustrated in Figure 4.1-1 below.



Figure 4.1-1: Overall Architecture

## 4.2 Functional Split

The **gNB** and **ng-eNB** host the following functions:

- Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in uplink, downlink and sidelink (scheduling);

- IP and Ethernet header compression, uplink data decompression, encryption and integrity protection of data;

- Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information provided by the UE;

- Routing of User Plane data towards UPF(s);

- Routing of Control Plane information towards AMF;

- Connection setup and release;

- Scheduling and transmission of paging messages;

- Scheduling and transmission of system broadcast information (originated from the AMF or OAM);

- Measurement and measurement reporting configuration for mobility and scheduling;

- Transport level packet marking in the uplink;

- Session Management;

- Support of Network Slicing;

- QoS Flow management and mapping to data radio bearers;

- Support of UEs in RRC\_INACTIVE state;

- Distribution function for NAS messages;

- Radio access network sharing;

- Dual Connectivity;

- Tight interworking between NR and E-UTRA;

- Maintain security and radio configuration for User Plane CIoT 5GS Optimisation, as defined in TS 23.501 [3] (ng-eNB only).

NOTE 1: BL UE or UE in enhanced coverage is only supported by ng-eNB, see TS 36.300 [2].

NOTE 2: NB-IoT UE is only supported by ng-eNB, see TS 36.300 [2].

The **AMF** hosts the following main functions (see TS 23.501 [3]):

- NAS signalling termination;

- NAS signalling security;

- AS Security control;

- Inter CN node signalling for mobility between 3GPP access networks;

- Idle mode UE Reachability (including control and execution of paging retransmission);

- Registration Area management;

- Support of intra-system and inter-system mobility;

- Access Authentication;

- Access Authorization including check of roaming rights;

- Mobility management control (subscription and policies);

- Support of Network Slicing;

- SMF selection.

- Selection of CIoT 5GS optimisations;

The **UPF** hosts the following main functions (see TS 23.501 [3]):

- Anchor point for Intra-/Inter-RAT mobility (when applicable);

- External PDU session point of interconnect to Data Network;

- Packet routing & forwarding;

- Packet inspection and User plane part of Policy rule enforcement;

- Traffic usage reporting;

- Uplink classifier to support routing traffic flows to a data network;

- Branching point to support multi-homed PDU session;

- QoS handling for user plane, e.g. packet filtering, gating, UL/DL rate enforcement;

- Uplink Traffic verification (SDF to QoS flow mapping);

- Downlink packet buffering and downlink data notification triggering.

The Session Management function (**SMF**) hosts the following main functions (see TS 23.501 [3]):

- Session Management;

- UE IP address allocation and management;

- Selection and control of UP function;

- Configures traffic steering at UPF to route traffic to proper destination;

- Control part of policy enforcement and QoS;

- Downlink Data Notification.

This is summarized on the figure below where yellow boxes depict the logical nodes and white boxes depict the main functions.



Figure 4.2-1: Functional Split between NG-RAN and 5GC

## 4.3 Network Interfaces

### 4.3.1 NG Interface

#### 4.3.1.1 NG User Plane

The NG user plane interface (NG-U) is defined between the NG-RAN node and the UPF. The user plane protocol stack of the NG interface is shown on Figure 4.3.1.1-1. The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs between the NG-RAN node and the UPF.



Figure 4.3.1.1-1: NG-U Protocol Stack

NG-U provides non-guaranteed delivery of user plane PDUs between the NG-RAN node and the UPF.

Further details of NG-U can be found in TS 38.410 [16].

#### 4.3.1.2 NG Control Plane

The NG control plane interface (NG-C) is defined between the NG-RAN node and the AMF. The control plane protocol stack of the NG interface is shown on Figure 4.3.1.2-1. The transport network layer is built on IP transport. For the reliable transport of signalling messages, SCTP is added on top of IP. The application layer signalling protocol is referred to as NGAP (NG Application Protocol). The SCTP layer provides guaranteed delivery of application layer messages. In the transport, IP layer point-to-point transmission is used to deliver the signalling PDUs.



Figure 4.3.1.2-1: NG-C Protocol Stack

NG-C provides the following functions:

- NG interface management;

- UE context management;

- UE mobility management;

- Transport of NAS messages;

- Paging;

- PDU Session Management;

- Configuration Transfer;

- Warning Message Transmission.

Further details of NG-C can be found in TS 38.410 [16].

### 4.3.2 Xn Interface

#### 4.3.2.1 Xn User Plane

The Xn User plane (Xn-U) interface is defined between two NG-RAN nodes. The user plane protocol stack on the Xn interface is shown in Figure 4.3.2.1-1. The transport network layer is built on IP transport and GTP-U is used on top of UDP/IP to carry the user plane PDUs.



Figure 4.3.2.1-1: Xn-U Protocol Stack

Xn-U provides non-guaranteed delivery of user plane PDUs and supports the following functions:

- Data forwarding;

- Flow control.

Further details of Xn-U can be found in TS 38.420 [17].

#### 4.3.2.2 Xn Control Plane

The Xn control plane interface (Xn-C) is defined between two NG-RAN nodes. The control plane protocol stack of the Xn interface is shown on Figure 4.3.2.2-1. The transport network layer is built on SCTP on top of IP. The application layer signalling protocol is referred to as XnAP (Xn Application Protocol). The SCTP layer provides the guaranteed delivery of application layer messages. In the transport IP layer point-to-point transmission is used to deliver the signalling PDUs.



Figure 4.3.2.2-1: Xn-C Protocol Stack

The Xn-C interface supports the following functions:

- Xn interface management;

- UE mobility management, including context transfer and RAN paging;

- Dual connectivity.

Further details of Xn-C can be found in TS 38.420 [17].

## 4.4 Radio Protocol Architecture

### 4.4.1 User Plane

The figure below shows the protocol stack for the user plane, where SDAP, PDCP, RLC and MAC sublayers (terminated in gNB on the network side) perform the functions listed in clause 6.



Figure 4.4.1-1: User Plane Protocol Stack

### 4.4.2 Control Plane

The figure below shows the protocol stack for the control plane, where:

- PDCP, RLC and MAC sublayers (terminated in gNB on the network side) perform the functions listed in clause 6;

- RRC (terminated in gNB on the network side) performs the functions listed in clause 7;

- NAS control protocol (terminated in AMF on the network side) performs the functions listed in TS 23.501 [3]), for instance: authentication, mobility management, security control…



Figure 4.4.2-1: Control Plane Protocol Stack

## 4.5 Multi-Radio Dual Connectivity

NG-RAN supports Multi-Radio Dual Connectivity (MR-DC) operation whereby a UE in RRC\_CONNECTED is configured to utilise radio resources provided by two distinct schedulers, located in two different NG-RAN nodes connected via a non-ideal backhaul, one providing NR access and the other one providing either E-UTRA or NR access. Further details of MR-DC operation, including Conditional PSCell Addition (CPA) and Conditional PSCell Change (CPC), can be found in TS 37.340 [21].

## 4.6 Radio Access Network Sharing

NG-RAN supports radio access network sharing as defined in TS 23.501 [3].

If NR access is shared, system information broadcast in a shared cell indicates a TAC and a Cell Identity for each subset of PLMNs, PNI-NPNs and SNPNs. NR access provides only one TAC and one Cell Identity per cell per PLMN, SNPN or PNI-NPN. In this version of the specification, a Cell Identity can only belong to one network type among PLMN, PNI-NPN or SNPN as defined in TS 23.501 [3].

Each Cell Identity associated with a subset of PLMNs, SNPNs or PNI-NPNs identifies its serving NG-RAN node.

*Unchanged Text is omitted*

# 5 Physical Layer

## 5.1 Waveform, numerology and frame structure

The downlink transmission waveform is conventional OFDM using a Cyclic Prefix. The uplink transmission waveform is conventional OFDM using a CP with a transform precoding function performing DFT spreading that can be disabled or enabled. For operation with shared spectrum channel access in FR1, the uplink transmission waveform subcarrier mapping can map to subcarriers in one or more PRB interlaces.



Figure 5.1-1: Transmitter block diagram for CP-OFDM with optional DFT-spreading

The numerology is based on exponentially scalable sub-carrier spacing *Δf* = 2*µ* × 15 kHz with *µ*={0,1,3,4,5,6} for PSS, SSS and PBCH and *µ*={0,1,2,3,5,6} for other channels. Normal CP is supported for all sub-carrier spacings, Extended CP is supported for *µ*=2. 12 consecutive sub-carriers form a Physical Resource Block (PRB). Up to 275 PRBs are supported on a carrier.

Table 5.1-1: Supported transmission numerologies.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | CP | Supported for data | Supported for synch |
| 0 | 15 | Normal | Yes | Yes |
| 1 | 30 | Normal | Yes | Yes |
| 2 | 60 | Normal, Extended | Yes | No |
| 3 | 120 | Normal | Yes | Yes |
| 4 | 240 | Normal | No | Yes |
| 5 | 480 | Normal | Yes | Yes |
| 6 | 960 | Normal | Yes | Yes |

The UE may be configured with one or more bandwidth parts on a given component carrier, of which only one can be active at a time, as described in clauses 7.8 and 6.10 respectively. The active bandwidth part defines the UE's operating bandwidth within the cell's operating bandwidth. For initial access, and until the UE's configuration in a cell is received, initial bandwidth part detected from system information is used.

Downlink and uplink transmissions are organized into frames with 10 ms duration, consisting of ten 1 ms subframes. Each frame is divided into two equally-sized half-frames of five subframes each. The slot duration is 14 symbols with Normal CP and 12 symbols with Extended CP, and scales in time as a function of the used sub-carrier spacing so that there is always an integer number of slots in a subframe.

Timing Advance *TA* is used to adjust the uplink frame timing relative to the downlink frame timing.



Figure 5.1-2: Uplink-downlink timing relation

Operation on both paired and unpaired spectrum is supported.

## 5.2 Downlink

### 5.2.1 Downlink transmission scheme

Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8, 12, 16 and 24 orthogonal DL DMRS ports are supported for type 1, type 2, enhanced type 1, and enhanced type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions.

The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG).

Transmission durations from 2 to 14 symbols in a slot is supported.

Aggregation of multiple slots with Transport Block (TB) repetition is supported.

### 5.2.2 Physical-layer processing for physical downlink shared channel

The downlink physical-layer processing of transport channels consists of the following steps:

- Transport block CRC attachment;

- Code block segmentation and code block CRC attachment;

- Channel coding: LDPC coding;

- Physical-layer hybrid-ARQ processing;

- Rate matching;

- Scrambling;

- Modulation: QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM;

- Layer mapping;

- Mapping to assigned resources and antenna ports.

The UE may assume that at least one symbol with demodulation reference signal is present on each layer in which PDSCH is transmitted to a UE, and up to 3 additional DMRS can be configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

The DL-SCH physical layer model is described in TS 38.202 [20].

### 5.2.3 Physical downlink control channels

The Physical Downlink Control Channel (PDCCH) can be used to schedule DL transmissions on PDSCH and UL transmissions on PUSCH, where the Downlink Control Information (DCI) on PDCCH includes:

- Downlink assignments containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to DL-SCH;

- Uplink scheduling grants containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to UL-SCH.

In addition to scheduling, PDCCH can be used to for:

- Activation and deactivation of configured PUSCH transmission with configured grant;

- Activation and deactivation of PDSCH semi-persistent transmission;

- Notifying one or more UEs of the slot format;

- Notifying one or more UEs of the PRB(s) and OFDM symbol(s) where the UE may assume no transmission is intended for the UE;

- Transmission of TPC commands for PUCCH and PUSCH;

- Transmission of one or more TPC commands for SRS transmissions by one or more UEs;

- Switching a UE's active bandwidth part;

- Initiating a random access procedure;

- Indicating the UE(s) to monitor the PDCCH during the next occurrence of the DRX on-duration;

- In IAB context, indicating the availability for soft symbols of an IAB-DU;

- Triggering one shot HARQ-ACK codebook feedback;

- For operation with shared spectrum channel access:

- Triggering search space set group switching;

- Indicating one or more UEs about the available RB sets and channel occupancy time duration;

- Indicating downlink feedback information for configured grant PUSCH (CG-DFI).

A UE monitors a set of PDCCH candidates in the configured monitoring occasions in one or more configured COntrol REsource SETs (CORESETs) according to the corresponding search space configurations.

A CORESET consists of a set of PRBs with a time duration of 1 to 3 OFDM symbols. The resource units Resource Element Groups (REGs) and Control Channel Elements (CCEs) are defined within a CORESET with each CCE consisting a set of REGs. Control channels are formed by aggregation of CCE. Different code rates for the control channels are realized by aggregating different number of CCE. Interleaved and non-interleaved CCE-to-REG mapping are supported in a CORESET.

The PDCCH repetition is operated by using two search spaces which are explicitly linked by configuration provided by the RRC layer, and are associated with corresponding CORESETs. For PDCCH repetition, two linked search spaces are configured with the same number of candidates, and two PDCCH candidates in two search spaces are linked with the same candidate index. When PDCCH repetition is scheduled to a UE, an intra-slot repetition is allowed and each repetition has the same number of CCEs and coded bits, and corresponds to the same DCI payload.

Polar coding is used for PDCCH.

Each resource element group carrying PDCCH carries its own DMRS.

QPSK modulation is used for PDCCH.

### 5.2.4 Synchronization signal and PBCH block

The Synchronization Signal and PBCH block (SSB) consists of primary and secondary synchronization signals (PSS, SSS), each occupying 1 symbol and 127 subcarriers, and PBCH spanning across 3 OFDM symbols and 240 subcarriers, but on one symbol leaving an unused part in the middle for SSS as show in Figure 5.2.4-1. For the 3 MHz channel bandwidth, the PBCH is further equally punctured from both edges to span 144 subcarriers. The possible time locations of SSBs within a half-frame are determined by sub-carrier spacing and the periodicity of the half-frames where SSBs are transmitted is configured by the network. During a half-frame, different SSBs may be transmitted in different spatial directions (i.e. using different beams, spanning the coverage area of a cell).

Within the frequency span of a carrier, multiple SSBs can be transmitted. The PCIs of SSBs transmitted in different frequency locations do not have to be unique, i.e. different SSBs in the frequency domain can have different PCIs. However, when an SSB is associated with an RMSI, the SSB is referred to as a Cell-Defining SSB (CD-SSB). A PCell is always associated to a CD-SSB located on the synchronization raster.

When an SSB is not associated with an RMSI, the SSB is referred to as a non-Cell Defining SSB (NCD-SSB), which can be used to perform RLM, BFD, and RRM measurements and measurements for RA resource selection inside the active DL BWP when the active BWP does not contain the CD-SSB. A UE may be configured with multiple SSBs provided that each BWP is configured with at most one SSB (CD-SSB or NCD-SSB).



Figure 5.2.4-1: Time-frequency structure of SSB

Polar coding is used for PBCH.

The UE may assume a band-specific sub-carrier spacing for the SSB unless a network has configured the UE to assume a different sub-carrier spacing.

PBCH symbols carry its own frequency-multiplexed DMRS.

QPSK modulation is used for PBCH.

The PBCH physical layer model is described in TS 38.202 [20].

Editor’s note: FFS if any changes in this section are needed for OD-SIB1, OD-SSB and SSB adaptation.

### 5.2.5 Physical layer procedures

#### 5.2.5.1 Link adaptation

Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one transmission duration and within a MIMO codeword.

For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation.

#### 5.2.5.2 Power Control

Downlink power control can be used.

#### 5.2.5.3 Cell search

Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the Cell ID of that cell. NR cell search is based on the primary and secondary synchronization signals, and PBCH DMRS, located on the synchronization raster.

#### 5.2.5.4 HARQ

Asynchronous Incremental Redundancy Hybrid ARQ is supported. The gNB provides the UE with the HARQ-ACK feedback timing either dynamically in the DCI or semi-statically in an RRC configuration. Retransmission of HARQ-ACK feedback is supported by using enhanced dynamic codebook and/or one-shot triggering of HARQ-ACK transmission for (i) all configured CCs and HARQ processes in the PUCCH group, (ii) a configured subset of CCs and/or HARQ processes in the PUCCH group, or (iii) a dynamically indicated HARQ-ACK feedback instance. For HARQ-ACK of SPS PDSCH without associated PDCCH, in case of HARQ-ACK dropping due to TDD specific collisions, the HARQ-ACK feedback can be deferred to a next available PUCCH transmission occasion.

The UE may be configured to receive code block group based transmissions where retransmissions may be scheduled to carry a sub-set of all the code blocks of a TB.

#### 5.2.5.5 Reception of SIB1

The Master Information Block (MIB) on PBCH provides the UE with parameters (e.g. CORESET#0 configuration) for monitoring of PDCCH for scheduling PDSCH that carries the System Information Block 1 (SIB1). PBCH may also indicate that there is no associated SIB1, in which case the UE may be pointed to another frequency from where to search for an SSB that is associated with a SIB1 as well as a frequency range where the UE may assume no SSB associated with SIB1 is present. The indicated frequency range is confined within a contiguous spectrum allocation of the same operator in which SSB is detected. MIB on PBCH may also indicate that SIB1 is not being broadcasted, in which case the UE may transmit OD-SIB1 request if it has a valid UL-WUS configuration for this cell.

Editor’s note: FFS if any additional changes in this section are needed for OD-SIB1.

### 5.2.6 Downlink Reference Signals and Measurements for Positioning

The DL Positioning Reference Signals (DL PRS) are defined to facilitate support of different positioning methods such as DL-TDOA, DL-AoD, multi-RTT through the following set of UE measurements DL RSTD, DL PRS-RSRP/DL PRS-RSRPP, and UE Rx-Tx time difference respectively as described in TS 38.305 [42]. The DL PRS also facilitates Carrier Phase Positioning measurements such as DL-RSCP and DL-RSCPD as described in TS 38.305 [42].

Besides DL PRS signals, UE can use SSB and CSI-RS for RRM (RSRP and RSRQ) measurements for E-CID type of positioning.

## 5.3 Uplink

### 5.3.1 Uplink transmission scheme

Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission.

For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI.

DMRS based spatial multiplexing is supported for PUSCH. Up to 8, 12, 16, and 24 orthogonal UL DMRS ports are supported for type 1, type 2, enhanced type 1, and enhanced type 2 DMRS respectively. For a given UE, up to 4 or up to 8 layer transmissions are supported. The number of code words is one for 1 to 4 layer transmission and two for 5 to 8 layer transmission. When transform precoding is used, only a single MIMO layer transmission is supported.

Transmission durations from 1 to 14 symbols in a slot is supported.

Aggregation of multiple slots with TB repetition is supported.

Two types of frequency hopping are supported, intra-slot frequency hopping, and in case of slot aggregation, inter-slot frequency hopping. Intra-slot and inter-slot frequency hopping are not supported when PRB interlace uplink transmission waveform is used.

PUSCH may be scheduled with DCI on PDCCH, or a semi-static configured grant may be provided over RRC, where two types of operation are supported:

- The first PUSCH is triggered with a DCI, with subsequent PUSCH transmissions following the RRC configuration and scheduling received on the DCI, or

- The PUSCH is triggered by data arrival to the UE's transmit buffer and the PUSCH transmissions follow the RRC configuration.

### 5.3.2 Physical-layer processing for physical uplink shared channel

The uplink physical-layer processing of transport channels consists of the following steps:

- Transport Block CRC attachment;

- Code block segmentation and Code Block CRC attachment;

- Channel coding: LDPC coding;

- Physical-layer hybrid-ARQ processing;

- Rate matching;

- Scrambling;

- Modulation: π/2 BPSK (with transform precoding only), QPSK, 16QAM, 64QAM and 256QAM;

- Layer mapping, transform precoding (enabled/disabled by configuration), and pre-coding;

- Mapping to assigned resources and antenna ports.

The UE transmits at least one symbol with demodulation reference signal on each layer on each frequency hop in which the PUSCH is transmitted, and up to 3 additional DMRS can be configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

The UL-SCH physical layer model is described in TS 38.202 [20].

For configured grants operation with shared spectrum channel access, described in clause 10.3, a CG-UCI (Configured Grant Uplink Control Information) can be transmitted in PUSCH scheduled by configured uplink grant.

### 5.3.3 Physical uplink control channel

Physical uplink control channel (PUCCH) carries the Uplink Control Information (UCI) from the UE to the gNB. Five formats of PUCCH exist, depending on the duration of PUCCH and the UCI payload size:

- Format #0: Short PUCCH of 1 or 2 symbols with small UCI payloads of up to two bits with UE multiplexing capacity of up to 6 UEs with 1-bit payload in the same PRB;

- Format #1: Long PUCCH of 4-14 symbols with small UCI payloads of up to two bits with UE multiplexing capacity of up to 84 UEs without frequency hopping and 36 UEs with frequency hopping in the same PRB;

- Format #2: Short PUCCH of 1 or 2 symbols with large UCI payloads of more than two bits with no UE multiplexing capability in the same PRBs;

- Format #3: Long PUCCH of 4-14 symbols with large UCI payloads with no UE multiplexing capability in the same PRBs;

- Format #4: Long PUCCH of 4-14 symbols with moderate UCI payloads with multiplexing capacity of up to 4 UEs in the same PRBs.

The short PUCCH format of up to two UCI bits is based on sequence selection, while the short PUCCH format of more than two UCI bits frequency multiplexes UCI and DMRS. The long PUCCH formats time-multiplex the UCI and DMRS. Frequency hopping is supported for long PUCCH formats and for short PUCCH formats of duration of 2 symbols. Short and long PUCCH formats can be repeated over multiple slots or sub-slots, where the repetition factor is either indicated dynamically in the DCI or semi-statically in an RRC configuration.

For operation with shared spectrum channel access in FR1, PUCCH Format #0, #1, #2, #3 are extended to use resource in one PRB interlace (up to two interlaces for Format #2 and Format #3) in one RB Set. PUCCH Format #2 and #3 are enhanced to support multiplexing capacity of up to 4 UEs in the same PRB interlace when one interlace is used.

For operation in FR2-2, PUCCH Format #0, #1, #4 are extended to use resource in configurable number of continuous PRBs, up to 16 PRBs.

Up to two PUCCH configurations can be configured for a UE per PUCCH group (see TS 38.331 [12]), where the first PUCCH configuration is associated with a PUCCH of priority index 0 (low) and the second PUCCH configuration is associated with a PUCCH of priority index 1 (high).

UCI multiplexing in PUCCH is supported when PUCCH transmissions of UCIs coincide in time, and are associated with the same priority (high/low). In addition, multiplexing of HARQ-ACK of priority index 0 (low) and UCI of priority index 1 (high) in PUCCH of priority index 1 (high) is supported when PUCCH transmissions of HARQ-ACK of priority index 0 and UCI of priority index 1 (high) coincide in time.

UCI multiplexing in PUSCH is supported when UCI and PUSCH transmissions coincide in time, either due to transmission of a UL-SCH transport block or due to triggering of A-CSI transmission without UL-SCH transport block, and are associated with the same priority (high/low). In addition, HARQ-ACK multiplexing of a certain priority in PUSCH of a different priority is supported when HARQ-ACK and PUSCH transmissions coincide in time, either due to transmission of a UL-SCH transport block or due to triggering of A-CSI transmission without UL-SCH transport block:

- UCI carrying HARQ-ACK feedback with 1 or 2 bits is multiplexed by puncturing PUSCH;

- In all other cases UCI is multiplexed by rate matching PUSCH.

UCI consists of the following information:

- CSI;

- ACK/NAK;

- Scheduling request.

Simultaneous transmission of PUCCH and PUSCH associated with different priorities on cells of different bands in a PUCCH group is supported, where UCI multiplexing in the PUCCH associated with a priority in combination of UCI multiplexing in a PUSCH associated with a different priority is supported if the UCI multiplexed on PUSCH is of same priority as the PUSCH.

Simultaneous transmission of PUCCH and PUSCH associated with same priority on cells of different bands in a PUCCH group is supported (see clause 9 of TS 38.213 [38]).

For operation with shared spectrum channel access, multiplexing of CG-UCI and PUCCH carrying HARQ-ACK feedback can be configured by the gNB. If not configured, when PUCCH overlaps with PUSCH scheduled by a configured grant within a PUCCH group and PUCCH carries HARQ ACK feedback, PUSCH scheduled by configured grant is skipped.

QPSK and π/2 BPSK modulation can be used for long PUCCH with more than 2 bits of information, QPSK is used for short PUCCH with more than 2 bits of information and BPSK and QPSK modulation can be used for long PUCCH with up to 2 information bits.

Transform precoding is applied to PUCCH Format #3 and Format #4.

Channel coding used for uplink control information is described in table 5.3.3-1.

Table 5.3.3-1: Channel coding for uplink control information

|  |  |
| --- | --- |
| Uplink Control Information size including CRC, if present | Channel code |
| 1 | Repetition code |
| 2 | Simplex code |
| 3-11 | Reed Muller code |
| >11 | Polar code |

### 5.3.4 Random access

Random access preamble sequences, of four different lengths are supported. Sequence length 839 is applied with subcarrier spacings of 1.25 and 5 kHz, sequence length 139 is applied with subcarrier spacings of 15, 30, 60, 120, 480, and 960 kHz, sequence length of 571 is applied with subcarrier spacings of 30, 120, and 480 kHz, and sequence length 1151 is applied with subcarrier spacings of 15 and 120 kHz. Sequence length 839 supports unrestricted sets and restricted sets of Type A and Type B, while sequence lengths 139, 571, and 1151 support unrestricted sets only. Sequence length 839 is only used for operation with licensed channel access while sequence length 139 can be used for operation with either licensed or shared spectrum channel access. For FR1, sequence lengths of 571 and 1151 can be used only for operation with shared spectrum channel access. For FR2-2, sequence lengths of 571 can be used for operation with either licensed or shared spectrum channel access only with subcarrier spacings of 120 kHz and 480 kHz and sequence lengths of 1151 can be used for operation with either licensed or shared spectrum channel access only with subcarrier spacings of 120 kHz.

Multiple PRACH preamble formats are defined with one or more PRACH OFDM symbols, and different CP and guard time. The PRACH preamble configuration to use is provided to the UE in the system information.

For IAB additional random access configurations are defined. These configurations are obtained by extending the random access configurations defined for UEs via scaling the periodicity and/or offsetting the time domain position of the RACH occasions.

IAB-MTs can be provided with random access configurations (as defined for UEs or after applying the aforementioned scaling/offsetting) different from random access configurations provided to UEs.

The UE calculates the PRACH transmit power for the retransmission of the preamble based on the most recent estimate pathloss and power ramping counter.

The system information provides information for the UE to determine the association between the SSB and the RACH resources. The RSRP threshold for SSB selection for RACH resource association is configurable by network.

### 5.3.5 Physical layer procedures

#### 5.3.5.1 Link adaptation

Four types of link adaptation are supported as follows:

- Adaptive transmission bandwidth;

- Adaptive transmission duration;

- Transmission power control;

- Adaptive modulation and channel coding rate.

For channel state estimation purposes, the UE may be configured to transmit SRS that the gNB may use to estimate the uplink channel state and use the estimate in link adaptation.

#### 5.3.5.2 Uplink Power control

The gNB determines the desired uplink transmit power and provides uplink transmit power control commands to the UE. The UE uses the provided uplink transmit power control commands to adjust its transmit power.

#### 5.3.5.3 Uplink timing control

The gNB (including IAB-DU and IAB-donor-DU) determines the desired Timing Advance setting and provides that to the UE (or IAB-MT). The UE/IAB-MT uses the provided TA to determine its uplink transmit timing relative to the UE's/IAB-MTs observed downlink receive timing.

An IAB-node may support additional modes for uplink timing:

- The IAB-MT uses the provided TA plus a provided additional offset to determine its uplink transmission timing, to facilitate parent node's IAB-MT Rx / IAB-DU Rx multiplexing;

- The IAB-MT aligns its uplink transmission timing to that of the collocated IAB-DU downlink transmission timing, to facilitate IAB-MT Tx / IAB-DU Tx multiplexing of this IAB-node.

The IAB-node uplink timing mode is indicated by the parent node via MAC-CE.

#### 5.3.5.4 HARQ

Asynchronous Incremental Redundancy Hybrid ARQ is supported. The gNB schedules each uplink transmission and retransmission using the uplink grant on DCI. For operation with shared spectrum channel access, UE can also retransmit on configured grants if configured.

The UE may be configured to transmit code block group based transmissions where retransmissions may be scheduled to carry a sub-set of all the code blocks of a transport block.

Up to two HARQ-ACK codebooks corresponding to a priority (high/low) can be constructed simultaneously. For each HARQ-ACK codebook, more than one PUCCH for HARQ-ACK transmission within a slot is supported. Each PUCCH is limited within one sub-slot, and the sub-slot pattern is configured per HARQ-ACK codebook.

#### 5.3.5.5 Prioritization of overlapping transmissions

PUSCH and PUCCH can be associated with a priority (high/low) by RRC or L1 signalling. If a PUCCH transmission overlaps in time with a transmission of a PUSCH or another PUCCH, only the PUCCH or PUSCH associated with a high priority can be transmitted.

### 5.3.6 Uplink Reference Signals and Measurements for Positioning

The periodic, semipersistent and aperiodic transmission of Rel-15 SRS is defined for gNB UL RTOA, UL SRS-RSRP, UL-AoA measurements to facilitate support of UL TDOA and UL AoA positioning methods as described in TS 38.305 [42].

The periodic, semipersistent and aperiodic transmission of SRS for positioning is defined for gNB UL RTOA, UL SRS-RSRP/UL-SRS-RSRPP, UL-AoA, gNB Rx-Tx time difference measurements to facilitate support of UL TDOA, UL AoA and multi-RTT positioning methods as described in TS 38.305 [42]. Carrier phase positioning measurement UL-RSCP can be used by UL TDOA or multi-RTT positioning methods as described in TS 38.305 [42].

## 5.4 Carrier aggregation

### 5.4.1 Carrier aggregation

In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities:

- A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG);

- A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell;

- A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG).

CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE.

### 5.4.2 Supplementary Uplink

In conjunction with a UL/DL carrier pair (FDD band) or a bidirectional carrier (TDD band), a UE may be configured with additional, Supplementary Uplink (SUL). SUL differs from the aggregated uplink in that the UE may be scheduled to transmit either on the supplementary uplink or on the uplink of the carrier being supplemented, but not on both at the same time.

### 5.4.3 Uplink Tx switching

In uplink CA or SUL, a UE configured with uplink Tx switching can have Tx chain(s) dynamically switched from one uplink band or two uplink bands to another uplink band or two uplink bands for enabling up to 2Tx UL transmission in one uplink band or simultaneous UL transmissions in two uplink bands at a time.

## 5.5 Transport Channels

The physical layer offers information transfer services to MAC and higher layers. The physical layer transport services are described by *how* and with what characteristics data are transferred over the radio interface. An adequate term for this is "Transport Channel". This should be clearly separated from the classification of *what* is transported, which relates to the concept of logical channels at MAC sublayer.

Downlink transport channel types are:

1. **Broadcast Channel (BCH)** characterised by:

- fixed, pre-defined transport format;

- requirement to be broadcast in the entire coverage area of the cell, either as a single message or by beamforming different BCH instances.

2. **Downlink Shared Channel (DL-SCH)** characterised by:

- support for HARQ;

- support for dynamic link adaptation by varying the modulation, coding and transmit power;

- possibility to be broadcast in the entire cell;

- possibility to use beamforming;

- support for both dynamic and semi-static resource allocation;

- support for UE discontinuous reception (DRX) to enable UE power saving.

3. **Paging Channel (PCH)** characterised by:

- support for UE discontinuous reception (DRX) to enable UE power saving (DRX cycle is indicated by the network to the UE);

- requirement to be broadcast in the entire coverage area of the cell, either as a single message or by beamforming different PCH instances;

- mapped to physical resources which can be used dynamically also for traffic/other control channels.

Uplink transport channel types are:

1. **Uplink Shared Channel (UL-SCH)** characterised by:

- possibility to use beamforming;

- support for dynamic link adaptation by varying the transmit power and potentially modulation and coding;

- support for HARQ;

- support for both dynamic and semi-static resource allocation.

2. **Random Access Channel(s) (RACH)** characterised by:

- limited control information;

- collision risk.

Sidelink transport channel types are:

1. **Sidelink broadcast channel (SL-BCH)** characterised by:

- pre-defined transport format.

2. **Sidelink shared channel (SL-SCH)** characterised by:

- support for unicast transmission, groupcast transmission and broadcast transmission;

- support for both UE autonomous resource selection and scheduled resource allocation by NG-RAN;

- support for both dynamic and semi-static resource allocation when UE is allocated resources by the NG-RAN;

- support for HARQ;

- support for dynamic link adaptation by varying the transmit power, modulation and coding;

- support for SL discontinuous reception (SL DRX) to enable UE power saving.

Association of transport channels to physical channels is described in TS 38.202 [20].

## 5.6 Access to Shared Spectrum

### 5.6.1 Overview

NR Radio Access operating with shared spectrum channel access can operate in different modes where either PCell, PSCell, or SCells can be in shared spectrum and an SCell may or may not be configured with uplink. The applicable deployment scenarios are described in Annex B.3.

The gNB performs channel access mode procedures as described in TS 37.213 [37]. The gNB and the UE may apply Listen-Before-Talk (LBT) before performing a transmission on a cell configured with shared spectrum channel access. When LBT is applied, the transmitter listens to/senses the channel to determine whether the channel is free or busy and performs transmission only if the channel is sensed free.

When the UE detects consistent uplink LBT failures, it takes actions as specified in TS 38.321 [6]. The detection is per Bandwidth Part (BWP) and based on all uplink transmissions within this BWP. When consistent uplink LBT failures are detected on SCell(s), the UE reports this to the corresponding gNB (MN for MCG, SN for SCG) via MAC CE on a different serving cell than the SCell(s) where the failures were detected. If no resources are available to transmit the MAC CE, a Scheduling Request (SR) can be transmitted by the UE. When consistent uplink LBT failures are detected on SpCell, the UE switches to another UL BWP with configured RACH resources on that cell, initiates RACH, and reports the failure via MAC CE. When multiple UL BWPs are available for switching, it is up to the UE implementation which one to select. For PSCell, if consistent uplink LBT failures are detected on all the UL BWPs with configured RACH resources, the UE declares SCG RLF and reports the failure to the MN via *SCGFailureInformation.* For PCell, if the uplink LBT failures are detected on all the UL BWP(s) with configured RACH resources, the UE declares RLF.

### 5.6.2 Channel Access Priority Classes

The Channel Access Priority Classes (CAPC) of radio bearers and MAC CEs are either fixed or configurable for operation in FR1:

- Fixed to the lowest priority for the padding BSR and recommended bit rate MAC CEs;

- Fixed to the highest priority for SRB0, SRB1, SRB3 and other MAC CEs;

- Configured by the gNB for SRB2 and DRB.

When choosing the CAPC of a DRB, the gNB takes into account the 5QIs of all the QoS flows multiplexed in that DRB while considering fairness between different traffic types and transmissions. Table 5.6.2-1 below shows which CAPC should be used for which standardized 5QIs i.e. which CAPC to use for a given QoS flow.

NOTE: A QoS flow corresponding to a non-standardized 5QI (i.e. operator specific 5QI) should use the CAPC of the standardized 5QI which best matches the QoS characteristics of the non-standardized 5QI.

Table 5.6.2-1: Mapping between Channel Access Priority Classes and 5QI

|  |  |
| --- | --- |
| CAPC | 5QI |
| 1 | 1, 3, 5, 65, 66, 67, 69, 70, 79, 80, 82, 83, 84, 85 |
| 2 | 2, 7, 71 |
| 3 | 4, 6, 8, 9, 72, 73, 74, 76 |
| 4 | - |
| NOTE: lower CAPC value means higher priority  - | |

When performing Type 1 LBT for the transmission of an uplink TB (see TS 37.213 [37], clause 4.2.1.1) and when the CAPC is not indicated in the DCI, the UE shall select the CAPC as follows:

- If only MAC CE(s) are included in the TB, the highest priority CAPC of those MAC CE(s) is used; or

- If CCCH SDU(s) are included in the TB, the highest priority CAPC is used; or

- If DCCH SDU(s) are included in the TB, the highest priority CAPC of the DCCH(s) is used; or

- The lowest priority CAPC of the logical channel(s) with MAC SDU multiplexed in the TB is used otherwise.

*Unchanged Text is omitted*

# 6 Layer 2

## 6.1 Overview

The layer 2 of NR is split into the following sublayers: Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and Service Data Adaptation Protocol (SDAP). The two figures below depict the Layer 2 architecture for downlink and uplink, where:

- The physical layer offers to the MAC sublayer transport channels;

- The MAC sublayer offers to the RLC sublayer logical channels;

- The RLC sublayer offers to the PDCP sublayer RLC channels;

- The PDCP sublayer offers to the SDAP sublayer radio bearers;

- The SDAP sublayer offers to 5GC QoS flows;

- *Comp.* refers to header compression or uplink data compression;

- *Segm.* refers to segmentation;

- Control channels (BCCH, PCCH are not depicted for clarity).

NOTE: The gNB may not be able to guarantee that a L2 buffer overflow will never occur. If such overflow occurs, the UE may discard packets in the L2 buffer.



Figure 6.1-1: Downlink Layer 2 Structure



Figure 6.1-2: Uplink Layer 2 Structure

Radio bearers are categorized into two groups: data radio bearers (DRB) for user plane data and signalling radio bearers (SRB) for control plane data.

For IAB, the Layer 2 of NR includes: MAC, RLC, Backhaul Adaptation Protocol (BAP), PDCP and optionally SDAP. The BAP sublayer supports routing across the IAB topology and traffic mapping to BH RLC channels for enforcement of traffic prioritization and QoS.

Figures 6.1-3 below depicts the Layer-2 architecture for downlink on the IAB-donor. Figures 6.1-4 and 6.1-5 depict the Layer-2 architecture for downlink and uplink on the IAB-node, where the BAP sublayer offers routing functionality and mapping to BH RLC channels.



Figure 6.1-3: DL L2-structure for user plane at IAB-donor



Figure 6.1-4: DL L2-structure at IAB-node



Figure 6.1-5: UL L2-structure at IAB-node

## 6.2 MAC Sublayer

### 6.2.1 Services and Functions

The main services and functions of the MAC sublayer include:

- Mapping between logical channels and transport channels;

- Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels;

- Scheduling information reporting;

- Error correction through HARQ (one HARQ entity per cell in case of CA);

- Priority handling between UEs by means of dynamic scheduling;

- Priority handling between logical channels of one UE by means of logical channel prioritisation;

- Priority handling between overlapping resources of one UE;

- Padding.

A single MAC entity can support multiple numerologies, transmission timings and cells. Mapping restrictions in logical channel prioritisation control which numerology(ies), cell(s), and transmission timing(s) a logical channel can use (see clause 16.1.2).

### 6.2.2 Logical Channels

Different kinds of data transfer services as offered by MAC. Each logical channel type is defined by what type of information is transferred. Logical channels are classified into two groups: Control Channels and Traffic Channels. Control channels are used for the transfer of control plane information only:

- Broadcast Control Channel (BCCH): a downlink channel for broadcasting system control information.

- Paging Control Channel (PCCH): a downlink channel that carries paging messages.

- Common Control Channel (CCCH): channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network.

- Dedicated Control Channel (DCCH): a point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.

Traffic channels are used for the transfer of user plane information only:

**-** Dedicated Traffic Channel (DTCH): point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

### 6.2.3 Mapping to Transport Channels

In Downlink, the following connections between logical channels and transport channels exist:

- BCCH can be mapped to BCH;

- BCCH can be mapped to DL-SCH;

- PCCH can be mapped to PCH;

- CCCH can be mapped to DL-SCH;

- DCCH can be mapped to DL-SCH;

- DTCH can be mapped to DL-SCH.

In Uplink, the following connections between logical channels and transport channels exist:

- CCCH can be mapped to UL-SCH;

- DCCH can be mapped to UL- SCH;

- DTCH can be mapped to UL-SCH.

### 6.2.4 HARQ

The HARQ functionality ensures delivery between peer entities at Layer 1. A single HARQ process supports one TB when the physical layer is not configured for downlink/uplink spatial multiplexing, and when the physical layer is configured for downlink/uplink spatial multiplexing, a single HARQ process supports one or multiple TBs.

## 6.3 RLC Sublayer

### 6.3.1 Transmission Modes

The RLC sublayer supports three transmission modes:

- Transparent Mode (TM);

- Unacknowledged Mode (UM);

- Acknowledged Mode (AM).

The RLC configuration is per logical channel with no dependency on numerologies and/or transmission durations, and ARQ can operate on any of the numerologies and/or transmission durations the logical channel is configured with.

For SRB0, paging and broadcast system information, TM mode is used. For other SRBs AM mode used. For DRBs, either UM or AM mode are used.

### 6.3.2 Services and Functions

The main services and functions of the RLC sublayer depend on the transmission mode and include:

- Transfer of upper layer PDUs;

- Sequence numbering independent of the one in PDCP (UM and AM);

- Error Correction through ARQ (AM only);

- Segmentation (AM and UM) and re-segmentation (AM only) of RLC SDUs;

- Reassembly of SDU (AM and UM);

- Duplicate Detection (AM only);

- RLC SDU discard (AM and UM);

- RLC re-establishment;

- Protocol error detection (AM only).

### 6.3.3 ARQ

The ARQ within the RLC sublayer has the following characteristics:

- ARQ retransmits RLC SDUs or RLC SDU segments based on RLC status reports;

- Polling for RLC status report is used when needed by RLC;

- RLC receiver can also trigger RLC status report after detecting a missing RLC SDU or RLC SDU segment.

## 6.4 PDCP Sublayer

### 6.4.1 Services and Functions

The main services and functions of the PDCP sublayer include:

- Transfer of data (user plane or control plane);

- Maintenance of PDCP SNs;

- Header compression and decompression using the ROHC protocol;

- Header compression and decompression using EHC protocol;

- Compression and decompression of uplink PDCP SDUs: DEFLATE based UDC only;

- Ciphering and deciphering;

- Integrity protection and integrity verification;

- Timer based SDU discard;

- For split bearers, routing;

- Duplication;

- Reordering and in-order delivery;

- Out-of-order delivery;

- Duplicate discarding.

Since PDCP does not allow COUNT to wrap around in DL and UL, it is up to the network to prevent it from happening (e.g. by using a release and add of the corresponding radio bearer or a full configuration).

## 6.5 SDAP Sublayer

The main services and functions of SDAP include:

- Mapping between a QoS flow and a data radio bearer;

NOTE: When remapping an XR QoS flow carrying PDU sets (see clause 16.15) from one DRB to another (as exemplified in Annex A), all SDAP SDUs belonging to a PDU Set should be mapped to the same DRB.

- Marking QoS flow ID (QFI) in both DL and UL packets.

A single protocol entity of SDAP is configured for each individual PDU session.

## 6.6 L2 Data Flow

An example of the Layer 2 Data Flow is depicted on Figure 6.6-1, where a transport block is generated by MAC by concatenating two RLC PDUs from RB*x* and one RLC PDU from RB*y*. The two RLC PDUs from RB*x* each corresponds to one IP packet (*n* and *n+1*) while the RLC PDU from RB*y* is a segment of an IP packet (*m*).

NOTE: H depicts the headers and subheaders.



Figure 6.6-1: Data Flow Example

## 6.7 Carrier Aggregation

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.



Figure 6.7-1: Layer 2 Structure for DL with CA configured



Figure 6.7-2: Layer 2 Structure for UL with CA configured

## 6.8 Dual Connectivity

When the UE is configured with SCG, the UE is configured with two MAC entities: one MAC entity for the MCG and one MAC entity for the SCG. Further details of DC operation can be found in TS 37.340 [21].

## 6.9 Supplementary Uplink

In case of Supplementary Uplink (SUL, see TS 38.101-1 [18]), the UE is configured with 2 ULs for one DL of the same cell, and uplink transmissions on those two ULs are controlled by the network to avoid overlapping PUSCH/PUCCH transmissions in time. Overlapping transmissions on PUSCH are avoided through scheduling while overlapping transmissions on PUCCH are avoided through configuration (PUCCH can only be configured for only one of the 2 ULs of the cell). In addition, initial access is supported in each of the uplink (see clause 9.2.6). An example of SUL is given in Annex B.

## 6.10 Bandwidth Adaptation

With Bandwidth Adaptation (BA), the receive and transmit bandwidth of a UE need not be as large as the bandwidth of the cell and can be adjusted: the width can be ordered to change (e.g. to shrink during period of low activity to save power); the location can move in the frequency domain (e.g. to increase scheduling flexibility); and the subcarrier spacing can be ordered to change (e.g. to allow different services). A subset of the total cell bandwidth of a cell is referred to as a Bandwidth Part (BWP) and BA is achieved by configuring the UE with BWP(s) and telling the UE which of the configured BWPs is currently the active one.

Figure 6.10-1 below describes a scenario where 3 different BWPs are configured:

- BWP1 with a width of 40 MHz and subcarrier spacing of 15 kHz;

- BWP2 with a width of 10 MHz and subcarrier spacing of 15 kHz;

- BWP3 with a width of 20 MHz and subcarrier spacing of 60 kHz.



Figure 6.10-1: BA Example

## 6.11 Backhaul Adaptation Protocol Sublayer

### 6.11.1 Services and Functions

The main service and functions of the BAP sublayer include:

- Transfer of data;

- Routing of packets to next hop;

- Determination of BAP destination and BAP path for packets from upper layers;

- Determination of egress BH RLC channels for packets routed to next hop;

- Differentiating traffic to be delivered to upper layers from traffic to be delivered to egress link;

- Flow control feedback and polling signalling;

- BH RLF detection indication, BH RLF recovery indication, and BH RLF indication;

- BAP header rewriting.

### 6.11.2 Traffic Mapping from Upper Layers to Layer-2

In upstream direction, the IAB-donor-CU configures the IAB-node with mappings between upstream F1 and non-F1 traffic originated at the IAB-node, and the appropriate BAP routing ID, next-hop BAP address and BH RLC channel. A specific mapping is configured:

- for each F1-U GTP-U tunnel;

- for non-UE associated F1AP messages;

- for UE-associated F1AP messages;

- for non-F1 traffic.

Multiple mappings can contain the same BH RLC channel and/or next-hop BAP address and/or BAP routing ID. In case the IAB-MT is NR-dual-connected (SA mode only), the mapping may include two separate BH RLC channels, where the two BH RLC channels are established toward different parent nodes.

In case the IAB-node is configured with multiple IP addresses for F1-C on the NR leg, multiple mappings can be configured for non-UE-associated F1AP messages or UE-associated F1AP messages. The appropriate mapping is selected based on the IAB-node's implementation.

These traffic mapping configurations are performed via F1AP. For a boundary IAB-node, the traffic mapping configuration includes information that allows the boundary IAB-node to determine the IAB topology the mapping applies to.

During IAB-node integration, a default BH RLC channel and a default BAP routing ID may be configured via RRC, which can be used for non-F1-U traffic. These default configurations may be updated during topology adaptation scenarios as discussed in TS 38.401 [4].

In downstream direction, traffic mapping occurs internal to the IAB-donor. Transport for IAB-donors that use split-gNB architecture is handled in TS 38.401 [4].

### 6.11.3 Routing, BAP Header Rewriting and BH-RLC-channel Mapping on BAP sublayer



Figure 6.11.3-1: Routing and BH RLC channel selection on BAP sublayer

Routing on BAP sublayer uses the BAP routing ID, which is configured by the IAB-donor-CU. The BAP routing ID consists of BAP address and BAP path ID. The BAP address is used for the following purposes:

1. Determination if a packet has reached the destination node, i.e. IAB-node or IAB-donor-DU, on BAP sublayer. This is the case if the BAP address in the packet's BAP header matches the BAP address configured via RRC on the IAB-node, or via F1AP on the IAB-donor-DU. For a dual-connected boundary IAB-node that is configured with two BAP addresses, the BAP address in the packet's BAP header is matched with the BAP address configured by the CU of the IAB topology, where the packet has been received.

2. Determination of the next-hop node for packets that have not reached their destination. This applies to packets arriving from a prior hop on BAP sublayer or that have been received from IP layer.

For packets arriving from a prior hop or from upper layers, the determination of the next-hop node is based on a routing configuration provided by the IAB-donor-CU via F1AP signalling or a default configuration provided by the IAB-donor-CU via RRC signalling. This F1AP configuration contains the mapping between the BAP routing ID carried in the packet's BAP header and the next-hop node's BAP address.

Table 6.11.3-1: Routing configuration

|  |  |
| --- | --- |
| BAP routing ID | Next-hop BAP address |
| Derived from BAP packet's BAP header | Egress BH link to forward packet |

The IAB-node resolves the next-hop BAP address to a physical backhaul link. For this purpose, the IAB-donor-CU provides the IAB-node/IAB-donor-DU with its child-node's BAP address via F1AP, and it provides the IAB-node with its parent-node's BAP address via RRC. For a boundary IAB-node, the routing configuration also indicates the IAB topology it applies to. The BH link to the next-hop node and the next-hop BAP address belong to the IAB topology of the CU that provided the RRC configuration of the BH link to that next-hop node.

The IAB-node can receive multiple routing configurations with the same destination BAP address but different BAP path IDs. These routing configurations may resolve to the same or different egress BH links.

In case the BH link resolved from the routing entry is considered *unavailable* for this packet, the IAB-node may perform local rerouting as defined in TS 38.340 [31], i.e., select another BH link by considering only the packet's BAP address or, in some cases, by header rewriting. In this manner, the packet can be delivered via an alternative path as defined in TS 38.340 [31].

A BH link may be considered *unavailable* in case the BH link has RLF. A parent link may be considered *unavailable* after a BH RLF detection indication has been received on this parent link and before a subsequent BH RLF recovery indication has been received on the same parent link. For DL traffic, a BH link may be considered *unavailable* for BAP PDUs carrying a certain BAP routing ID due to congestion derived from flow-control feedback information related to this BAP routing ID, as defined in TS 38.340 [31].

For a boundary IAB-node, the routing configuration may carry information on the IAB topology the configuration applies to.

The IAB-node may rewrite the BAP routing ID in the packet's BAP header under the following circumstances:

- A packet is routed between two IAB topologies via a boundary IAB-node as defined in TS 38.401[31]. In this case, the BAP routing ID carried by the received BAP PDU is allocated by the IAB-donor-CU of the ingress IAB topology, while the BAP routing ID carried by the BAP PDU after header rewriting is allocated by the IAB-donor-CU of the egress IAB topology.

- An upstream packet is locally re-routed to a different IAB-donor-DU than indicated by the BAP address in the BAP header of the received packet. The rewritten BAP header carries the BAP address of the alternative IAB-donor-DU and the BAP path ID for a path to this alternative IAB-donor-DU. BAP header rewriting for upstream inter-IAB-donor-DU local rerouting is only applied if neither routing nor local re-routing without header rewriting resolve to an available egress BH link.

For packets that are routed between two IAB topologies via a boundary node, the BAP header rewriting configuration is provided via F1AP, and it includes the ingress BAP routing ID, the egress BAP routing ID, and it indicates the egress IAB topology:

Table 6.11.3-2a: BAP header rewriting configuration

|  |  |  |
| --- | --- | --- |
| Ingress BAP routing ID | Egress BAP routing ID | Egress topology indicator |
| BAP routing ID carried in the BAP header of the received BAP PDU | BAP routing ID carried in the BAP header of the transmitted BAP PDU | Indicates the egress IAB topology. |

For upstream packets that are locally re-routed to a different IAB-donor-DU, the BAP header is rewritten with a BAP routing ID contained in the routing entry that was selected for re-routing.

Details of BAP header rewriting are defined in TS 38.340 [31].

When routing a packet from an ingress to an egress BH link, the IAB-node derives the egress BH RLC channel on the egress BH link through an F1AP-configured mapping from the BH RLC channel used on the ingress BH link. The BH RLC channel IDs used for ingress and egress BH RLC channels are generated by the IAB-donor-CU. Since the BH RLC channel ID only has link-local scope, the mapping configurations also include the BAP addresses of prior and next hop:

Table 6.11.3-2: BH RLC channel mapping configuration

|  |  |  |  |
| --- | --- | --- | --- |
| Next-hop BAP address | Prior-hop BAP address | Ingress RLC channel ID | Egress RLC channel ID |
| Derived from routing configuration | Derived from packet's ingress BH link | Derived from packet's ingress BH RLC channel | BH RLC channel on egress BH link to forward packet |

For a boundary IAB-node, the BH RLC channel mapping configuration may also include indicators for the IAB topology of the ingress and of the egress BH link.

The IAB-node resolves the BH RLC channel IDs from logical channel IDs based on the configuration by the IAB-donor-CU. The IAB-MT obtains the BH RLC channel ID in the RRC configuration of the corresponding logical channel. The IAB-DU obtains the BH RLC channel ID in the F1AP configuration of the BH RLC channel.

## 6.12 Multiple Transmit/Receive Point Operation

In Multiple Transmit/Receive Point (multi-TRP) operation, a serving cell can schedule the UE from two TRPs, providing better coverage, reliability and/or data rates for PDSCH, PDCCH, PUSCH, and PUCCH.

There are two different operation modes to schedule multi-TRP PDSCH transmissions: single-DCI and multi-DCI. For both modes, control of uplink and downlink operation can be done by physical layer and MAC layer, within the configuration provided by the RRC layer. In single-DCI mode, the UE is scheduled by the same DCI for both TRPs and in multi-DCI mode, the UE is scheduled by independent DCIs from each TRP.

There are two different operation modes for multi-TRP PDCCH: PDCCH repetition as in Clause 5.2.3 and Single Frequency Network (SFN) based PDCCH transmission. In both modes, the UE can receive two PDCCH transmissions, one from each TRP, carrying the same DCI. In PDCCH repetition mode, the UE can receive the two PDCCH transmissions carrying the same DCI from two linked search spaces each associated with a different CORESET. In SFN based PDCCH transmission mode, the UE can receive the two PDCCH transmissions carrying the same DCI from a single search space/CORESET using different TCI states.

For multi-TRP PUSCH repetition, according to indications in a single DCI or in a semi-static configured grant provided over RRC, the UE performs PUSCH transmission of the same contents toward two TRPs with corresponding beam directions associated with different spatial relations. For multi-TRP PUCCH repetition, the UE performs PUCCH transmission of the same contents toward two TRPs with corresponding beam directions associated with different spatial relations.

For inter-cell multi-TRP operation, for multi-DCI PDSCH transmission, one or more TCI states can be associated with SSB with a PCI different from the serving cell PCI. The activated TCI states can be associated with at most one PCI different from the serving cell PCI at a time.

For inter-cell and intra-cell multi-DCI multi-TRP operation, up to two TAGs with associated TAG IDs can be configured per serving cell. Each UL/Joint TCI state is associated with a TAG ID and the UE applies the timing advance of the TAG ID associated with the UL/joint TCI state utilized for UL transmission.

For single-DCI multi-TRP Simultaneous Transmission with Multi-Panel (STxMP) Spatial Domain Multiplexing (SDM) PUSCH transmission, different layers of one PUSCH are separately transmitted towards two TRPs. For single-DCI multi-TRP STxMP SFN PUSCH transmission, same layers of one PUSCH are transmitted towards two TRPs. For multi-DCI based multi-TRP STxMP PUSCH+PUSCH transmission, two PUSCHs are transmitted towards two TRPs. For single-DCI multi-TRP STxMP SFN PUCCH transmission, one PUCCH is transmitted towards two TRPs.

# 7 RRC

## 7.1 Services and Functions

The main services and functions of the RRC sublayer over the Uu interface include:

- Broadcast of System Information related to AS and NAS;

- Paging initiated by 5GC or NG-RAN;

- Establishment, maintenance and release of an RRC connection between the UE and NG-RAN including:

- Addition, modification and release of carrier aggregation;

- Addition, modification and release of Dual Connectivity in NR or between E-UTRA and NR.

- Security functions including key management;

- Establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs);

- Mobility functions including:

- Handover and context transfer;

- UE cell selection and reselection and control of cell selection and reselection;

- Inter-RAT mobility.

- QoS management functions;

- UE measurement reporting and control of the reporting;

- Detection of and recovery from radio link failure;

- NAS message transfer to/from NAS from/to UE.

The sidelink specific services and functions of the RRC sublayer over the Uu interface include:

- Configuration of sidelink resource allocation via system information or dedicated signalling;

- Reporting of UE sidelink information;

- Measurement configuration and reporting related to sidelink;

- Reporting of UE assistance information for SL traffic pattern(s).

## 7.2 Protocol States

RRC supports the following states which can be characterised as follows:

**- RRC\_IDLE**:

- PLMN selection;

- Broadcast of system information;

- Cell re-selection mobility;

- Paging for mobile terminated data is initiated by 5GC;

- Transfer of MBS broadcast data to the UE over MRB(s);

- DRX for CN paging configured by NAS.

- **RRC\_INACTIVE**:

- PLMN selection;

- Broadcast of system information;

- Cell re-selection mobility;

- Paging is initiated by NG-RAN (RAN paging);

- RAN-based notification area (RNA) is managed by NG- RAN;

- DRX for RAN paging configured by NG-RAN;

- 5GC - NG-RAN connection (both C/U-planes) is established for UE;

- The UE Inactive AS context is stored in NG-RAN and the UE;

- NG-RAN knows the RNA which the UE belongs to;

- Transfer of MBS multicast/broadcast data to the UE over MRB(s);

- Transfer of unicast data and/or signalling to/from the UE over radio bearers configured for SDT.

- **RRC\_CONNECTED**:

- 5GC - NG-RAN connection (both C/U-planes) is established for UE;

- The UE AS context is stored in NG-RAN and the UE;

- NG-RAN knows the cell which the UE belongs to;

- Transfer of unicast data to/from the UE;

- Transfer of MBS multicast/broadcast data to the UE over MRB(s);

- Network controlled mobility including measurements.

## 7.3 System Information Handling

### 7.3.1 Overview

System Information (SI) consists of a MIB and a number of SIBs, which are divided into Minimum SI and Other SI:

- **Minimum SI** comprises basic information required for initial access and information for acquiring any other SI. Minimum SI consists of:

- *MIB* contains cell barred status information and essential physical layer information of the cell required to receive further system information, e.g. CORESET#0 configuration. *MIB* is periodically broadcast on BCH.

- *SIB1* defines the scheduling of other system information blocks and contains information required for initial access. SIB1 is also referred to as Remaining Minimum SI (RMSI) and is periodically broadcast on DL-SCH or sent in a dedicated manner on DL-SCH to UEs in RRC\_CONNECTED. SIB1 can be broadcast on-demand upon request from UEs in RRC\_IDLE, RRC\_INACTIVE or RRC\_CONNECTED state when T311 is running if a UE and cell support OD-SIB1 as described in 15.4.2.x2.

- **Other SI** encompasses all SIBs not broadcast in the Minimum SI. Those SIBs can either be periodically broadcast on DL-SCH, broadcast on-demand on DL-SCH (i.e. upon request from UEs in RRC\_IDLE, RRC\_INACTIVE, or RRC\_CONNECTED), or sent in a dedicated manner on DL-SCH to UEs in RRC\_CONNECTED (i.e., upon request, if configured by the network, from UEs in RRC\_CONNECTED or when the UE has an active BWP with no common search space configured or when the UE configured with inter cell beam management is receiving DL-SCH from a TRP with PCI different from serving cell's PCI). Other SI consists of:

- *SIB2* contains cell re-selection information, mainly related to the serving cell;

- *SIB3* contains information about the serving frequency and intra-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);

- *SIB4* contains information about other NR frequencies and inter-frequency neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters), which can also be used for NR idle/inactive measurements;

- *SIB5* contains information about E-UTRA frequencies and E-UTRA neighbouring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters);

- *SIB6* contains an ETWS primary notification;

- *SIB7* contains an ETWS secondary notification;

- *SIB8* contains a CMAS warning notification;

- *SIB9* contains information related to GPS time and Coordinated Universal Time (UTC);

- *SIB10* contains the Human-Readable Network Names (HRNN) of the NPNs listed in SIB1;

- *SIB11* contains information related to idle/inactive measurements;

- *SIB15* contains information related to disaster roaming;

*- SIB16* contains slice-based cell reselection information;

- *SIB17* and *SIB17bis* contain information related to TRS configuration for UEs in RRC\_IDLE/RRC\_INACTIVE;

- *SIBpos* contains positioning assistance data as defined in TS 37.355 [43] and TS 38.331 [12];

- *SIB18* contains information related to the Group IDs for Network selection (GINs) associated with SNPNs listed in SIB1.

*- SIB19* in TN contains NTN-specific parameters for NTN neighbour cells as defined in TS 38.331 [12].

*- SIBxx* contains UL-WUS configurations of serving and neighbour OD-SIB1 cells as defined in TS 38.331 [12].

For sidelink, Other SI also includes:

- *SIB12* contains information related to NR sidelink communication, ranging and sidelink positioning;

- *SIB13* contains information related to *SystemInformationBlockType21* for V2X sidelink communication as specified in TS 36.331 clause 5.2.2.28 [29];

- *SIB14* contains information related to *SystemInformationBlockType26* for V2X sidelink communication as specified in TS 36.331 clause 5.2.2.33 [29];

- *SIB23* contains information related to ranging and sidelink positioning.

For non-terrestrial network, Other SI also includes:

- *SIB19* contains NTN-specific parameters for serving cell and optionally NTN-specific parameters for neighbour cells as defined in TS 38.331 [12].

- *SIB25* contains TN coverage information as defined in TS 38.331 [12].

For MBS broadcast, Other SI also includes:

- *SIB20* contains MCCH configuration;

- *SIB21* contains information related to service continuity for MBS broadcast reception.

For MBS multicast reception in RRC\_INACTIVE state, Other SI also includes:

- *SIB24* contains the information required to acquire the multicast MCCH/MTCH configuration as defined in TS 38.331 [12].

For ATG network, Other SI also includes:

- *SIB22* contains ATG-specific parameters for serving cell and optionally ATG-specific parameters for neighbour cells as defined in TS 38.331 [12].

Figure 7.3.1-1 below summarises System Information provisioning.



Figure 7.3.1-1: System Information Provisioning

For a cell/frequency that is considered for camping by the UE, the UE is not required to acquire the contents of the minimum SI of that cell/frequency from another cell/frequency layer. This does not preclude the case that the UE applies stored SI from previously visited cell(s).

If the UE cannot determine the full contents of the minimum SI of a cell by receiving from that cell, the UE shall consider that cell as barred.

Editor’s note: Update Figure 7.3.1-1 and FFS if any additional descriptions for OD-SIB1 are needed in this section.

In case of BA, the UE only acquires SI on the active BWP.

If the UE is configured with inter cell beam management:

- the UE is not required to acquire the SI from the serving cell while it is receiving DL-SCH from a TRP with PCI different from serving cell's PCI.

### 7.3.2 Scheduling

The MIB is mapped on the BCCH and carried on BCH while all other SI messages are mapped on the BCCH, where they are dynamically carried on DL-SCH. The scheduling of SI messages part of Other SI is indicated by *SIB1*.

For UEs in RRC\_IDLE and RRC\_INACTIVE while SDT procedure is not ongoing (see clause 18), a request for Other SI triggers a random access procedure (see clause 9.2.6) where MSG3 includes the SI request message unless the requested SI is associated to a subset of the PRACH resources, in which case MSG1 is used for indication of the requested Other SI. When MSG1 is used, the minimum granularity of the request is one SI message (i.e. a set of SIBs), one RACH preamble and/or PRACH resource can be used to request multiple SI messages and the gNB acknowledges the request in MSG2. When MSG 3 is used, the gNB acknowledges the request in MSG4. For UEs in RRC\_IDLE, RRC\_INACTIVE and RRC\_CONNECTED when T311 is running, a request for OD-SIB1 triggers a random access procedure, in which case MSG1 is used for indicating OD-SIB1 request and the gNB acknowledges the request in MSG2.

For UEs in RRC\_CONNECTED, a request for Other SI may be sent to the network, if configured by the network, in a dedicated manner (i.e., via UL-DCCH) and the granularity of the request is one SIB. The gNB may respond with an *RRCReconfiguration* including the requested SIB(s). It is a network choice to decide which requested SIBs are delivered in a dedicated or broadcasted manner.

The Other SI may be broadcast at a configurable periodicity and for a certain duration. The Other SI may also be broadcast when it is requested by UE in RRC\_IDLE/RRC\_INACTIVE/RRC\_CONNECTED.

For a UE to be allowed to camp on a cell it must have acquired the contents of the Minimum SI from that cell. There may be cells in the system that do not broadcast the Minimum SI and where the UE therefore cannot camp.

Editor’s note: FFS if any additional changes in this section are needed for OD-SIB1 scheduling.

### 7.3.3 SI Modification

Change of system information (other than for ETWS/CMAS, see clause 16.4) only occurs at specific radio frames, i.e. the concept of a modification period is used. System information may be transmitted a number of times with the same content within a modification period, as defined by its scheduling. The modification period is configured by system information.

When the network changes (some of the) system information, it first notifies the UEs about this change, i.e. this may be done throughout a modification period. In the next modification period, the network transmits the updated system information. Upon receiving a change notification, the UE acquires the new system information from the start of the next modification period. The UE applies the previously acquired system information until the UE acquires the new system information.

## 7.4 Access Control

NG-RAN supports overload and access control functionality such as RACH back off, RRC Connection Reject, RRC Connection Release and UE based access barring mechanisms.

One unified access control framework as specified in TS 22.261 [19] applies to all UE states (RRC\_IDLE, RRC\_INACTIVE and RRC\_CONNECTED) for NR. NG-RAN broadcasts barring control information associated with Access Categories and Access Identities (in case of network sharing, the barring control information can be set individually for each PLMN). The UE determines whether an access attempt is authorized based on the barring information broadcast for the selected PLMN, and the selected Access Category and Access Identity(ies) for the access attempt:

- For NAS triggered requests, NAS determines the Access Category and Access Identity(ies);

- For AS triggered requests, RRC determines the Access Category while NAS determines the Access Identity(ies).

The gNB handles access attempts with establishment or resume causes "emergency", "mps-PriorityAccess" and "mcs-PriorityAccess" (i.e. Emergency calls, MPS, MCS subscribers) with high priority and responds with RRC Reject to these access attempts only in extreme network load conditions that may threaten the gNB stability.

Unified access control does not apply to IAB-MTs or NCR-MTs.

## 7.5 UE Capability Retrieval framework

The UE reports its UE radio access capabilities which are static at least when the network requests. The gNB can request what capabilities for the UE to report based on band information. The UE capability can be represented by a capability ID, which may be exchanged in NAS signalling over the air and in network signalling instead of the UE capability structure.

In IAB, it is optional for an IAB-MT to support UE capability Retrieval framework and the related signalling. In case IAB-MT does not support UE capability Retrieval framework, IAB-MT capabilities are assumed to be known to the network by other means, e.g. OAM.

## 7.6 Transport of NAS Messages

NR provides reliable in-sequence delivery of NAS messages over SRBs in RRC, except at handover where losses or duplication can occur when PDCP is re-established. In RRC, NAS messages are sent in transparent containers. Piggybacking of NAS messages can occur in the following scenarios:

- At bearer establishment/modification/release in the DL;

- For transferring the initial NAS message during connection setup and connection resume in the UL.

NOTE: In addition to the integrity protection and ciphering performed by NAS, NAS messages can also be integrity protected and ciphered by PDCP.

Multiple NAS messages can be sent in a single downlink RRC message during PDU Session Resource establishment or modification. In this case, the order of the NAS messages contained in the RRC message shall be in the same order as that in the corresponding NG-AP message in order to ensure the in-sequence delivery of NAS messages.

NG-RAN node may trigger the NAS Non Delivery Indication procedure to report the non-delivery of the non PDU Session related NAS PDU received from the AMF as specified in TS 38.413 [26].

## 7.7 Carrier Aggregation

When CA is configured, the UE only has one RRC connection with the network. At RRC connection establishment/re-establishment/handover, one serving cell provides the NAS mobility information, and at RRC connection re-establishment/handover, one serving cell provides the security input. This cell is referred to as the Primary Cell (PCell). Depending on UE capabilities, Secondary Cells (SCells) can be configured to form together with the PCell a set of serving cells. The configured set of serving cells for a UE therefore always consists of one PCell and one or more SCells.

The reconfiguration, addition and removal of SCells can be performed byRRC. At intra-NR handover and during connection resume from RRC\_INACTIVE, the network can also add, remove, keep, or reconfigure SCells for usage with the target PCell. When adding a new SCell, dedicated RRC signalling is used for sending all required system information of the SCell i.e. while in connected mode, UEs need not acquire broadcast system information directly from the SCells.

## 7.8 Bandwidth Adaptation

To enable BA on the PCell, the gNB configures the UE with UL and DL BWP(s). To enable BA on SCells in case of CA, the gNB configures the UE with DL BWP(s) at least (i.e. there may be none in the UL). For the PCell, the BWP used for initial access is configured via system information. For the SCell(s), the BWP used after initial activation is configured via dedicated RRC signalling.

In paired spectrum, DL and UL can switch BWP independently. In unpaired spectrum, DL and UL switch BWP simultaneously. Switching between configured BWPs happens by means of RRC signalling, DCI, inactivity timer or upon initiation of random access. When an inactivity timer is configured for a serving cell, the expiry of the inactivity timer associated to that cell switches the active BWP to a default BWP configured by the network. There can be at most one active BWP per cell, except when the serving cell is configured with SUL, in which case there can be at most one on each UL carrier.

## 7.9 UE Assistance Information

When configured to do so, the UE can signal the network through *UEAssistanceInformation*:

- If it prefers an adjustment in the connected mode DRX cycle length, for the purpose of delay budget reporting;

- If it is experiencing internal overheating;

- If it prefers certain DRX parameter values, and/or a reduced maximum number of secondary component carriers, and/or a reduced maximum aggregated bandwidth and/or a reduced maximum number of MIMO layers and/or minimum scheduling offsets K0 and K2 for power saving purpose;

- If it expects not to send or receive any more data in the near future, and in this case, it can provide its preference to transition out of RRC\_CONNECTED where this indication may express its preferred RRC state, or alternately, it may cancel an earlier indicated preference to transition out of RRC\_CONNECTED;

- If it prefers (not) to be provisioned with reference time information;

- If it prefers to transition out of RRC\_CONNECTED state for MUSIM operation and its preferred RRC state after transition;

- If it wants to include assistance information for setup or release of MUSIM gaps, and/or for setup the priority of periodic MUSIM gaps, and/or for keeping the colliding MUSIM gaps;

- If it prefers to restrict UE capability temporarily or remove the restriction for MUSIM operation;

- When affected by IDC problems that it cannot solve by itself:

- The list of frequencies affected by IDC problems (see clause 23.4 of TS 36.300 [2]);

- The list of frequency ranges/frequency range combinations affected by the IDC problems;

- DRX based TDM assistance information (see clause 23.4.2 of TS 36.300 [2]);

- Its RRM measurement relaxation status indicating whether RRM measurement relaxation criteria are met or not;

- Its RLM measurement relaxation status indicating whether the UE is applying RLM measurements relaxation;

- Its BFD measurement relaxation status indicating whether the UE is applying BFD measurements relaxation;

- If it prefers not operating on multi-Rx (i.e. not supporting simultaneous reception with different QCL-typeD) for FR2.

NOTE: The requirements on RRM/RLM/CSI measurements in different phases of IDC interference defined in TS 36.300 [2] are applicable except that for NR serving cell, the requirements in TS 38.133 [13] and TS 38.101-1 [18], TS 38.101-2 [35], TS 38.101-3 [36] apply.

In the second case, the UE can express a preference for temporarily reducing the number of maximum secondary component carriers, the maximum aggregated bandwidth and the number of maximum MIMO layers. In all cases, it is up to the gNB whether to accommodate the request.

For sidelink, the UE can report SL traffic pattern(s) to NG-RAN, for periodic traffic.

## 7.10 Segmentation of RRC messages

An RRC message may be segmented in case the size of the encoded RRC message PDU exceeds the maximum PDCP SDU size. Segmentation is performed in the RRC layer using a separate RRC PDU to carry each segment. The receiver reassembles the segments to form the complete RRC message. All segments of an RRC message are transmitted before sending another RRC message. Segmentation is supported in both uplink and downlink as specified in TS 38.331 [12].

*Unchanged Text is omitted*

# 9 Mobility and State Transitions

## 9.1 Overview

Load balancing is achieved in NR with handover, redirection mechanisms upon RRC release and through the usage of inter-frequency and inter-RAT absolute priorities and inter-frequency Qoffset parameters.

Measurements to be performed by a UE for connected mode mobility are classified in at least four measurement types:

- Intra-frequency NR measurements;

- Inter-frequency NR measurements;

- Inter-RAT measurements for E-UTRA;

- Inter-RAT measurements for UTRA.

For each measurement type one or several measurement objects can be defined (a measurement object defines e.g. the carrier frequency to be monitored).

For each measurement object one or several reporting configurations can be defined (a reporting configuration defines the reporting criteria). Three reporting criteria are used: event triggered reporting, periodic reporting and event triggered periodic reporting.

The association between a measurement object and a reporting configuration is created by a measurement identity (a measurement identity links together one measurement object and one reporting configuration of the same RAT). By using several measurement identities (one for each measurement object, reporting configuration pair) it is then possible to:

- Associate several reporting configurations to one measurement object and;

- Associate one reporting configuration to several measurement objects.

The measurements identity is used as well when reporting results of the measurements.

Measurement quantities are considered separately for each RAT.

Measurement commands are used by NG-RAN to order the UE to start, modify or stop measurements.

Handover can be performed within the same RAT and/or CN, or it can involve a change of the RAT and/or CN.

Inter system fallback towards E-UTRAN is performed when 5GC does not support emergency services, voice services, for load balancing etc. Depending on factors such as CN interface availability, network configuration and radio conditions, the fallback procedure results in either RRC\_CONNECTED state mobility (handover procedure) or RRC\_IDLE state mobility (redirection), see TS 23.501 [3] and TS 38.331 [12].

SRVCC from 5G to UTRAN, if supported by both the UE and the network, may be performed to handover a UE with an ongoing voice call from NR to UTRAN. The overall procedure is described in TS 23.216 [34]. See also TS 38.331 [12] and TS 38.413 [26].

In the NG-C signalling procedure, the AMF based on support for emergency services, voice service, any other services or for load balancing etc, may indicate the target CN type as EPC or 5GC to the gNB node. When the target CN type is received by gNB, the target CN type is also conveyed to the UE in *RRCRelease* Message.

Inter-gNB CSI-RS based mobility, i.e. handover, is supported between two neighbour gNBs by enabling that neighbour gNBs can exchange and forward their own CSI-RS configurations and on/off status.

## 9.2 Intra-NR

### 9.2.1 Mobility in RRC\_IDLE

#### 9.2.1.1 Cell Selection

The principles of PLMN selection in NR are based on the 3GPP PLMN selection principles. Cell selection is required on transition from RM-DEREGISTERED to RM-REGISTERED, from CM-IDLE to CM-CONNECTED and from CM-CONNECTED to CM-IDLE and is based on the following principles:

- The UE NAS layer identifies a selected PLMN and equivalent PLMNs;

- Cell selection is always based on CD-SSBs located on the synchronization raster (see clause 5.2.4):

- The UE searches the NR frequency bands and for each carrier frequency identifies the strongest cell as per the CD-SSB. It then reads cell system information broadcast to identify its PLMN(s):

- The UE may search each carrier in turn ("initial cell selection") or make use of stored information to shorten the search ("stored information cell selection").

- The UE seeks to identify a suitable cell; if it is not able to identify a suitable cell it seeks to identify an acceptable cell. When a suitable cell is found or if only an acceptable cell is found it camps on that cell and commence the cell reselection procedure:

- A suitable cell is one for which the measured cell attributes satisfy the cell selection criteria; the cell PLMN is the selected PLMN, registered or an equivalent PLMN; the cell is not barred or reserved and the cell is not part of a tracking area which is in the list of "forbidden tracking areas for roaming";

- An acceptable cell is one for which the measured cell attributes satisfy the cell selection criteria and the cell is not barred.

- The IAB-MT and NCR-MT apply the cell selection procedure as described for the UE with the following differences:

- The IAB-MT and NCR-MT ignore cell-barring or cell-reservation indications contained in cell system information broadcast;

- The IAB-MT only considers a cell as a candidate for cell selection if the cell system information broadcast indicates IAB support for the selected PLMN or the selected SNPN, and the NCR-MT only considers a cell as a candidate for cell selection if the cell system information broadcast indicates Network-Controlled Repeater support.

- The mobile IAB-MT applies the cell selection procedure as described for the IAB-MT with the following differences:

- The mobile IAB-MT only considers a cell as a candidate cell for cell selection if the cell system information broadcast indicates mobile IAB support.

Transition to RRC\_IDLE:

On transition from RRC\_CONNECTED or RRC\_INACTIVE to RRC\_IDLE, a UE should camp on a cell as result of cell selection according to the frequency be assigned by RRC in the state transition message if any.

Recovery from out of coverage:

The UE should attempt to find a suitable cell in the manner described for stored information or initial cell selection above. If no suitable cell is found on any frequency or RAT, the UE should attempt to find an acceptable cell.

In multi-beam operations, the cell quality is derived amongst the beams corresponding to the same cell (see clause 9.2.4).

#### 9.2.1.2 Cell Reselection

A UE in RRC\_IDLE performs cell reselection. The principles of the procedure are the following:

- Cell reselection is always based on CD-SSBs located on the synchronization raster (see clause 5.2.4).

- The UE makes measurements of attributes of the serving and neighbour cells to enable the reselection process:

- For the search and measurement of inter-frequency neighbouring cells, only the carrier frequencies need to be indicated.

- Cell reselection identifies the cell that the UE should camp on. It is based on cell reselection criteria which involves measurements of the serving and neighbour cells:

- Intra-frequency reselection is based on ranking of cells;

- Inter-frequency reselection is based on absolute priorities where a UE tries to camp on the highest priority frequency available;

- A Neighbour Cell List (NCL) can be provided by the serving cell to handle specific cases for intra- and inter-frequency neighbouring cells;

- Exclude-lists can be provided to prevent the UE from reselecting to specific intra- and inter-frequency neighbouring cells;

- Allow-lists can be provided to request the UE to reselect to only specific intra- and inter-frequency neighbouring cells;

- Cell reselection can be speed dependent;

- Service specific prioritisation;

- Slice-based cell reselection information can be provided to facilitate the UE to reselect a cell that supports specific slices.

In multi-beam operations, the cell quality is derived amongst the beams corresponding to the same cell (see clause 9.2.4).

Editor’s note: FFS if any changes in this section are needed for OD-SIB1.

#### 9.2.1.3 State Transitions

The following figure describes the UE triggered transition from RRC\_IDLE to RRC\_CONNECTED (for the NAS part, see TS 23.502 [22]):



Figure 9.2.1.3-1: UE triggered transition from RRC\_IDLE to RRC\_CONNECTED

1. The UE requests to setup a new connection from RRC\_IDLE.

2/2a. The gNB completes the RRC setup procedure.

NOTE: The scenario where the gNB rejects the request is described below.

3. The first NAS message from the UE, piggybacked in *RRCSetupComplete*, is sent to AMF.

4/4a/5/5a. Additional NAS messages may be exchanged between UE and AMF, see TS 23.502 [22].

6. The AMF prepares the UE context data (including PDU session context, the Security Key, UE Radio Capability and UE Security Capabilities, etc.) and sends it to the gNB.

7/7a. The gNB activates the AS security with the UE.

8/8a. The gNB performs the reconfiguration to setup SRB2 and DRBs for UE, or SRB2 and optionally DRBs for IAB-MT.

9. The gNB informs the AMF that the setup procedure is completed.

NOTE 1: RRC messages in step 1 and 2 use SRB0, all the subsequent messages use SRB1. Messages in steps 7/7a are integrity protected. From step 8 on, all the messages are integrity protected and ciphered.

NOTE 2: For signalling only connection, step 8 is skipped since SRB2 and DRBs are not setup.

The following figure describes the rejection from the network when the UE attempts to setup a connection from RRC\_IDLE:



Figure 9.2.1.3-2: Rejection of UE triggered transition from RRC\_IDLE

1. UE attempts to setup a new connection from RRC\_IDLE.

2. The gNB is not able to handle the procedure, for instance due to congestion.

3. The gNB sends *RRCReject* (with a wait time) to keep the UE in RRC\_IDLE.

### 9.2.2 Mobility in RRC\_INACTIVE

#### 9.2.2.1 Overview

RRC\_INACTIVE is a state where a UE remains in CM-CONNECTED and can move within an area configured by NG-RAN (the RNA) without notifying NG-RAN. In RRC\_INACTIVE, the last serving gNB node keeps the UE context and the UE-associated NG connection with the serving AMF and UPF.

For a UE in RRC\_INACTIVE with eDRX cycle longer than 10.24 seconds, the NG-RAN node may, based on implementation, send a request to the AMF to perform MT Communication Handling as described in TS 23.501 [3]. If the UE accesses a gNB other than the last serving gNB and upon successful UE context retrieval, the AMF considers that the UE is reachable (i.e., the MT Communicating Handling is deactivated) and triggers the MT DL data/signalling delivery upon receiving the NGAP Path Switch Request message.

If the last serving gNB receives DL data from the UPF or DL UE-associated signalling from the AMF (except the UE Context Release Command message) while the UE is in RRC\_INACTIVE, it pages in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s).

Upon receiving the RAN Paging Request message from the AMF while the UE is in RRC\_INACTIVE with eDRX beyond 10.24 seconds, the last serving gNB may page in its cells comprised in the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s), in order to trigger the UE to resume connection in RRC\_CONNECTED state, or in RRC\_INACTIVE state for DL SDT, based on the DL data size if included in the NGAP RAN Paging Request message.

Upon receiving the UE Context Release Command message while the UE is in RRC\_INACTIVE, the last serving gNB may page in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s), in order to release UE explicitly.

Upon receiving the NG RESET message while the UE is in RRC\_INACTIVE, the last serving gNB may page involved UEs in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbour gNB(s) if the RNA includes cells of neighbour gNB(s) in order to explicitly release involved UEs.

Upon RAN paging failure, the gNB behaves according to TS 23.501 [3].

The AMF provides to the NG-RAN node the Core Network Assistance Information to assist the NG-RAN node's decision whether the UE can be sent to RRC\_INACTIVE, and to assist UE configuration and paging in RRC\_INACTIVE. The Core Network Assistance Information includes the registration area configured for the UE, the Periodic Registration Update timer, and the UE Identity Index value, and may include the UE specific DRX, an indication if the UE is configured with Mobile Initiated Connection Only (MICO) mode by the AMF, the Expected UE Behaviour, the UE Radio Capability for Paging, the PEI with Paging Subgrouping assistance information, the NR Paging eDRX Information, the Paging Cause Indication for Voice Service, the Hashed UE Identity Index Value and the CN support indication for MT Communication Handling. The UE registration area is taken into account by the NG-RAN node when configuring the RNA. The UE specific DRX and UE Identity Index value are used by the NG-RAN node for RAN paging. The Periodic Registration Update timer is taken into account by the NG-RAN node to configure Periodic RNA Update timer. The NG-RAN node takes into account the Expected UE Behaviour to assist the UE RRC state transition decision. The NG-RAN node may use the UE Radio Capability for Paging during RAN Paging. The NG-RAN node takes into account the PEI with Paging Subgrouping assistance information for subgroup paging in RRC\_INACTIVE except when the UE context contains an emergency PDU session in which case the PEI with Paging Subgrouping assistance information shall not be used according to TS 24.501 [28]. When sending the XnAP RAN Paging to neighbour NG-RAN node(s), the PEI with Paging Subgrouping assistance information may be included. The NG-RAN node takes into account the NR Paging eDRX Information to configure the RAN Paging when the NR UE is in RRC\_INACTIVE. When sending XnAP RAN Paging to neighbour NG-RAN node(s), the NR Paging eDRX Information for RRC\_IDLE and for RRC\_INACTIVE may be included. The NG-RAN node takes into consideration the Paging Cause Indication for Voice Service to include the Paging Cause in RAN Paging for a UE in RRC\_INACTIVE state. When sending XnAP RAN Paging to neighbour NG-RAN node(s), the Paging Cause may be included. When sending XnAP RAN Paging to neighbour NG-RAN node(s), the Hashed UE Identity Index Value may be included to determine the start point of PTW. The NG-RAN takes into account the CN support indication for MT Communication Handling when deciding to request the AMF for MT Communication Handling for a UE in RRC\_INACTIVE state with long eDRX beyond 10.24 seconds as described in TS 23.501 [3].

At transition to RRC\_INACTIVE the NG-RAN node may configure the UE with a periodic RNA Update timer value. At periodic RNA Update timer expiry without notification from the UE, the gNB behaves as specified in TS 23.501 [3].

If the UE accesses a gNB other than the last serving gNB, the receiving gNB triggers the XnAP Retrieve UE Context procedure to get the UE context from the last serving gNB and may also trigger an Xn-U Address Indication procedure including tunnel information for potential recovery of data from the last serving gNB. Upon successful UE context retrieval, the receiving gNB shall perform the slice-aware admission control in case of receiving slice information and becomes the serving gNB and it further triggers the NGAP Path Switch Request and applicable RRC procedures. After the path switch procedure, the serving gNB triggers release of the UE context at the last serving gNB by means of the XnAP UE Context Release procedure.

In case the UE is not reachable at the last serving gNB, the gNB shall fail any AMF initiated UE-associated class 1 procedure which allows the signalling of unsuccessful operation in the respective response message. It may trigger the NAS Non Delivery Indication procedure to report the non-delivery of any non PDU Session related NAS PDU received from the AMF as specified in TS 38.413 [26].

If the UE accesses a gNB other than the last serving gNB and the receiving gNB does not find a valid UE Context, the receiving gNB can perform establishment of a new RRC connection instead of resumption of the previous RRC connection. UE context retrieval will also fail and hence a new RRC connection needs to be established if the serving AMF changes.

A UE in the RRC\_INACTIVE state is required to initiate RNA update procedure when it moves out of the configured RNA. When receiving RNA update request from the UE, the receiving gNB triggers the XnAP Retrieve UE Context procedure to get the UE context from the last serving gNB and may decide to send the UE back to RRC\_INACTIVE state, move the UE into RRC\_CONNECTED state, or send the UE to RRC\_IDLE. In case of periodic RNA update, if the last serving gNB decides not to relocate the UE context, it fails the Retrieve UE Context procedure and sends the UE back to RRC\_INACTIVE, or to RRC\_IDLE directly by an encapsulated *RRCRelease* message.

#### 9.2.2.2 Cell Reselection

A UE in RRC\_INACTIVE performs cell reselection. The principles of the procedure are as for the RRC\_IDLE state (see clause 9.2.1.2).

#### 9.2.2.3 RAN-Based Notification Area

A UE in the RRC\_INACTIVE state can be configured by the last serving NG-RAN node with an RNA, where:

- the RNA can cover a single or multiple cells, and shall be contained within the CN registration area; in this release Xn connectivity should be available within the RNA;

- a RAN-based notification area update (RNAU) is periodically sent by the UE and is also sent when the cell reselection procedure of the UE selects a cell that does not belong to the configured RNA.

There are several different alternatives on how the RNA can be configured:

- List of cells:

- A UE is provided an explicit list of cells (one or more) that constitute the RNA.

- List of RAN areas:

- A UE is provided (at least one) RAN area ID, where a RAN area is a subset of a CN Tracking Area or equal to a CN Tracking Area. A RAN area is specified by one RAN area ID, which consists of a TAC and optionally a RAN area Code;

- A cell broadcasts one or, in case of network sharing with multiple cell ID broadcast, more RAN area IDs in the system information.

NG-RAN may provide different RNA definitions to different UEs but not mix different definitions to the same UE at the same time. UE shall support all RNA configuration options listed above.

#### 9.2.2.4 State Transitions

##### 9.2.2.4.1 UE triggered transition from RRC\_INACTIVE to RRC\_CONNECTED

The following figure describes the UE triggered transition from RRC\_INACTIVE to RRC\_CONNECTED in case of UE context retrieval success:



Figure 9.2.2.4.1-1: UE triggered transition from RRC\_INACTIVE to RRC\_CONNECTED  
(UE context retrieval success)

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI, allocated by the last serving gNB.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.

3. The last serving gNB provides UE context data.

4/5. The gNB and UE completes the resumption of the RRC connection.

NOTE: User Data can also be sent in step 5 if the grant allows.

6. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

7/8. The gNB performs path switch.

9. The gNB triggers the release of the UE resources at the last serving gNB.

After step 1 above, when the gNB decides to use a single RRC message to reject the Resume Request right away and keep the UE in RRC\_INACTIVE without any reconfiguration (e.g. as described in the two examples below), or when the gNB decides to setup a new RRC connection, SRB0 (without security) is used. Conversely, when the gNB decides to reconfigure the UE (e.g. with a new DRX cycle or RNA) or when the gNB decides to push the UE to RRC\_IDLE, SRB1 (with integrity protection and ciphering as previously configured for that SRB) shall be used.

NOTE: SRB1 can only be used once the UE Context is retrieved i.e. after step 3.

The following figure describes the UE triggered transition from RRC\_INACTIVE to RRC\_CONNECTED in case of UE context retrieval failure:



Figure 9.2.2.4.1-2: UE triggered transition from RRC\_INACTIVE to RRC\_CONNECTED  
(UE context retrieval failure)

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI, allocated by the last serving gNB.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.

3. The last serving gNB cannot retrieve or verify the UE context data.

4. The last serving gNB indicates the failure to the gNB.

5. The gNB performs a fallback to establish a new RRC connection by sending *RRCSetup*.

6. A new connection is setup as described in clause 9.2.1.3.

The following figure describes the rejection form the network when the UE attempts to resume a connection from RRC\_INACTIVE:



Figure 9.2.2.4.1-3: Reject from the network, UE attempts to resume a connection

1. UE attempts to resume the connection from RRC\_INACTIVE.

2. The gNB is not able to handle the procedure, for instance due to congestion.

3. The gNB sends *RRCReject* (with a wait time) to keep the UE in RRC\_INACTIVE.

##### 9.2.2.4.2 Network triggered transition from RRC\_INACTIVE to RRC\_CONNECTED

The following figure describes the network triggered transition from RRC\_INACTIVE to RRC\_CONNECTED:



Figure 9.2.2.4.2-1: Network triggered transition from RRC\_INACTIVE to RRC\_CONNECTED

1. A RAN paging trigger event occurs (incoming DL user plane, DL signalling from 5GC, etc.).

2. RAN paging is triggered; either only in the cells controlled by the last serving gNB or also by means of Xn RAN Paging in cells controlled by other gNBs, configured to the UE in the RAN-based Notification Area (RNA).

3. The UE is paged with the I-RNTI.

4. If the UE has been successfully reached, it attempts to resume from RRC\_INACTIVE, as described in clause 9.2.2.4.1.

#### 9.2.2.5 RNA update

The following figure describes the UE triggered RNA update procedure involving context retrieval over Xn. The procedure may be triggered when the UE moves out of the configured RNA, or periodically.



Figure 9.2.2.5-1: RNA update procedure with UE context relocation

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.

3. The last serving gNB may provide the UE context (as assumed in the following). Alternatively, the last serving gNB may decide to move the UE to RRC\_IDLE (and the procedure follows steps 3 and later of figure 9.2.2.5-3) or, if the UE is still within the previously configured RNA, to keep the UE context in the last serving gNB and to keep the UE in RRC\_INACTIVE (and the procedure follows steps 3 and later of figure 9.2.2.5-2).

4. The gNB may move the UE to RRC\_CONNECTED (and the procedure follows step 4 of Figure 9.2.2.4.1-1), or send the UE back to RRC\_IDLE (in which case an *RRCRelease* message is sent by the gNB), or send the UE back to RRC\_INACTIVE as assumed in the following.

5. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

6./7. The gNB performs path switch.

8. The gNB keeps the UE in RRC\_INACTIVE state by sending *RRCRelease* with suspend indication.

9. The gNB triggers the release of the UE resources at the last serving gNB.

The following figure describes the RNA update procedure for the case when the UE is still within the configured RNA and the last serving gNB decides not to relocate the UE context and to keep the UE in RRC\_INACTIVE:



Figure 9.2.2.5-2: Periodic RNA update procedure without UE context relocation

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.

3. The last serving gNB stores received information to be used in the next resume attempt (e.g. C-RNTI and PCI related to the resumption cell), and responds to the gNB with the RETRIEVE UE CONTEXT FAILURE message including an encapsulated *RRCRelease* message. The *RRCRelease* message includes Suspend Indication.

4. The gNB forwards the *RRCRelease* message to the UE.

The following figure describes the RNA update procedure for the case when the last serving gNB decides to move the UE to RRC\_IDLE:



Figure 9.2.2.5-3: RNA update procedure with transition to RRC\_IDLE

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI allocated by the last serving gNB and appropriate cause value, e.g., RAN notification area update.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context, providing the cause value received in step 1.

3. Instead of providing the UE context, the last serving gNB provides an *RRCRelease* message to move the UE to RRC\_IDLE.

4. The last serving gNB deletes the UE context.

5. The gNB sends the *RRCRelease* which triggers the UE to move to RRC\_IDLE.

#### 9.2.2.6 Resume request responded with Release with Redirect, with UE context relocation

The following figure describes a UE triggered NAS procedure responded by the network with a release with redirect, with UE context relocation.



Figure 9.2.2.6-1: Resume request responded with Release with Redirect, with UE Context relocation

1. The UE resumes from RRC\_INACTIVE, providing the I-RNTI allocated by the last serving gNB.

2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.

3. The last serving gNB provides the UE context.

4. The gNB may move the UE to RRC\_CONNECTED (and the procedure follows step 4 of Figure 9.2.2.4.1-1), or send the UE back to RRC\_IDLE (in which case an *RRCRelease* message is sent by the gNB), or send the UE back to RRC\_INACTIVE, including a release with redirect indication (as assumed in the following).

5. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

6./7. The gNB performs path switch.

8. The gNB keeps the UE in RRC\_INACTIVE state by sending *RRCRelease* with suspend indication, including redirection information (frequency layer the UE performs cell selection upon entering RRC\_INACTIVE).

9. The gNB triggers the release of the UE resources at the last serving gNB.

NOTE1: Upon receiving the release with redirect, the higher layers trigger a pending procedure so the UE tries to resume again after cell selection.

### 9.2.3 Mobility in RRC\_CONNECTED

#### 9.2.3.1 Overview

Network controlled mobility applies to UEs in RRC\_CONNECTED and is categorized into two types of mobility: cell level mobility and beam level mobility. Beam level mobility includes intra-cell beam level mobility and inter-cell beam level mobility.

**Cell Level Mobility** requires explicit RRC signalling to be triggered, i.e. handover. For inter-gNB handover, the signalling procedures consist of at least the following elemental components illustrated in Figure 9.2.3.1-1:



Figure 9.2.3.1-1: Inter-gNB handover procedures

1. The source gNB initiates handover and issues a HANDOVER REQUEST over the Xn interface.

2. The target gNB performs admission control and provides the new RRC configuration as part of the HANDOVER REQUEST ACKNOWLEDGE.

3. The source gNB provides the RRC configuration to the UE by forwarding the *RRCReconfiguration* message received in the HANDOVER REQUEST ACKNOWLEDGE. The *RRCReconfiguration* message includes at least cell ID and all information required to access the target cell so that the UE can access the target cell without reading system information. For some cases, the information required for contention-based and contention-free random access can be included in the *RRCReconfiguration* message. The access information to the target cell may include beam specific information, if any.

4. The UE moves the RRC connection to the target gNB and replies with the *RRCReconfigurationComplete*.

NOTE 1: User Data can also be sent in step 4 if the grant allows.

In case of DAPS handover, the UE continues the downlink user data reception from the source gNB until releasing the source cell and continues the uplink user data transmission to the source gNB until successful random access procedure to the target gNB.

Only source and target PCell are used during DAPS handover. CA, DC, SUL, multi-TRP, EHC, CHO, UDC, LTM, NR sidelink configurations and V2X sidelink configurations are released by the source gNB before the handover command is sent to the UE and are not configured by the target gNB until the DAPS handover has completed (i.e. at earliest in the same message that releases the source PCell).

The handover mechanism triggered by RRC requires the UE at least to reset the MAC entity and re-establish RLC, except for DAPS handover, where upon reception of the handover command, the UE:

- Creates a MAC entity for target;

- Establishes the RLC entity and an associated DTCH logical channel for target for each DRB configured with DAPS;

- For each DRB configured with DAPS, reconfigures the PDCP entity with separate security and ROHC functions for source and target and associates them with the RLC entities configured by source and target respectively;

- Retains the rest of the source configurations until release of the source.

The cell switch mechanism triggered by MAC, (i.e., LTM cell switch) requires the UE at least to reset the MAC entity. RLC and PDCP handling depends on the network configuration.

NOTE 2: Void.

NOTE 3: Void.

RRC managed handovers with and without PDCP entity re-establishment are both supported. For DRBs using RLC AM mode, PDCP can either be re-established together with a security key change or initiate a data recovery procedure without a key change. For DRBs using RLC UM mode, PDCP can either be re-established together with a security key change or remain as it is without a key change. For SRBs, PDCP can either remain as it is, discard its stored PDCP PDUs/SDUs without a key change or be re-established together with a security key change.

Data forwarding, in-sequence delivery and duplication avoidance at handover can be guaranteed when the target gNB uses the same DRB configuration as the source gNB.

Timer based handover failure procedure is supported in NR. RRC connection re-establishment procedure is used for recovering from handover failure except in certain CHO, DAPS handover or LTM cell switch scenarios:

- When DAPS handover fails, the UE falls back to the source cell configuration, resumes the connection with the source cell, and reports DAPS handover failure via the source without triggering RRC connection re-establishment if the source link has not been released.

- When initial CHO execution attempt fails or HO fails, the UE performs cell selection, and if the selected cell is a CHO candidate and if network configured the UE to try CHO after handover/CHO failure, then the UE attempts CHO execution once, otherwise re-establishment is performed.

- When LTM execution attempt triggered by LTM cell switch command MAC CE fails, the UE performs cell selection and if the selected cell is an LTM candidate cell and if network configured the UE to try LTM after LTM execution failure, then the UE attempts RACH-based LTM execution once, otherwise re-establishment is performed.

NOTE: PDCP SN gap for SRB may exist upon LTM attempt toward the selected cell after LTM fails. It is up to network implementation to avoid the latency caused by the PDCP SN gap.

DAPS handover for FR2 to FR2 case is not supported in this release of the specification.

The handover of the IAB-MT in SA mode follows the same procedure as described for the UE. After the backhaul has been established, the handover of the IAB-MT is part of the intra-CU or inter-CU topology adaptation procedures defined in TS 38.401 [4]. Modifications to the configuration of BAP sublayer and higher protocol layers above the BAP sublayer are described in TS 38.401 [4].

The handover of the mobile IAB-MT follows the same procedure as described for the UE. After the backhaul has been established, the handover of the mobile IAB-MT is part of the mobile IAB-MT migration procedure defined in TS 38.401 [4].

**Beam Level Mobility** does not require explicit RRC signalling to be triggered. Beam level mobility can be within a cell, or between cells, the latter is referred to as inter-cell beam management (ICBM). For ICBM, a UE can receive or transmit UE dedicated channels/signals via a TRP associated with a PCI different from the PCI of a serving cell, while non-UE-dedicated channels/signals can only be received via a TRP associated with a PCI of the serving cell. The gNB provides via RRC signalling the UE with measurement configuration containing configurations of SSB/CSI resources and resource sets, reports and trigger states for triggering channel and interference measurements and reports. In case of ICBM, a measurement configuration includes SSB resources associated with PCIs different from the PCI of a serving cell. Beam Level Mobility is then dealt with at lower layers by means of physical layer and MAC layer control signalling, and RRC is not required to know which beam is being used at a given point in time.

SSB-based Beam Level Mobility is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWPs, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. SSB-based Beam Level Mobility can be also performed based on an NCD-SSB, if configured for the active DL BWP. Beam Level Mobility can be also performed based on CSI-RS, if configured for the active DL BWP.

#### 9.2.3.2 Handover

##### 9.2.3.2.1 C-Plane Handling

The intra-NR RAN handover performs the preparation and execution phase of the handover procedure performed without involvement of the 5GC, i.e. preparation messages are directly exchanged between the gNBs. The release of the resources at the source gNB during the handover completion phase is triggered by the target gNB. The figure below depicts the basic handover scenario where neither the AMF nor the UPF changes:



Figure 9.2.3.2.1-1: Intra-AMF/UPF Handover

0. The UE context within the source gNB contains information regarding roaming and access restrictions which were provided either at connection establishment or at the last TA update.

1. The source gNB configures the UE measurement procedures and the UE reports according to the measurement configuration.

2. The source gNB decides to handover the UE, based on *MeasurementReport* and RRM information.

3. The source gNB issues a Handover Request message to the target gNB passing a transparent RRC container with necessary information to prepare the handover at the target side. The information includes at least the target cell ID, KgNB\*, the C-RNTI of the UE in the source gNB, RRM-configuration including UE inactive time, basic AS-configuration including *antenna Info and DL Carrier Frequency*, the current QoS flow to DRB mapping rules applied to the UE, the SIB1 information from source gNB, the UE capabilities for different RATs, PDU session related information, and can include the UE reported measurement information including beam-related information if available. The PDU session related information includes the slice information and QoS flow level QoS profile(s). The source gNB may also request a DAPS handover for one or more DRBs.

NOTE 1: After issuing a Handover Request, the source gNB should not reconfigure the UE, including performing Reflective QoS flow to DRB mapping.

4. Admission Control may be performed by the target gNB. Slice-aware admission control shall be performed if the slice information is sent to the target gNB. If the PDU sessions are associated with non-supported slices the target gNB shall reject such PDU Sessions.

5. The target gNB prepares the handover with L1/L2 and sends the HANDOVER REQUEST ACKNOWLEDGE to the source gNB, which includes a transparent container to be sent to the UE as an RRC message to perform the handover. The target gNB also indicates if a DAPS handover is accepted.

NOTE 2: As soon as the source gNB receives the HANDOVER REQUEST ACKNOWLEDGE, or as soon as the transmission of the handover command is initiated in the downlink, data forwarding may be initiated.

NOTE 3: For DRBs configured with DAPS, downlink PDCP SDUs are forwarded with SN assigned by the source gNB, until SN assignment is handed over to the target gNB in step 8b, for which the normal data forwarding follows as defined in 9.2.3.2.3.

6. The source gNB triggers the Uu handover by sending an *RRCReconfiguration* message to the UE, containing the information required to access the target cell: at least the target cell ID, the new C-RNTI, the target gNB security algorithm identifiers for the selected security algorithms. It can also include a set of dedicated RACH resources, the association between RACH resources and SSB(s), the association between RACH resources and UE-specific CSI-RS configuration(s), common RACH resources, and system information of the target cell, etc.

NOTE 4: For DRBs configured with DAPS, the source gNB does not stop transmitting downlink packets until it receives the HANDOVER SUCCESS message from the target gNB in step 8a.

NOTE 4a: CHO cannot be configured simultaneously with DAPS handover.

7a. For DRBs configured with DAPS, the source gNB sends the EARLY STATUS TRANSFER message. The DL COUNT value conveyed in the EARLY STATUS TRANSFER message indicates PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB. The source gNB does not stop assigning SNs to downlink PDCP SDUs until it sends the SN STATUS TRANSFER message to the target gNB in step 8b.

7. For DRBs not configured with DAPS, the source gNB sends the SN STATUS TRANSFER message to the target gNB to convey the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status of DRBs for which PDCP status preservation applies (i.e. for RLC AM). The uplink PDCP SN receiver status includes at least the PDCP SN of the first missing UL PDCP SDU and may include a bit map of the receive status of the out of sequence UL PDCP SDUs that the UE needs to retransmit in the target cell, if any. The downlink PDCP SN transmitter status indicates the next PDCP SN that the target gNB shall assign to new PDCP SDUs, not having a PDCP SN yet.

NOTE 5: In case of DAPS handover, the uplink PDCP SN receiver status and the downlink PDCP SN transmitter status for a DRB with RLC-AM and not configured with DAPS may be transferred by the SN STATUS TRANSFER message in step 8b instead of step 7.

NOTE 6: For DRBs configured with DAPS, the source gNB may additionally send the EARLY STATUS TRANSFER message(s) between step 7 and step 8b, to inform discarding of already forwarded PDCP SDUs. The target gNB does not transmit forwarded downlink PDCP SDUs to the UE, whose COUNT is less than the conveyed DL COUNT value and discards them if transmission has not been attempted already.

8. The UE synchronises to the target cell and completes the RRC handover procedure by sending *RRCReconfigurationComplete* message to target gNB. In case of DAPS handover, the UE does not detach from the source cell upon receiving the *RRCReconfiguration* message. The UE releases the source resources and configurations and stops DL/UL reception/transmission with the source upon receiving an explicit release from the target node.

NOTE 6a: From RAN point of view, the DAPS handover is considered to only be completed after the UE has released the source cell as explicitly requested from the target node. RRC suspend, a subsequent handover or inter-RAT handover cannot be initiated until the source cell has been released.

8a/b In case of DAPS handover, the target gNB sends the HANDOVER SUCCESS message to the source gNB to inform that the UE has successfully accessed the target cell. In return, the source gNB sends the SN STATUS TRANSFER message for DRBs configured with DAPS for which the description in step 7 applies, and the normal data forwarding follows as defined in 9.2.3.2.3.

NOTE 7: The uplink PDCP SN receiver status and the downlink PDCP SN transmitter status are also conveyed for DRBs with RLC-UM in the SN STATUS TRANSFER message in step 8b, if configured with DAPS.

NOTE 8: For DRBs configured with DAPS, the source gNB does not stop delivering uplink QoS flows to the UPF until it sends the SN STATUS TRANSFER message in step 8b. The target gNB does not forward QoS flows of the uplink PDCP SDUs successfully received in-sequence to the UPF until it receives the SN STATUS TRANSFER message, in which UL HFN and the first missing SN in the uplink PDCP SN receiver status indicates the start of uplink PDCP SDUs to be delivered to the UPF. The target gNB does not deliver any uplink PDCP SDUs which has an UL COUNT lower than the provided.

NOTE 9: Void.

9. The target gNB sends a PATH SWITCH REQUEST message to AMF to trigger 5GC to switch the DL data path towards the target gNB and to establish an NG-C interface instance towards the target gNB.

10. 5GC switches the DL data path towards the target gNB. The UPF sends one or more "end marker" packets on the old path to the source gNB per PDU session/tunnel and then can release any U-plane/TNL resources towards the source gNB.

11. The AMF confirms the PATH SWITCH REQUEST message with the PATH SWITCH REQUEST ACKNOWLEDGE message.

12. Upon reception of the PATH SWITCH REQUEST ACKNOWLEDGE message from the AMF, the target gNB sends the UE CONTEXT RELEASE to inform the source gNB about the success of the handover. The source gNB can then release radio and C-plane related resources associated to the UE context. Any ongoing data forwarding may continue.

The RRM configuration can include both beam measurement information (for layer 3 mobility) associated to SSB(s) and CSI-RS(s) for the reported cell(s) if both types of measurements are available. Also, if CA is configured, the RRM configuration can include the list of best cells on each frequency for which measurement information is available. And the RRM measurement information can also include the beam measurement for the listed cells that belong to the target gNB.

The common RACH configuration for beams in the target cell is only associated to the SSB(s). The network can have dedicated RACH configurations associated to the SSB(s) and/or have dedicated RACH configurations associated to CSI-RS(s) within a cell. The target gNB can only include one of the following RACH configurations in the Handover Command to enable the UE to access the target cell:

i) Common RACH configuration;

ii) Common RACH configuration + Dedicated RACH configuration associated with SSB;

iii) Common RACH configuration + Dedicated RACH configuration associated with CSI-RS.

The dedicated RACH configuration allocates RACH resource(s) together with a quality threshold to use them. When dedicated RACH resources are provided, they are prioritized by the UE and the UE shall not switch to contention-based RACH resources as long as the quality threshold of those dedicated resources is met. The order to access the dedicated RACH resources is up to UE implementation.

Upon receiving a handover command requesting DAPS handover, the UE suspends source cell SRBs, stops sending and receiving any RRC control plane signalling toward the source cell, and establishes SRBs for the target cell. The UE releases the source cell SRBs configuration upon receiving source cell release indication from the target cell after successful DAPS handover execution. When DAPS handover to the target cell fails and if the source cell link is available, then the UE reverts back to the source cell configuration and resumes source cell SRBs for control plane signalling transmission.

##### 9.2.3.2.2 U-Plane Handling

The U-plane handling during the Intra-NR-Access mobility activity for UEs in RRC\_CONNECTED takes the following principles into account to avoid data loss during HO:

- During HO preparation, U-plane tunnels can be established between the source gNB and the target gNB;

- During HO execution, user data can be forwarded from the source gNB to the target gNB;

- Forwarding should take place in order as long as packets are received at the source gNB from the UPF or the source gNB buffer has not been emptied.

- During HO completion:

- The target gNB sends a path switch request message to the AMF to inform that the UE has gained access and the AMF then triggers path switch related 5GC internal signalling and actual path switch of the source gNB to the target gNB in UPF;

- The source gNB should continue forwarding data as long as packets are received at the source gNB from the UPF or the source gNB buffer has not been emptied.

**For RLC-AM bearers**:

- For in-sequence delivery and duplication avoidance, PDCP SN is maintained on a per DRB basis and the source gNB informs the target gNB about the next DL PDCP SN to allocate to a packet which does not have a PDCP sequence number yet (either from source gNB or from the UPF).

- For security synchronisation, HFN is also maintained and the source gNB provides to the target one reference HFN for the UL and one for the DL i.e. HFN and corresponding SN.

- In both the UE and the target gNB, a window-based mechanism is used for duplication detection and reordering.

- The occurrence of duplicates over the air interface in the target gNB is minimised by means of PDCP SN based reporting at the target gNB by the UE. In uplink, the reporting is optionally configured on a per DRB basis by the gNB and the UE should first start by transmitting those reports when granted resources are in the target gNB. In downlink, the gNB is free to decide when and for which bearers a report is sent and the UE does not wait for the report to resume uplink transmission.

- The target gNB re-transmits and prioritizes all downlink data forwarded by the source gNB (i.e. the target gNB should first send all forwarded PDCP SDUs with PDCP SNs, then all forwarded downlink PDCP SDUs without SNs before sending new data from 5GC), excluding PDCP SDUs for which the reception was acknowledged through PDCP SN based reporting by the UE.

NOTE 1: Lossless delivery when a QoS flow is mapped to a different DRB at handover, requires the old DRB to be configured in the target cell. For in-order delivery in the DL, the target gNB should first transmit the forwarded PDCP SDUs on the old DRB before transmitting new data from 5GC on the new DRB. In the UL, the target gNB should not deliver data of the QoS flow from the new DRB to 5GC before receiving the end marker on the old DRB from the UE.

- The UE re-transmits in the target gNB all uplink PDCP SDUs starting from the oldest PDCP SDU that has not been acknowledged at RLC in the source, excluding PDCP SDUs for which the reception was acknowledged through PDCP SN based reporting by the target.

- In case of handovers involving Full Configuration, the following description below for RLC-UM bearers applies for RLC-AM bearers instead. Data loss may happen.

**For RLC-UM bearers**:

- The PDCP SN and HFN are reset in the target gNB, unless the bearer is configured with DAPS handover;

- No PDCP SDUs are retransmitted in the target gNB;

- The target gNB prioritises all downlink SDAP SDUs forwarded by the source gNB over the data from the core network;

NOTE 2: To minimise losses when a QoS flow is mapped to a different DRB at handover, the old DRB needs to be configured in the target cell. For in-order delivery in the DL, the target gNB should first transmit the forwarded PDCP SDUs on the old DRB before transmitting new data from 5GC on the new DRB. In the UL, the target gNB should not deliver data of the QoS flow from the new DRB to 5GC before receiving the end marker on the old DRB from the UE.

- The UE does not retransmit any PDCP SDU in the target cell for which transmission had been completed in the source cell.

**For DAPS handover:**

A DAPS handover can be used for an RLC-AM or RLC-UM bearer. For a DRB configured with DAPS, the following principles are additionally applied.

Downlink:

- During HO preparation, a forwarding tunnel is always established.

- The source gNB is responsible for allocating downlink PDCP SNs until the SN assignment is handed over to the target gNB and data forwarding in 9.2.3.2.3 takes place. That is, the source gNB does not stop assigning PDCP SNs to downlink packets until it receives the HANDOVER SUCCESS message and sends the SN STATUS TRANSFER message to the target gNB.

- Upon allocation of downlink PDCP SNs by the source gNB, it starts scheduling downlink data on the source radio link and also starts forwarding downlink PDCP SDUs along with assigned PDCP SNs to the target gNB.

- For security synchronisation, HFN is maintained for the forwarded downlink SDUs with PDCP SNs assigned by the source gNB. The source gNB sends the EARLY STATUS TRANSFER message to convey the DL COUNT value, indicating PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB.

- HFN and PDCP SN are maintained after the SN assignment is handed over to the target gNB. The SN STATUS TRANSFER message indicates the next DL PDCP SN to allocate to a packet which does not have a PDCP sequence number yet, even for RLC-UM.

- During handover execution period, the source and target gNBs separately perform ROHC header compression, ciphering, and adding PDCP header.

- During handover execution period, the UE continues to receive downlink data from both source and target gNBs until the source gNB connection is released by an explicit release command from the target gNB.

- During handover execution period, the UE PDCP entity configured with DAPS maintains separate security and ROHC header decompression functions associated with each gNB, while maintaining common functions for reordering, duplicate detection and discard, and PDCP SDUs in-sequence delivery to upper layers. PDCP SN continuity is supported for both RLC AM and UM DRBs configured with DAPS.

Uplink:

- The UE transmits UL data to the source gNB until the random access procedure toward the target gNB has been successfully completed. Afterwards the UE switches its UL data transmission to the target gNB.

- Even after switching its UL data transmissions towards the target gNB, the UE continues to send UL layer 1 CSI feedback, HARQ feedback, layer 2 RLC feedback, ROHC feedback, HARQ data (re-)transmissions, and RLC data (re-)transmissions to the source gNB.

- During handover execution period, the UE maintains separate security context and ROHC header compressor context for uplink transmissions towards the source and target gNBs. The UE maintains common UL PDCP SN allocation. PDCP SN continuity is supported for both RLC AM and UM DRBs configured with DAPS.

- During handover execution period, the source and target gNBs maintain their own security and ROHC header decompressor contexts to process UL data received from the UE.

- The establishment of a forwarding tunnel is optional.

- HFN and PDCP SN are maintained in the target gNB. The SN STATUS TRANSFER message indicates the COUNT of the first missing PDCP SDU that the target should start delivering to the 5GC, even for RLC-UM.

##### 9.2.3.2.3 Data Forwarding

The following description depicts the data forwarding principles for intra-system handover.

The source NG-RAN node may suggest downlink data forwarding per QoS flow established for a PDU session and may provide information how it maps QoS flows to DRBs. The target NG-RAN node decides data forwarding per QoS flow established for a PDU Session.

If "lossless handover" is required and the QoS flows to DRB mapping applied at the target NG-RAN node allows applying for data forwarding the same QoS flows to DRB mapping as applied at the source NG-RAN node for a DRB and if all QoS flows mapped to that DRB are accepted for data forwarding, the target NG-RAN node establishes a downlink forwarding tunnel for that DRB.

For a DRB for which preservation of SN status applies, the target NG-RAN node may decide to establish an UL data forwarding tunnel.

The target NG-RAN node may also decide to establish a downlink forwarding tunnel for each PDU session. In this case the target NG-RAN node provides information for which QoS flows data forwarding has been accepted and corresponding UP TNL information for data forwarding tunnels to be established between the source NG-RAN node and the target NG-RAN node.

If QoS flows have been re-mapped at the source NG-RAN node and user packets along the old source mapping are still being processed at handover preparation, and if the source NG-RAN node has not yet received the SDAP end marker for certain QoS flows when providing the SN status to the target NG-RAN node, the source NG-RAN node provides the old side QoS mapping information for UL QoS flows to the target NG-RAN node for which no SDAP end marker was yet received. The target NG-RAN will receive for those QoS flows the end marker when the UE finalises to send UL user data according to the old source side mapping.

The source NG-RAN node may also propose to establish uplink forwarding tunnels for some PDU sessions in order to transfer SDAP SDUs corresponding to QoS flows for which flow re-mapping happened before the handover and the SDAP end marker has not yet been received, and for which user data was received at the source NG-RAN node via the DRB to which the QoS flow was remapped. If accepted the target NG-RAN node shall provide the corresponding UP TNL information for data forwarding tunnels to be established between the source NG-RAN node and the target NG-RAN node.

As long as data forwarding of DL user data packets takes place, the source NG-RAN node shall forward user data in the same forwarding tunnel, i.e.

- for any QoS flow accepted for data forwarding by the target NG-RAN node and for which a DRB DL forwarding tunnel was established for a DRB to which this QoS flow was mapped at the source NG-RAN node, any fresh packets of this QoS flow shall be forwarded as PDCP SDUs via the mapped DRB DL forwarding tunnel.

- for DRBs for which preservation of SN status applies, the source NG-RAN node may forward in order to the target NG-RAN node via the DRB DL forwarding tunnel all downlink PDCP SDUs with their SN corresponding to PDCP PDUs which have not been acknowledged by the UE.

NOTE: The SN of forwarded PDCP SDUs is carried in the "PDCP PDU number" field of the GTP-U extension header.

- for any QoS flow accepted for data forwarding by the target NG-RAN node for which a DL PDU session forwarding tunnel was established, the source NG-RAN node forwards SDAP SDUs as received on NG-U from the UPF.

If the data forwarding is performed and the source NG-RAN node receives SDAP SDUs with PDU Set Information Container in the GTP-U extension header on NG-U from the UPF and the target NG-RAN node supports PDU Set based handling, the source NG-RAN node forwards either the PDCP SDUs for DRB-level data forwarding or the SDAP SDUs for PDU-session-level data forwarding with the corresponding PDU Set Information Container in the GTP-U extension header to the target NG-RAN node.

For handovers involving Full Configuration, the source NG-RAN node behaviour is unchanged from the description above. In case a DRB DL forwarding tunnel was established, the target NG-RAN node may identify the PDCP SDUs for which delivery was attempted by the source NG-RAN node, by the presence of the PDCP SN in the forwarded GTP-U packet and may discard them.

As long as data forwarding of UL user data packets takes place for DRBs for which preservation of SN status applies the source NG-RAN node either:

- discards the uplink PDCP PDUs received out of sequence if the source NG-RAN node has not accepted the request from the target NG-RAN node for uplink forwarding or if the target NG-RAN node has not requested uplink forwarding for the bearer during the Handover Preparation procedure; or

- forwards to the target NG-RAN node via the corresponding DRB UL forwarding tunnel, the uplink PDCP SDUs with their SN corresponding to PDCP PDUs received out of sequence if the source NG-RAN node has accepted the request from the target NG-RAN node for uplink forwarding for the bearer during the Handover Preparation procedure, including PDCP SDUs corresponding to user data of those QoS flows, for which re-mapping happened for a QoS flow before the handover and the SDAP end marker has not yet been received at the source NG-RAN node.

As long as data forwarding of UL user data packets takes place for a PDU session, the source NG-RAN node forwards via the corresponding PDU session UL forwarding tunnel, the uplink SDAP SDUs corresponding to QoS flows for which flow re-mapping happened before the handover and the SDAP end marker has not yet been received at the source NG-RAN node, and which were received at the source NG-RAN node via the DRB to which the QoS flow was remapped.

For DRBs configured with DAPS handover, data forwarding after the source gNB receives the HANDOVER SUCCESS message from the target gNB follows the same behaviours as described above.

For DRBs configured with DAPS handover, before the source gNB receives the HANDOVER SUCCESS message:

- The source gNB may forward to the target gNB downlink PDCP SDUs with SNs assigned by the source gNB. No downlink PDCP SDU without a SN assigned or SDAP SDU is forwarded. No uplink PDCP SDU or SDAP SDU is forwarded.

- The source gNB sends the EARLY STATUS TRANSFER message to maintain HFN continuity by indicating PDCP SN and HFN of the first PDCP SDU that the source gNB forwards to the target gNB. The subsequent messages may be sent for discarding of already forwarded downlink PDCP SDUs in the target gNB.

- The source gNB does not stop transmitting downlink packets to the UE. The source gNB keeps forwarding to the 5GC the uplink SDAP SDUs successfully received in-sequence from the UE.

Handling of end marker packets:

- The source NG-RAN node receives one or several GTP-U end marker packets per PDU session from the UPF and replicates the end marker packets into each data forwarding tunnel when no more user data packets are to be forwarded over that tunnel.

- End marker packets sent via a data forwarding tunnel are applicable to all QoS flows forwarded via that tunnel. After end marker packets have been received over a forwarding tunnel, the target NG-RAN node can start taking into account the packets of QoS flows associated with that forwarding tunnel received at the target NG-RAN node from the NG-U PDU session tunnel.

#### 9.2.3.3 Re-establishment procedure

A UE in RRC\_CONNECTED may initiate the re-establishment procedure to continue the RRC connection when a failure condition occurs (e.g. radio link failure, reconfiguration failure, integrity check failure…).

The following figure describes the re-establishment procedure started by the UE:



Figure 9.2.3.3-1: Re-establishment procedure

1. The UE re-establishes the connection, providing the UE Identity (PCI+C-RNTI) to the gNB where the trigger for the re-establishment occurred.

2. If the UE Context is not locally available, the gNB, requests the last serving gNB to provide UE Context data.

3. The last serving gNB provides UE context data.

4/4a. The gNB continues the re-establishment of the RRC connection. The message is sent on SRB1.

5/5a. The gNB may perform the reconfiguration to re-establish SRB2 and DRBs when the re-establishment procedure is ongoing.

6/7. If loss of user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses, and the last serving gNB provides the SN status to the gNB.

8/9. The gNB performs path switch.

10. The gNB triggers the release of the UE resources at the last serving gNB.

The IAB-MT in SA mode follows the same re-establishment procedure as described for the UE. After the backhaul has been established, the re-establishment procedure of the IAB-MT is part of the intra-CU backhaul RLF recovery procedure for IAB-nodes defined in TS 38.401 [4]. Modifications to the configuration of BAP sublayer and higher protocol layers above the BAP sublayer are described in TS 38.401 [4].

#### 9.2.3.4 Conditional Handover

##### 9.2.3.4.1 General

A Conditional Handover (CHO) is defined as a handover that is executed by the UE when one or more handover execution conditions are met. The UE starts evaluating the execution condition(s) upon receiving the CHO configuration, and stops evaluating the execution condition(s) once a handover is executed.

The following principles apply to CHO:

- The CHO configuration contains the configuration of CHO candidate cell(s) generated by the candidate gNB(s) and execution condition(s) generated by the source gNB.

- An execution condition may consist of one or two trigger condition(s) (CHO events A3/A5, as defined in [12]). Only single RS type is supported and at most two different trigger quantities (e.g. RSRP and RSRQ, RSRP and SINR, etc.) can be configured simultaneously for the evalution of CHO execution condition of a single candidate cell.

- Before any CHO execution condition is satisfied, upon reception of HO command (without CHO configuration) or LTM cell switch command MAC CE, the UE executes the HO procedure as described in clause 9.2.3.2 or LTM cell switch procedure as described in clause 9.2.3.5, regardless of any previously received CHO configuration.

- While executing CHO, i.e. from the time when the UE starts synchronization with target cell, UE does not monitor source cell.

CHO is also supported for the IAB-MT in context of intra- and inter-donor IAB-node migration and BH RLF recovery.

CHO is not supported for NG-C based handover in this release of the specification.

##### 9.2.3.4.2 C-plane handling

As in intra-NR RAN handover, in intra-NR RAN CHO, the preparation and execution phase of the conditional handover procedure is performed without involvement of the 5GC; i.e. preparation messages are directly exchanged between gNBs. The release of the resources at the source gNB during the conditional handover completion phase is triggered by the target gNB. The figure below depicts the basic conditional handover scenario where neither the AMF nor the UPF changes:



Figure 9.2.3.4.2-1: Intra-AMF/UPF Conditional Handover

0/1. Same as step 0, 1 in Figure 9.2.3.2.1-1 of clause 9.2.3.2.1.

2. The source gNB decides to use CHO.

3. The source gNB requests CHO for one or more candidate cells belonging to one or more candidate gNBs. A CHO request message is sent for each candidate cell.

4. Same as step 4 in Figure 9.2.3.2.1-1 of clause 9.2.3.2.1.

5. The candidate gNB(s) sends CHO response (HO REQUEST ACKNOWLEDGE) including configuration of CHO candidate cell(s) to the source gNB. The CHO response message is sent for each candidate cell.

6. The source gNB sends an *RRCReconfiguration* message to the UE, containing the configuration of CHO candidate cell(s) and CHO execution condition(s).

NOTE 1: CHO configuration of candidate cells can be followed by another reconfiguration from the source gNB.

NOTE 1a: A configuration of a CHO candidate cell cannot contain a DAPS handover configuration.

7. The UE sends an *RRCReconfigurationComplete* message to the source gNB.

7a If early data forwarding is applied, the source gNB sends the EARLY STATUS TRANSFER message.

8. The UE maintains connection with the source gNB after receiving CHO configuration, and starts evaluating the CHO execution conditions for the candidate cell(s). If at least one CHO candidate cell satisfies the corresponding CHO execution condition, the UE detaches from the source gNB, applies the stored corresponding configuration for that selected candidate cell, synchronises to that candidate cell and completes the RRC handover procedure by sending *RRCReconfigurationComplete* message to the target gNB. The UE releases stored CHO configurations after successful completion of RRC handover procedure.

8a/b The target gNB sends the HANDOVER SUCCESS message to the source gNB to inform that the UE has successfully accessed the target cell. In return, the source gNB sends the SN STATUS TRANSFER message following the principles described in step 7 of Intra-AMF/UPF Handover in clause 9.2.3.2.1.

NOTE 2: Late data forwarding may be initiated as soon as the source gNB receives the HANDOVER SUCCESS message.

8c. The source gNB sends the HANDOVER CANCEL message toward the other signalling connections or other candidate target gNBs, if any, to cancel CHO for the UE.

##### 9.2.3.4.3 U-plane handling

The U-plane handling for Conditional Handover follows the same principles for DAPS handover in 9.2.3.2.2, if early data forwarding is applied, except that, in case of Full Configuration, HFN and PDCP SN are reset in the target gNB after the SN assignment is handed over to the target gNB. If late data forwarding is applied, the U-plane handling follows the RLC-AM or RLC-UM bearer principles defined in 9.2.3.2.2.

##### 9.2.3.4.4 Data Forwarding

If late data forwarding is applied, the source NG-RAN node initiates data forwarding once it knows which target NG-RAN node the UE has successfully accessed. In that case the behavior of the Conditional Handover data forwarding follows the same behavior as defined in 9.2.3.2.3 for the intra-system handover data forwarding, except the behavior for DRBs configured with DAPS handover.

If early data forwarding is applied instead, the source NG-RAN node initiates data forwarding before the UE executes the handover, to a candidate target node of interest. The behavior of early data forwarding for the Conditional Handover follows the same principles for DRBs configured with DAPS handover in the intra-system handover as defined in 9.2.3.2.3.

#### 9.2.3.5 L1/L2 Triggered Mobility

##### 9.2.3.5.1 General

LTM is a procedure in which a gNB receives L1 or L3 measurement report(s) from a UE, and on their basis the gNB may change UE serving cell by a cell switch command signalled via a MAC CE. The cell switch command indicates an LTM candidate configuration that the gNB previously prepared and provided to the UE through RRC signalling. Then the UE switches to the target configuration according to the cell switch command. The LTM procedure can be used to reduce the mobility latency as described in Annex G.

When configured by the network, it is possible to activate TCI states of one or multiple cells that are different from the current serving cell. For instance, the TCI states of the LTM candidate cells can be activated in advance before any of those cells become the serving cell. This allows the UE to be DL synchronized with those cells, thereby facilitating a faster cell switch to one of those cells when cell switch is triggered. All the activated TCI states except those received in the cell switch command are deactivated upon LTM cell switch execution.

When configured by the network, it is possible to initiate UL TA acquisition (called early TA) procedure of one or multiple cells that are different from the current serving cells. If the cell has the same NTA as the current serving cells or NTA=0, early TA acquisition procedure is not required. The network may request the UE to perform early TA acquisition of a candidate cell before a cell switch. The early TA acquisition procedure is triggered by PDCCH order as specified in clause 9.2.6 or realized through UE-based TA measurement as configured by RRC. In the former case, the gNB/gNB-DU to which the candidate cell belongs calculates the TA value and sends it to the gNB/gNB-DU to which the serving cell belongs via gNB-CU. The serving cell sends the TA value in the LTM cell switch command MAC CE when triggering LTM cell switch. In the latter case, the UE performs TA measurement for the candidate cells after being configured by RRC but the exact time the UE performs TA measurement is up to UE implementation. The UE applies the TA value measured by itself and performs RACH-less LTM upon receiving the cell switch command, if it does not include any valid TA value. The network may also send a TA value in the LTM cell switch command MAC CE without early TA acquisition.

When two TAG IDs are configured for an LTM candidate cell, the gNB-DU to which the LTM candidate cell belongs assigns the same TAG ID pointer value for each TRP to be used by the UEs.

Depending on the availability of a valid TA value, the UE performs either a RACH-less LTM or RACH-based LTM cell switch. If the valid TA value is provided in the cell switch command, the UE applies the TA value as instructed by the network. In the case where UE-based TA measurement is configured, but no valid TA value is provided in the cell switch command, the UE applies the valid TA value by itself if available. The UE performs RACH-less LTM cell switch upon receiving the cell switch command whenever a valid TA value is available. If no valid TA value is available, the UE performs RACH-based LTM cell switch.

Regardless of whether the UE is configured for UE-based TA measurement for a certain candidate cell, it will still follow the PDCCH order, which includes performing a random access procedure towards one or more candidate cells. This also applies to the candidate cells for which the UE is capable of deriving TA values by itself. Additionally, regardless of whether the UE has already performed a random access procedure towards the candidate cells, it will still follow the UE-based measurement configuration if configured by the network.

For RACH-less LTM, the UE accesses the target cell using either a configured grant or a dynamic grant. The configured grant is provided in the LTM candidate configuration, and the UE selects the configured grant occasion associated with the beam indicated in the cell switch command. Upon initiation of LTM cell switch to the target cell, the UE starts to monitor PDCCH on the target cell for dynamic scheduling. Before RACH-less LTM procedure completion, the UE shall not trigger random access procedure if it does not have a valid PUCCH resource for triggered SRs.

The following principles apply to LTM:

- Security keys are maintained upon an LTM cell switch;

- Subsequent LTM is supported.

LTM supports both intra-gNB-DU and inter-gNB-DU mobility within the same gNB-CU. LTM supports both intra-frequency and inter-frequency mobility, including mobility to inter-frequency cell that is not a current serving cell. LTM is supported only for licensed spectrum. The following scenarios are supported:

- PCell change in non-CA scenario and non-DC scenario;

- PCell and SCell(s) change in CA scenario;

- Dual connectivity scenario: including PCell and MCG SCell(s) change and intra-SN PSCell and SCG SCell(s) change without MN involvement. LTM for simultaneous PCell and PSCell change is not supported.

While the UE has stored LTM candidate configurations the UE can also execute any L3 handover except for DAPS handover. In the RRC message which the UE applies for any L3 handover (except DAPS), LTM candidate configurations can be added/modified/released by the target cell.

##### 9.2.3.5.2 C-Plane Handling

Cell switch command is conveyed in a MAC CE, which contains the necessary information to perform the LTM cell switch.

The overall procedure for LTM is shown in Figure 9.2.3.5.2-1 below. Subsequent LTM is done by repeating the early synchronization, LTM cell switch execution, and LTM cell switch completion steps without the need to release, reconfigure or add other LTM candidate configurations after each LTM cell switch completion. The general procedure over the air interface is applicable to SCG LTM. Further details of SCG LTM can be found in TS 37.340 [21].



Figure 9.2.3.5.2-1. Signalling procedure for LTM

The procedure for LTM is as follows:

1. The UE sends a *MeasurementReport* message to the gNB. The gNB decides to configure LTM and initiates LTM preparation.

2. The gNB transmits an *RRCReconfiguration* message to the UE including the LTM candidate configurations.

3. The UE stores the LTM candidate configurations and transmits an *RRCReconfigurationComplete* message to the gNB.

4a. The UE performs DL synchronization with the LTM candidate cell(s) before receiving the cell switch command. The UE may activate and deactivate TCI states of LTM candidate cell(s), as triggered by the gNB and defined in TS 38.133 [13].

4b. The UE may perform UL synchronization with LTM candidate cell(s) before receiving the cell switch command, by using UE-based TA measurement, if configured, and/or by transmitting a preamble towards the candidate cell, as triggered by the gNB. When UE-based TA measurement is configured, UE acquires the TA value(s) of the candidate cell(s) by measurement. UE performs early TA acquisition with the candidate cell(s) as requested by the network before receiving the cell switch command as specified in clause 9.2.6 and TS 38.133 [13]. This is done via CFRA triggered by a PDCCH order from the source cell, following which the UE sends preamble towards the indicated candidate cell. In order to minimize the data interruption of the source cell due to CFRA towards the candidate cell(s), the UE does not receive random access response from the network for the purpose of TA value acquisition and the TA value of the candidate cell is indicated in the cell switch command. The UE does not maintain the TA timer for the candidate cell and relies on network implementation to guarantee the TA validity.

5. The UE performs L1 measurements on the configured LTM candidate cell(s) and transmits L1 measurement reports to the gNB. L1 measurement should be performed as long as RRC reconfiguration (step 2) is applicable. The UE can also perform L3 measurement reporting to the gNB, including beam level measurement results on cell(s) which are configured as LTM candidate cell(s) according to the received network configuration.

6. The gNB decides to execute cell switch to a target cell and transmits an LTM cell switch command MAC CE triggering cell switch by including a target configuration ID which indicates the index of the candidate configuration of the target cell, a beam indicated with a TCI state or beams indicated with DL and UL TCI states, and a timing advance command for the target cell, if available. The UE switches to the target cell and applies the candidate configuration indicated by the target configuration ID.

7. The UE performs the random access procedure towards the target cell, if UE does not have valid TA of the target cell as specified in clause 5.18.35 of TS 38.321[6].

8. The UE completes the LTM cell switch procedure by sending *RRCReconfigurationComplete* message to target cell. If the UE has performed a RA procedure in step 7 the UE considers that LTM cell switch execution is successfully completed when the random access procedure is successfully completed. For RACH-less LTM, the UE considers that LTM cell switch execution is successfully completed when the UE determines that the network has successfully received its first UL data.

The steps 4-8 can be performed multiple times for subsequent LTM cell switch executions using the LTM candidate configuration(s) provided in step 2.

The procedure over the air interface described in Figure 9.2.3.5.2-1 is applicable to both intra-gNB-DU LTM and inter-gNB-DU LTM. The overall LTM procedures over F1-C interface are captured in TS 38.401[4].

##### 9.2.3.5.3 U-Plane Handling

After receiving an LTM cell switch command MAC CE, the UE performs MAC reset. Whether the UE performs RLC re-establishment and PDCP data recovery during cell switch is explicitly controlled by the network through RRC signalling.

#### 9.2.3.6 RACH-less handover

During intra-gNB HO procedure, RACH-less handover can be configured for a UE. The RACH-less handover procedure applies the following functionality:

- The UE uses the same timing advance value (i.e., NTA value) at the target cell as in the source cell or timing advance value (i.e., NTA value) of 0.

- The handover command for the UE may contain a beam identifier for the beam to be used by the UE at the target cell. The beam may be determined based on a UE measurement report and/or left up to gNB implementation, e.g., using the target cell's knowledge about the beam(s) used by the UE at the co-located source cell.

- The handover command may include a configured UL grant. UE can fallback to RACH when there is no valid configured uplink grant. Alternatively, an UL grant is dynamically signalled by the target cell.

- The UE transmits the *RRCReconfigurationComplete* message using the configured or dynamically signalled UL grant. Successful UL data reception on the target cell terminates the RACH-less handover execution.

### 9.2.4 Measurements

In RRC\_CONNECTED, the UE measures multiple beams (at least one) of a cell and the measurements results (power values) are averaged to derive the cell quality. In doing so, the UE is configured to consider a subset of the detected beams. Filtering takes place at two different levels: at the physical layer to derive beam quality and then at RRC level to derive cell quality from multiple beams. Cell quality from beam measurements is derived in the same way for the serving cell(s) and for the non-serving cell(s). Measurement reports may contain the measurement results of the *X* best beams if the UE is configured to do so by the gNB.

The corresponding high-level measurement model is described below:



Figure 9.2.4-1: Measurement Model

NOTE 1: K beams correspond to the measurements on SSB or CSI-RS resources configured for L3 mobility by gNB and detected by UE at L1.

- **A**: measurements (beam specific samples) internal to the physical layer.

- **Layer 1 filtering**: internal layer 1 filtering of the inputs measured at point A. Exact filtering is implementation dependent. How the measurements are actually executed in the physical layer by an implementation (inputs A and Layer 1 filtering) is not constrained by the standard.

- **A1**: measurements (i.e. beam specific measurements) reported by layer 1 to layer 3 after layer 1 filtering.

**- Beam Consolidation/Selection**: beam specific measurements are consolidated to derive cell quality. The behaviour of the Beam consolidation/selection is standardised and the configuration of this module is provided by RRC signalling. Reporting period at B equals one measurement period at A1.

**- B**: a measurement (i.e. cell quality) derived from beam-specific measurements reported to layer 3 after beam consolidation/selection.

- **Layer 3 filtering for cell quality**: filtering performed on the measurements provided at point B. The behaviour of the Layer 3 filters is standardised and the configuration of the layer 3 filters is provided by RRC signalling. Filtering reporting period at C equals one measurement period at B.

- **C**: a measurement after processing in the layer 3 filter. The reporting rate is identical to the reporting rate at point B. This measurement is used as input for one or more evaluation of reporting criteria.

- **Evaluation of reporting criteria**: checks whether actual measurement reporting is necessary at point D. The evaluation can be based on more than one flow of measurements at reference point C e.g. to compare between different measurements. This is illustrated by input C and C1. The UE shall evaluate the reporting criteria at least every time a new measurement result is reported at point C, C1. The reporting criteria are standardised and the configuration is provided by RRC signalling (UE measurements).

- **D**: measurement report information (message) sent on the radio interface.

- **L3 Beam filtering**: filtering performed on the measurements (i.e. beam specific measurements) provided at point A1. The behaviour of the beam filters is standardised and the configuration of the beam filters is provided by RRC signalling. Filtering reporting period at E equals one measurement period at A1.

- **E**: a measurement (i.e. beam-specific measurement) after processing in the beam filter. The reporting rate is identical to the reporting rate at point A1. This measurement is used as input for selecting the X measurements to be reported.

- **Beam Selection for beam reporting**: selects the X measurements from the measurements provided at point E. The behaviour of the beam selection is standardised and the configuration of this module is provided by RRC signalling.

- **F**: beam measurement information included in measurement report (sent) on the radio interface.

Layer 1 filtering introduces a certain level of measurement averaging. How and when the UE exactly performs the required measurements is implementation specific to the point that the output at B fulfils the performance requirements set in TS 38.133 [13]. Layer 3 filtering for cell quality and related parameters used are specified in TS 38.331 [12] and do not introduce any delay in the sample availability between B and C. Measurement at point C, C1 is the input used in the event evaluation. L3 Beam filtering and related parameters used are specified in TS 38.331 [12] and do not introduce any delay in the sample availability between E and F.

Measurement reports are characterized by the following:

- Measurement reports include the measurement identity of the associated measurement configuration that triggered the reporting;

- Cell and beam measurement quantities to be included in measurement reports are configured by the network;

- The number of non-serving cells to be reported can be limited through configuration by the network;

- Cells belonging to an exclude-list configured by the network are not used in event evaluation and reporting, and conversely when an allow-list is configured by the network, only the cells belonging to the allow-list are used in event evaluation and reporting;

- Beam measurements to be included in measurement reports are configured by the network (beam identifier only, measurement result and beam identifier, or no beam reporting).

Intra-frequency neighbour (cell) measurements and inter-frequency neighbour (cell) measurements are defined as follows:

- SSB based intra-frequency measurement: a measurement is defined as an SSB based intra-frequency measurement provided the center frequency of the SSB of the serving cell and the center frequency of the SSB of the neighbour cell are the same, and the subcarrier spacing of the two SSBs is also the same.

- SSB based inter-frequency measurement: a measurement is defined as an SSB based inter-frequency measurement provided the center frequency of the SSB of the serving cell and the center frequency of the SSB of the neighbour cell are different, or the subcarrier spacing of the two SSBs is different.

NOTE 2: For SSB based measurements, one measurement object corresponds to one SSB and the UE considers different SSBs as different cells.

NOTE 2a: If a UE is configured to perform serving cell measurements based on an NCD-SSB configured in its active BWP, this NCD-SSB is considered as the SSB of the serving cell in the definition of intra-frequency and inter-frequency measurements as above.

- CSI-RS based intra-frequency measurement: a measurement is defined as a CSI-RS based intra-frequency measurement provided that:

- The subcarrier spacing of CSI-RS resources on the neighbour cell configured for measurement is the same as the SCS of CSI-RS resources on the serving cell indicated for measurement; and

- For 60kHz subcarrier spacing, the CP type of CSI-RS resources on the neighbour cell configured for measurement is the same as the CP type of CSI-RS resources on the serving cell indicated for measurement; and

- The centre frequency of CSI-RS resources on the neighbour cell configured for measurement is the same as the centre frequency of CSI-RS resource on the serving cell indicated for measurement.

- CSI-RS based inter-frequency measurement: a measurement is defined as a CSI-RS based inter-frequency measurement if it is not a CSI-RS based intra-frequency measurement.

NOTE 3: Extended CP for CSI-RS based measurement is not supported in this release.

Whether a measurement is non-gap-assisted or gap-assisted depends on the capability of the UE, the active BWP of the UE and the current operating frequency:

- For SSB based inter-frequency measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided in the following cases:

- If the UE only supports per-UE measurement gaps;

- If the UE supports per-FR measurement gaps and any of the serving cells are in the same frequency range of the measurement object.

- For SSB based intra-frequency measurement, if the measurement gap requirement information is reported by the UE, a measurement gap configuration may be provided according to the information. Otherwise, a measurement gap configuration is always provided in the following case:

- Other than the initial BWP, if any of the UE configured BWPs do not contain the frequency domain resources of the SSB associated to the initial DL BWP, and are not configured with NCD-SSB for serving cell measurement.

- For CSI-RS based intra-frequency measurement, no measurement gap is needed;

- For CSI-RS based inter-frequency measurement, a measurement gap configuration is always provided in the following cases:

- If the UE only supports per-UE measurement gaps;

- If the UE supports per-FR measurement gaps and any of the serving cells are in the same frequency range of the measurement object.

In non-gap-assisted scenarios, the UE shall be able to carry out such measurements without measurement gaps. In gap-assisted scenarios, the UE cannot be assumed to be able to carry out such measurements without measurement gaps.

Network may request the UE to measure NR and/or E-UTRA carriers in RRC\_IDLE or RRC\_INACTIVE via system information or via dedicated measurement configuration in *RRCRelease*. If the UE was configured to perform measurements of NR and/or E-UTRA carriers while in RRC\_IDLE or in RRC\_INACTIVE, it may provide an indication of the availability of corresponding measurement results to the gNB in the *RRCSetupComplete* message. The network may request the UE to report those measurements after security activation. The request for the measurements can be sent by the network immediately after transmitting the Security Mode Command (i.e. before the reception of the Security Mode Complete from the UE).

If the UE was configured to perform measurements of NR and/or E-UTRA carriers while in RRC\_INACTIVE, the gNB can request the UE to provide corresponding measurement results in the *RRCResume* message and then the UE can include the available measurement results in the *RRCResumeComplete* message. Alternatively, the UE may provide an indication of the availability of the measurement results to the gNB in the *RRCResumeComplete* message and the gNB can then request the UE to provide these measurement results.

### 9.2.5 Paging

Paging allows the network to reach UEs in RRC\_IDLE and in RRC\_INACTIVE state through *Paging* messages, and to notify UEs in RRC\_IDLE, RRC\_INACTIVE and RRC\_CONNECTED state of system information change (see clause 7.3.3) and ETWS/CMAS indications (see clause 16.4) through *Short Messages*. Both *Paging* messages and *Short Messages* are addressed with P-RNTI on PDCCH, but while the former is sent on PCCH, the latter is sent over PDCCH directly (see clause 6.5 of TS 38.331 [12]).

While in RRC\_IDLE the UE monitors the paging channels for CN-initiated paging. While in RRC\_INACTIVE with no ongoing SDT procedure (see clause 18.0) the UE monitors paging channels for RAN-initiated paging and CN-initiated paging. A UE need not monitor paging channels continuously though; Paging DRX is defined where the UE in RRC\_IDLE or RRC\_INACTIVE is only required to monitor paging channels during one Paging Occasion (PO) per DRX cycle (see TS 38.304 [10]). The Paging DRX cycles are configured by the network:

1) For CN-initiated paging, a default cycle is broadcast in system information;

2) For CN-initiated paging, a UE specific cycle can be configured via NAS signalling;

3) For RAN-initiated paging, a UE-specific cycle is configured via RRC signalling;

- The UE uses the shortest of the DRX cycles applicable i.e. a UE in RRC\_IDLE uses the shortest of the first two cycles above, while a UE in RRC\_INACTIVE uses the shortest of the three.

The POs of a UE for CN-initiated and RAN-initiated paging are based on the same UE ID, resulting in overlapping POs for both. The number of different POs in a DRX cycle is configurable via system information and a network may distribute UEs to those POs based on their IDs.

While in RRC\_CONNECTED and while in RRC\_INACTIVE with ongoing SDT procedure, the UE monitors the paging channels in any PO signalled in system information for SI change indication and PWS notification. In case of BA, a UE in RRC\_CONNECTED only monitors paging channels on the active BWP with common search space configured.

For operation with shared spectrum channel access, a UE can be configured for an additional number of PDCCH monitoring occasions in its PO to monitor for paging. However, when the UE detects a PDCCH transmission within the UE's PO addressed with P-RNTI, the UE is not required to monitor the subsequent PDCCH monitoring occasions within this PO.

If Paging Cause is included in the Paging message, a UE in RRC\_IDLE or RRC\_INACTIVE state may use the Paging Cause as per TS 23.501[3].

**Paging optimization for UEs in CM\_IDLE**: at UE context release, the NG-RAN node may provide the AMF with a list of recommended cells and NG-RAN nodes as assistance info for subsequent paging. The AMF may also provide Paging Attempt Information consisting of a Paging Attempt Count and the Intended Number of Paging Attempts and may include the Next Paging Area Scope. If Paging Attempt Information is included in the Paging message, each paged NG-RAN node receives the same information during a paging attempt. The Paging Attempt Count shall be increased by one at each new paging attempt. The Next Paging Area Scope, when present, indicates whether the AMF plans to modify the paging area currently selected at next paging attempt. If the UE has changed its state to CM CONNECTED the Paging Attempt Count is reset.

**Paging optimization for UEs in RRC\_INACTIVE**: at RAN Paging, the serving NG-RAN node provides RAN Paging area information. The serving NG-RAN node may also provide RAN Paging attempt information. Each paged NG-RAN node receives the same RAN Paging attempt information during a paging attempt with the following content: Paging Attempt Count, the intended number of paging attempts and the Next Paging Area Scope. The Paging Attempt Count shall be increased by one at each new paging attempt. The Next Paging Area Scope, when present, indicates whether the serving NG\_RAN node plans to modify the RAN Paging Area currently selected at next paging attempt. If the UE leaves RRC\_INACTIVE state the Paging Attempt Count is reset.

**UE power saving for paging monitoring:** in order to reduce UE power consumption due to false paging alarms, the group of UEs monitoring the same PO can be further divided into multiple subgroups. With subgrouping, a UE shall monitor PDCCH in its PO for paging if the subgroup to which the UE belongs is paged as indicated via associated PEI. If a UE cannot find its subgroup ID with the PEI configurations in a cell or if the UE is unable to monitor the associated PEI occasion corresponding to its PO, it shall monitor the paging in its PO.

These subgroups have the following characteristics:

- They are formed based on either CN controlled subgrouping or UE ID based subgrouping;

- If CN controlled subgroup ID is not provided from AMF, UE ID based subgrouping is used if supported by the UE and network;

- The RRC state (RRC\_IDLE or RRC\_INACTIVE state) does not impact which subgroup the UE belongs to;

- Subgrouping support for a cell is broadcast in the system information as one of the following: Only CN controlled subgrouping supported, only UE ID based subgrouping supported, or both CN controlled subgrouping and UE ID based subgrouping supported;

- Total number of subgroups allowed in a cell is up to 8 and represents the sum of CN controlled and UE ID based subgrouping configured by the network;

- A UE configured with CN controlled subgroup ID applies CN controlled subgroup ID if the cell supports CN controlled subgrouping; otherwise, it derives UE ID based subgroup ID if the cell supports only UE ID based subgrouping.

PEI associated with subgroups has the following characteristics:

- If the PEI is supported by the UE, it shall at least support UE ID based subgrouping method;

- PEI monitoring can be limited via system information to the last used cell (i.e., the cell in which the UE most recently received *RRCRelease* without indicating that the last used cell for PEI shall not be updated);

- A PEI-capable UE shall store its last used cell information;

- gNBs supporting the PEI monitoring to the last used cell function provide the UE's last used cell information to the AMF in the NG-AP UE Context Release Complete message for PEI capable UEs, as described in TS 38.413 [26];

- UE that expects MBS group notification shall ignore the PEI and shall monitor paging in its PO.

**CN controlled subgrouping:** For CN controlled subgrouping, AMF is responsible for assigning subgroup ID to the UE. The total number of subgroups for CN controlled subgrouping which can be configured, e.g. by OAM is up to 8. It is assumed that CN controlled subgrouping support is homogeneous within an RNA.

The following figure describes the procedure for CN controlled subgrouping:



Figure 9.2.5-1: Procedure for CN controlled subgrouping

1. The UE indicates its support of CN controlled subgrouping via NAS signalling.

2. If the UE supports CN controlled subgrouping, the AMF determines the subgroup ID assignment for the UE.

3. The AMF sends subgroup ID to the UE via NAS signalling.

4. The AMF informs the gNB about the CN assigned subgroup ID for paging the UE in RRC\_IDLE/ RRC\_INACTIVE state.

5. When the paging message for the UE is received from the CN or is generated by the gNB, the gNB determines the PO and the associated PEI occasion for the UE.

6. Before the UE is paged in the PO, the gNB transmits the associated PEI and indicates the corresponding CN controlled subgroup of the UE that is to be paged in the PEI.

**UE ID based subgrouping:** For UE ID based subgrouping, the gNB and UE can determine the subgroup ID based on the UE ID and the total number of subgroups for UE ID based subgrouping in the cell. The total number of subgroups for UE ID based subgrouping is decided by the gNB for each cell and can be different in different cells. The following figure describes the procedure for UE ID based subgrouping:



Figure 9.2.5-2: Procedure for UE ID based subgrouping

1. The gNB determines the total number of subgroups for UE ID based subgrouping in a cell.

2. The gNB broadcasts the total number of subgroups for UE ID based subgrouping in a cell.

3. UE determines its subgroup in a cell.

4. When paging message for the PEI capable UE is received from the CN at the gNB or is generated by the gNB, the gNB determines the PO and the associated PEI occasion for the UE.

5. Before the UE is paged in the PO, the gNB transmits the associated PEI and indicates the corresponding subgroup derived based on UE ID of the UE that is paged in the PEI.

**Paging adaptation for cell level energy saving** **for UEs in CM\_IDLE and RRC\_INACTIVE**: in order to increase gNB sleeping time, the value of N and Ns are extended to concentrate the POs in sparser PFs. The UE supporting paging adaptation shall monitor PDCCH in POs separately signalled for these paging adaptations, if configured.

Editor’s note: FFS if any additional changes in this section are needed for paging adaptation and PEI configuration/handling.

### 9.2.6 Random Access Procedure

The random access procedure is triggered by a number of events:

- Initial access from RRC\_IDLE;

- RRC Connection Re-establishment procedure;

- DL or UL data arrival, during RRC\_CONNECTED or during RRC\_INACTIVE while SDT procedure (see clause 18.0) is ongoing, when UL synchronisation status is "non-synchronised";

- UL data arrival, during RRC\_CONNECTED or during RRC\_INACTIVE while SDT procedure is ongoing, when there are no PUCCH resources for SR available;

- Handover, except for when RACH-less HO is configured;

- SR failure;

- Explicit request by RRC upon synchronous reconfiguration;

- RRC Connection Resume procedure from RRC\_INACTIVE;

- To establish time alignment for a primary or a secondary TAG;

- Request for Other SI (see clause 7.3);

- Request for OD-SIB1 (see clause 7.3);

- Beam failure recovery;

- Consistent UL LBT failure on SpCell;

- SDT in RRC\_INACTIVE (see clause 18);

- Positioning purpose during RRC\_CONNECTED requiring random access procedure, e.g., when timing advance is needed for UE positioning;

- Early UL synchronization with an LTM candidate cell;

- RACH-based LTM cell switch.

Two types of random access procedure are supported: 4-step RA type with MSG1 and 2-step RA type with MSGA. Both types of RA procedure support contention-based random access (CBRA) and contention-free random access (CFRA) as shown on Figure 9.2.6-1 below.

The UE selects the type of random access at initiation of the random access procedure based on network configuration:

- when CFRA resources are not configured, an RSRP threshold is used by the UE to select between 2-step RA type and 4-step RA type;

- when CFRA resources for 4-step RA type are configured, UE performs random access with 4-step RA type;

- when CFRA resources for 2-step RA type are configured, UE performs random access with 2-step RA type.

The network does not configure CFRA resources for 4-step and 2-step RA types at the same time for a Bandwidth Part (BWP). CFRA with 2-step RA type is only supported for handover.

The MSG1 of the 4-step RA type consists of a preamble on PRACH. After MSG1 transmission, the UE monitors for a response from the network within a configured window. For CFRA, dedicated preamble for MSG1 transmission is assigned by the network and upon receiving random access response from the network, the UE ends the random access procedure as shown in Figure 9.2.6-1(c). For CBRA, upon reception of the random access response, the UE sends MSG3 using the UL grant scheduled in the response and monitors contention resolution as shown in Figure 9.2.6-1(a). If contention resolution is not successful after MSG3 (re)transmission(s), the UE goes back to MSG1 transmission.

The MSGA of the 2-step RA type includes a preamble on PRACH and a payload on PUSCH. After MSGA transmission, the UE monitors for a response from the network within a configured window. For CFRA, dedicated preamble and PUSCH resource are configured for MSGA transmission and upon receiving the network response, the UE ends the random access procedure as shown in Figure 9.2.6-1(d). For CBRA, if contention resolution is successful upon receiving the network response, the UE ends the random access procedure as shown in Figure 9.2.6-1(b); while if fallback indication is received in MSGB, the UE performs MSG3 transmission using the UL grant scheduled in the fallback indication and monitors contention resolution as shown in Figure 9.2.6-2. If contention resolution is not successful after MSG3 (re)transmission(s), the UE goes back to MSGA transmission.

If the random access procedure with 2-step RA type is not completed after a number of MSGA transmissions, the UE can be configured to switch to CBRA with 4-step RA type.

For the random access procedure towards an LTM candidate cell for early UL TA acquisition, CFRA triggered by a PDCCH order is used. The UE sends MSG1 towards the cell without monitoring for a response from it as shown in Figure 9.2.6-1 (e). To support UE power ramping, the UE may perform MSG1 retransmission as indicated by the network.

 

(a) CBRA with 4-step RA type (b) CBRA with 2-step RA type

 

(c) CFRA with 4-step RA type (d) CFRA with 2-step RA type



(e) CFRA without network response with 4-step RA type

Figure 9.2.6-1: Random Access Procedures



Figure 9.2.6-2: Fallback for CBRA with 2-step RA type

For random access in a cell configured with SUL, the network can explicitly signal which carrier to use (UL or SUL). Otherwise, the UE selects the SUL carrier if and only if the measured quality of the DL is lower than a broadcast threshold. UE performs carrier selection before selecting between 2-step and 4-step RA type. The RSRP threshold for selecting between 2-step and 4-step RA type can be configured separately for UL and SUL. Once started, all uplink transmissions of the random access procedure remain on the selected carrier.

The network can associate a set of RACH resources with feature(s) applicable to a Random Access procedure: Network Slicing (see clause 16.3), (e)RedCap (see clause 16.13), SDT (see clause 18), and NR coverage enhancement (see clause 19). A set of RACH resources associated with a feature is only valid for random access procedures applicable to at least that feature; and a set of RACH resources associated with several features is only valid for random access procedures having at least all of these features. The UE selects the set(s) of applicable RACH resources, after uplink carrier (i.e. NUL or SUL) and BWP selection and before selecting the RA type.

When CA is configured, random access procedure with 2-step RA type is only performed on PCell while contention resolution can be cross-scheduled by the PCell.

When CA is configured, for random access procedure with 4-step RA type, the first three steps of CBRA always occur on the PCell while contention resolution (step 4) can be cross-scheduled by the PCell. The three steps of a CFRA started on the PCell remain on the PCell. CFRA on SCell can only be initiated by the gNB to establish timing advance for a secondary TAG: the procedure is initiated by the gNB with a PDCCH order (step 0) that is sent on an activated SCell of the secondary TAG, preamble transmission (step 1) takes place on the SCell, and Random Access Response (step 2) takes place on PCell.

When two TAG IDs are configured for the serving cell, the TAG for which the TA command is applied is indicated in Random Access Response message or in MSGB. To establish timing advance for the other PTAG, CFRA is initiated by the gNB with a PDCCH order.

Editor’s note: FFS if any changes in this section are needed for OD-SIB1 and RACH adaptation.

### 9.2.7 Radio Link Failure

In RRC\_CONNECTED, the UE performs Radio Link Monitoring (RLM) in the active BWP based on reference signals (SSB/CSI-RS) and signal quality thresholds configured by the network. SSB-based RLM is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWP, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and, if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. Besides, SSB-based RLM can be also performed based on a non-cell defining SSB, if configured for the active DL BWP. RLM can be also performed based on CSI-RS, if configured for the active DL BWP. In case of DAPS handover, the UE continues the detection of radio link failure at the source cell until the successful completion of the random access procedure to the target cell.

The UE declares Radio Link Failure (RLF) when one of the following criteria are met:

- Expiry of a radio problem timer started after indication of radio problems from the physical layer (if radio problems are recovered before the timer is expired, the UE stops the timer); or

- Expiry of a timer started upon triggering a measurement report for a measurement identity for which the timer has been configured while another radio problem timer is running; or

- Random access procedure failure; or

- RLC failure; or

- Detection of consistent uplink LBT failures for operation with shared spectrum channel access as described in 5.6.1; or

- For IAB-MT, the reception of a BH RLF indication received from its parent node.

After RLF is declared, the UE:

- stays in RRC\_CONNECTED;

- in case of DAPS handover, for RLF in the source cell:

- stops any data transmission or reception via the source link and releases the source link, but maintains the source RRC configuration;

- if handover failure is then declared at the target cell, the UE:

- selects a suitable cell and then initiates RRC re-establishment;

- enters RRC\_IDLE if a suitable cell was not found within a certain time after handover failure was declared.

- in case of CHO, for RLF in the source cell:

- selects a suitable cell and if the selected cell is a CHO candidate and if network configured the UE to try CHO after RLF then the UE attempts CHO execution once, otherwise re-establishment is performed;

- enters RRC\_IDLE if a suitable cell was not found within a certain time after RLF was declared.

- in case of MCG LTM, for RLF in the source cell:

- selects a suitable cell and if the selected cell is an LTM candidate cell and if network configured the UE to try LTM after RLF then the UE attempts RACH-based LTM execution once, otherwise re-establishment is performed;

- enters RRC\_IDLE if a suitable cell was not found within a certain time after RLF was declared.

- otherwise, for RLF in the serving cell or in case of DAPS handover, for RLF in the target cell before releasing the source cell:

- selects a suitable cell and then initiates RRC re-establishment;

- enters RRC\_IDLE if a suitable cell was not found within a certain time after RLF was declared.

When RLF occurs at the IAB BH link, the same mechanisms and procedures are applied as for the access link. This includes BH RLF detection and RLF recovery.

The IAB-DU can transmit a BH RLF detection indication to its child nodes in the following cases:

- The collocated IAB-MT initiates RRC re-establishment;

- The collocated IAB-MT is dual-connected, detects BH RLF on a BH link, and cannot perform UL re-routing for any traffic. This includes the scenario of an IAB-node operating in EN-DC or NR-DC, which uses only one link for backhauling and has BH RLF on this BH link;

- The collocated IAB-MT has received a BH RLF detection indication from a parent node, and there is no remaining backhaul link that is unaffected by the BH RLF condition indicated.

Upon reception of the BH RLF detection indication, the child node may perform local rerouting for upstream traffic, if possible, over an available BH link.

If the IAB-DU has transmitted a BH RLF detection indication to a child node due to an RLF condition on the collocated IAB-MT's parent link, and the collocated IAB-MT's subsequent RLF recovery is successful, the IAB-DU may transmit a BH RLF recovery indication to this child node.

If the IAB-DU has transmitted a BH RLF detection indication to a child node due to the reception of a BH RLF detection indication by the collocated IAB-MT, and the collocated IAB-MT receives a BH RLF recovery indication, the IAB-DU may also transmit a BH RLF recovery indication to this child node.

Upon reception of the BH RLF recovery indication, the child node reverts the actions triggered by the reception of the previous BH RLF detection indication.

In case the RRC re-establishment procedure fails, the IAB-node may transmit a BH RLF indication to its child nodes. The BH RLF detection indication, BH RLF recovery indication and BH RLF indication are transmitted as BAP Control PDUs.

Editor’s note: FFS if any changes in this section are needed for OD-SIB1.

### 9.2.8 Beam failure detection and recovery

For beam failure detection, the gNB configures the UE with beam failure detection reference signals (SSB or CSI-RS) and the UE declares beam failure when the number of beam failure instance indications from the physical layer reaches a configured threshold before a configured timer expires. For beam failure detection in multi-TRP operation, the gNB configures the UE with two sets of beam failure detection reference signals, and the UE declares beam failure for a TRP / BFD-RS set when the number of beam failure instance indications associated with the corresponding set of beam failure detection reference signals from the physical layer reaches a configured threshold before a configured timer expires.

SSB-based Beam Failure Detection is based on the CD-SSB associated to the initial DL BWP and can be configured for the initial DL BWPs, for DL BWPs containing the CD-SSB associated to the initial DL BWP, and, if supported, for DL BWPs not containing the CD-SSB associated to the initial DL BWP. Besides, SSB-based Beam Failure Detection can be also performed based on the non-cell defining SSB, if configured for the active DL BWP. Beam Failure Detection can be also performed based on CSI-RS, if configured for the active DL BWP.

After beam failure is detected on PCell, the UE:

- triggers beam failure recovery by initiating a Random Access procedure on the PCell;

- selects a suitable beam to perform beam failure recovery (if the gNB has provided dedicated Random Access resources for certain beams, those will be prioritized by the UE).

- includes an indication of a beam failure on PCell in a BFR MAC CE if the Random Access procedure involves contention-based random access.

Upon completion of the Random Access procedure, beam failure recovery for PCell is considered complete.

After beam failure is detected on an SCell, the UE:

- triggers beam failure recovery by initiating a transmission of a BFR MAC CE for this SCell;

- selects a suitable beam for this SCell (if available) and indicates it along with the information about the beam failure in the BFR MAC CE.

Upon reception of a PDCCH indicating an uplink grant for a new transmission for the HARQ process used for the transmission of the BFR MAC CE, beam failure recovery for this SCell is considered complete.

After beam failure is detected for a BFD-RS set of a Serving Cell, the UE:

- triggers beam failure recovery by initiating a transmission of a BFR MAC CE for this BFD-RS set;

- selects a suitable beam for this BFD-RS set (if available) and indicates whether the suitable (new) beam is found or not along with the information about the beam failure in the BFR MAC CE for this BFD-RS set.

Upon reception of a PDCCH indicating an uplink grant for a new transmission for the HARQ process used for the transmission of the BFR MAC CE for this BFD-RS set, beam failure recovery for this BFD-RS set is considered complete.

After beam failure is detected for both BFD-RS sets of PCell concurrently, the UE:

- triggers beam failure recovery by initiating a Random Access procedure on the PCell;

- selects a suitable beam for each failed BFD-RS set (if available) and indicates whether the suitable (new) beam is found or not along with the information about the beam failure in the BFR MAC CE for each failed BFD-RS set;

- upon completion of the Random Access procedure, beam failure recovery for both BFD-RS sets of PCell is considered complete.

### 9.2.9 Timing Advance

In RRC\_CONNECTED, the gNB is responsible for maintaining the timing advance to keep the L1 synchronised. Serving cells having UL to which the same timing advance applies and using the same timing reference cell are grouped in a TAG. Each TAG contains at least one serving cell with configured uplink, and the mapping of each serving cell to a TAG is configured by RRC.

For the primary TAG the UE uses the PCell as timing reference, except with shared spectrum channel access where an SCell can also be used in certain cases (see clause 7.1, TS 38.133 [13]). In a secondary TAG, the UE may use any of the activated SCells of this TAG as a timing reference cell, but should not change it unless necessary.

Timing advance updates are signalled by the gNB to the UE via MAC CE commands. Such commands restart a TAG-specific timer which indicates whether the L1 can be synchronised or not: when the timer is running, the L1 is considered synchronised, otherwise, the L1 is considered non-synchronised (in which case uplink transmission can only take place through MSG1/MSGA).

When two TAG IDs are configured for the PCell, both TAGs are regarded as primary TAG.

### 9.2.10 Extended DRX for RRC\_IDLE and RRC\_INACTIVE

When extended DRX (eDRX) is used, the following applies:

- For RRC\_INACTIVE, eDRX configuration for RAN paging is decided and configured by NG-RAN. In RRC\_INACTIVE the UE monitors both RAN and CN paging;

- For RRC\_IDLE, eDRX for CN paging is configured by upper layers. In RRC\_IDLE the UE monitors only CN paging;

- Information on whether eDRX for CN paging and RAN paging is allowed on the cell is provided separately in system information;

- The maximum value of the eDRX cycle is 10485.76 seconds (2.91 hours) while the minimum value of the eDRX cycle is 2.56 seconds;

- The hyper SFN (H-SFN) is broadcast by the cell and increments by one when the SFN wraps around;

- Paging Hyperframe (PH) refers to the H-SFN in which the UE starts monitoring paging according to DRX during a Paging Time Window (PTW). The PH and PTW are determined based on a formula (see TS 38.304 [10]) that is known by the AMF, UE and NG-RAN;

- H-SFN, PH and PTW are used if the eDRX cycle is greater than 10.24 seconds;

- When the RRC\_IDLE eDRX cycle is longer than the system information modification period, the UE verifies that stored system information remains valid before resuming/establishing an RRC connection.

*Unchanged Text is omitted*

# 11 UE Power Saving

The PDCCH monitoring activity of the UE in RRC connected mode is governed by DRX, BA, DCP and cell DTX (see clause 15.4.2.3).

When DRX is configured, the UE does not have to continuously monitor PDCCH. DRX is characterized by the following:

- **on-duration**: duration that the UE waits for, after waking up, to receive PDCCHs. If the UE successfully decodes a PDCCH, the UE stays awake and starts the inactivity timer;

- **inactivity-timer**: duration that the UE waits to successfully decode a PDCCH, from the last successful decoding of a PDCCH, failing which it can go back to sleep. The UE shall restart the inactivity timer following a single successful decoding of a PDCCH for a first transmission only (i.e. not for retransmissions);

- **retransmission-timer**: duration until a retransmission can be expected;

- **cycle**: specifies the periodic repetition of the on-duration followed by a possible period of inactivity (see figure 11-1 below);

**- active-time**: total duration that the UE monitors PDCCH. This includes the "on-duration" of the DRX cycle, the time UE is performing continuous reception while the inactivity timer has not expired, and the time when the UE is performing continuous reception while waiting for a retransmission opportunity.



Figure 11-1: DRX Cycle

A SL UE can be configured with DRX, in which case, PDCCH providing SL grants can be send to the UE only during its active time.

When BA is configured, the UE only has to monitor PDCCH on the one active BWP i.e. it does not have to monitor PDCCH on the entire DL frequency of the cell. A BWP inactivity timer (independent from the DRX inactivity-timer described above) is used to switch the active BWP to the default one: the timer is restarted upon successful PDCCH decoding and the switch to the default BWP takes place when it expires.

In addition, the UE may be indicated, when configured accordingly, whether it is required to monitor or not the PDCCH during the next occurrence of the on-duration by a DCP monitored on the active BWP. If the UE does not detect a DCP on the active BWP, it does not monitor the PDCCH during the next occurrence of the on-duration, unless it is explicitly configured to do so in that case.

A UE can only be configured to monitor DCP when connected mode DRX is configured, and at occasion(s) at a configured offset before the on-duration. More than one monitoring occasion can be configured before the on-duration. The UE does not monitor DCP on occasions occurring during active-time, measurement gaps, BWP switching, or when it monitors response for a CFRA preamble transmission for beam failure recovery (see clause 9.2.6), in which case it monitors the PDCCH during the next on-duration. If no DCP is configured in the active BWP, UE follows normal DRX operation.

When CA is configured, DCP is only configured on the PCell.

One DCP can be configured to control PDCCH monitoring during on-duration for one or more UEs independently.

Power saving in RRC\_IDLE and RRC\_INACTIVE can also be achieved by UE relaxing neighbour cells RRM measurements when it meets the criteria determining it is in low mobility and/or not at cell edge. When UE is configured with both high speed measurements and RRM measurement relaxation as specified in TS 38.331 [12], it is up to UE implementation whether to apply the FR1 high speed RRM requirements or the relaxed RRM requirements when the low mobility related criterion is configured and fulfilled as specified in TS 38.133 [13].

UE power saving may be enabled by adapting the DL maximum number of MIMO layers by BWP switching.

Power saving is also enabled during active-time via cross-slot scheduling, which facilitates UE to achieve power saving with the assumption that it won't be scheduled to receive PDSCH, triggered to receive A-CSI or transmit a PUSCH scheduled by the PDCCH until the minimum scheduling offsets K0 and K2. Dynamic adaptation of the minimum scheduling offsets K0 and K2 is controlled by PDCCH.

Serving Cells of a MAC entity may be configured by RRC in two DRX groups with separate DRX parameters. When RRC does not configure a secondary DRX group, there is only one DRX group and all Serving Cells belong to that one DRX group. When two DRX groups are configured, each Serving Cell is uniquely assigned to either of the two groups. The DRX parameters that are separately configured for each DRX group are on-duration and inactivity-timer.

UE power saving in RRC\_IDLE/RRC\_INACTIVE may be achieved by providing the configuration for TRS with CSI-RS for tracking in TRS occasions. The TRS in TRS occasions may allow UEs in RRC\_IDLE/RRC\_INACTIVE to sleep longer before waking-up for its paging occasion. The TRS occasions configuration is provided in either SIB17 or SIB17bis. The availability of TRS in the TRS occasions is indicated by L1 availability indication. These TRSs may also be used by the UEs configured with eDRX.

UE power saving may be achieved by UE relaxing measurements for RLM/BFD. When configured, UE determines whether it is in low mobility state and/or whether its serving cell radio link quality is better than a threshold. The configuration for low mobility and good serving cell quality criterion is provided through dedicated RRC signalling.

RLM and BFD relaxation may be enabled/disabled separately through RRC Configuration. Additionally, RLM relaxation may be enabled/disabled on per Cell Group basis while BFD relaxation may be enabled/disabled on per serving cell basis.

The UE is only allowed to perform RLM and/or BFD relaxation when relaxed measurement criterion for low mobility and/or for good serving cell quality is met. If configured to do so, the UE shall trigger reporting of its RLM and/or BFD relaxation status through UE assistance information if the UE changes its respective RLM and/or BFD relaxation status while meeting the UE minimum requirements specified in TS 38.133 [13].

UE power saving may also be achieved through PDCCH monitoring adaptation mechanisms when configured by the network, including skipping of PDCCH monitoring and Search space set group (SSSG) switching. In this case UE does not monitor PDCCH during the PDCCH skipping duration except for the cases as specified in TS 38.213 [38], or monitors PDCCH according to the search space sets applied in SSSG.

*Unchanged Text is omitted*

# 14 UE Capabilities

The UE capabilities in NR rely on a hierarchical structure where each capability parameter is defined per UE, per duplex mode (FDD/TDD), per frequency range (FR1/FR2), per band, per band combinations, … as the UE may support different functionalities depending on those (see TS 38.306 [11]).

NOTE 1: Some capability parameters are always defined per UE (e.g. SDAP, PDCP and RLC parameters) while some other not always (e.g. MAC and Physical Layer Parameters).

The UE capabilities in NR do not rely on UE categories: UE categories associated to fixed peak data rates are only defined for marketing purposes and not signalled to the network. Instead, the peak data rate for a given set of aggregated carriers in a band or band combination is the sum of the peak data rates of each individual carrier in that band or band combination, where the peak data rate of each individual carrier is computed according to the capabilities supported for that carrier in the corresponding band or band combination.

For each block of contiguous serving cells in a band, the set of features supported thereon is defined in a Feature Set (FS). The UE may indicate several Feature Sets for a band (also known as feature sets per band) to advertise different alternative features for the associated block of contiguous serving cells in that band. The two-dimensional matrix of feature sets for all the bands of a band combination (i.e. all the feature sets per band) is referred to as a feature set combination. In a feature set combination, the number of feature sets per band is equal to the number of band entries in the corresponding band combination, and all feature sets per band have the same number of feature sets. Each band combination is linked to one feature set combination. This is depicted on Figure 14-1 below:



Figure 14-1: Feature Set Combinations

In addition, for some features in intra-band contiguous CA, the UE reports its capabilities individually per carrier. Those capability parameters are sent in feature set per component carrier and they are signalled in the corresponding FSs (per Band) i.e. for the corresponding block of contiguous serving cells in a band. The capability applied to each individual carrier in a block is agnostic to the order in which they are signalled in the corresponding FS.

NOTE 2: For intra-band non-contiguous CA, there are as many feature sets per band signalled as the number of (groups of contiguous) carriers that the UE is able to aggregate non-contiguously in the corresponding band.

To limit signalling overhead, the gNB can request the UE to provide NR capabilities for a restricted set of bands. When responding, the UE can skip a subset of the requested band combinations according to the UE capability fallback behaviour as specified in TS 38.306 [11] and in TS 38.331 [12]. An eRedCap UE may ignore UE capability filtering and send all supported bands in the mirrored UE capability filter with an explicit indication on whether the filter was ignored or not.

If supported by the UE and the network, the UE may provide an ID in NAS signalling that represents its radio capabilities for one or more RATs in order to reduce signalling overhead. The ID may be assigned either by the manufacturer or by the serving PLMN. The manufacturer-assigned ID corresponds to a pre-provisioned set of capabilities. In the case of the PLMN-assigned ID, assignment takes place in NAS signalling.

The AMF stores the UE Radio Capability uploaded by the gNB as specified in TS 23.501 [3].

The gNB can request the UE capabilities for RAT-Types NR, EUTRA, UTRA-FDD. The UTRAN capabilities, i.e. the INTER RAT HANDOVER INFO, include START-CS, START-PS and "predefined configurations", which are "dynamic" IEs. In order to avoid the START values desynchronisation and the key replaying issue, the gNB always requests the UE UTRA-FDD capabilities before handover to UTRA-FDD. The gNB does not upload the UE UTRA-FDD capabilities to the AMF.

# 15 Self-Configuration and Self-Optimisation

## 15.1 Definitions

Void.

## 15.2 Void

## 15.3 Self-configuration

### 15.3.1 Dynamic configuration of the NG-C interface

#### 15.3.1.1 Prerequisites

The following prerequisites are assumed:

- An initial remote IP end point to be used for SCTP initialisation is provided to the NG-RAN node for each AMF the NG-RAN node is supposed to connect to.

#### 15.3.1.2 SCTP initialization

NG-RAN establishes the first SCTP (IETF RFC 4960 [23]) using a configured IP address.

NOTE: The NG-RAN node may use different source and/or destination IP end point(s) if the SCTP establishment towards one IP end point fails. How the NG-RAN node gets the remote IP end point(s) and its own IP address are outside the scope of this specification.

#### 15.3.1.3 Application layer initialization

Once SCTP connectivity has been established, the NG-RAN node and the AMF shall exchange application level configuration data over NGAP with the NG Setup procedure, which is needed for these two nodes to interwork correctly on the NG interface:

- The NG-RAN node provides the relevant configuration information to the AMF, which includes list of supported TA(s), etc.;

- The AMF provides the relevant configuration information to the NG-RAN node, which includes PLMN ID, etc.;

- When the application layer initialization is successfully concluded, the dynamic configuration procedure is completed and the NG-C interface is operational.

After the application layer initialization is successfully completed, the AMF may add or update or remove SCTP endpoints to be used for NG-C signalling between the AMF and the NG-RAN node pair as specified in TS 23.501 [3].

### 15.3.2 Dynamic Configuration of the Xn interface

#### 15.3.2.1 Prerequisites

The following prerequisites are necessary:

- An initial remote IP end point to be used for SCTP initialisation is provided to the NG-RAN node.

#### 15.3.2.2 SCTP initialization

NG-RAN establishes the first SCTP (IETF RFC 4960 [23]) using a configured IP address.

NOTE: The NG-RAN node may use different source and/or destination IP end point(s) if the SCTP establishment towards one IP end point fails.

#### 15.3.2.3 Application layer initialization

Once SCTP connectivity has been established, the NG-RAN node and its candidate peer NG-RAN node are in a position to exchange application level configuration data over XnAP needed for the two nodes to interwork correctly on the Xn interface:

- The NG-RAN node provides the relevant configuration information to the candidate NG-RAN node, which includes served cell information;

- The candidate NG-RAN node provides the relevant configuration information to the initiating NG-RAN node, which includes served cell information;

- When the application layer initialization is successfully concluded, the dynamic configuration procedure is completed and the Xn interface is operational;

- The NG-RAN node shall keep neighbouring NG-RAN nodes updated with the complete list of served cells, or, if requested by the peer NG-RAN node, by a limited list of served cells, while the Xn interface is operational.

### 15.3.3 Automatic Neighbour Cell Relation Function

#### 15.3.3.1 General

The purpose of ANR function is to relieve the operator from the burden of manually managing NCRs. Figure 15.3.3.1-1 shows ANR and its environment:



Figure 15.3.3.1-1: Interaction between gNB and OAM due to ANR

The ANR function resides in the gNB and manages the Neighbour Cell Relation Table (NCRT). Located within ANR, the Neighbour Detection Function finds new neighbours and adds them to the NCRT. ANR also contains the Neighbour Removal Function which removes outdated NCRs. The Neighbour Detection Function and the Neighbour Removal Function are implementation specific.

An existing NCR from a source cell to a target cell means that gNB controlling the source cell:

a) Knows the global and physical IDs (e.g. NR CGI/NR PCI, ECGI/PCI) of the target cell; and

b) Has an entry in the NCRT for the source cell identifying the target cell; and

c) Has the attributes in this NCRT entry defined, either by OAM or set to default values.

NCRs are cell-to-cell relations, while an Xn link is set up between two gNBs. Neighbour Cell Relations are unidirectional, while an Xn link is bidirectional.

NOTE: The neighbour information exchange, which occurs during the Xn Setup procedure or in the gNB Configuration Update procedure, may be used for ANR purpose.

The ANR function also allows OAM to manage the NCRT. OAM can add and delete NCRs. It can also change the attributes of the NCRT. The OAM system is informed about changes in the NCRT.

#### 15.3.3.2 Intra-system Automatic Neighbour Cell Relation Function

ANR relies on NCGI (see clause 8.2) and ANR reporting of E-UTRA cells as specified in TS 36.300 [2].



Figure 15.3.3.2-1: Automatic Neighbour Relation Function

Figure 15.3.3.2-1 depicts an example where the NG-RAN node serving cell A has an ANR function. In RRC\_CONNECTED, the NG-RAN node instructs each UE to perform measurements on neighbour cells. The NG-RAN node may use different policies for instructing the UE to do measurements, and when to report them to the NG-RAN node. This measurement procedure is as specified in TS 38.331[12] and TS 36.331 [29].

1. The UE sends a measurement report regarding cell B. This report contains Cell B's PCI, but not its NCGI/ECGI.

When the NG-RAN node receives a UE measurement report containing the PCI, the following sequence may be used.

2. The NG-RAN node instructs the UE, using the newly discovered PCI as parameter, to read all the broadcast NCGI(s) /ECGI(s), TAC(s), RANAC(s), PLMN ID(s) and, for neighbour NR cells, NR frequency band(s) and the gNB ID length(s). To do so, the NG-RAN node may need to schedule appropriate idle periods to allow the UE to read the NCGI/ECGI from the broadcast channel of the detected neighbour cell. How the UE reads the NCGI/ECGI is specified in TS 38.331 [12] and TS 36.331 [29].

3. When the UE has found out the new cell's NCGI(s) /ECGI(s), the UE reports all the broadcast NCGI(s)/ECGI(s) to the serving cell NG-RAN node. In addition, the UE reports all the tracking area code(s), RANAC(s), PLMN IDs and, for neighbour NR cells, NR frequency band(s), and the gNB ID length(s) that have been read by the UE. In case the detected NR cell does not broadcast SIB1, the UE may report *noSIB1* indication as specified in TS 38.331 [12].

4. The NG-RAN node decides to add this neighbour relation, and can use PCI and NCGI(s)/ECGI(s) to:

a. Lookup a transport layer address to the new NG-RAN node;

b. Update the Neighbour Cell Relation List;

c. If needed, setup a new Xn interface towards this NG-RAN node.

#### 15.3.3.3 Void

#### 15.3.3.4 Void

#### 15.3.3.5 Inter-system Automatic Neighbour Cell Relation Function

For Inter-system ANR, each cell contains an Inter Frequency Search list. This list contains all frequencies that shall be searched. Figure 15.3.3.5-1 depicts an example where the NG-RAN node serving cell A has an ANR function.



Figure 15.3.3.5-1: Automatic Neighbour Relation Function in case of E-UTRAN detected cell

In RRC\_CONNECTED, the NG-RAN node instructs a UE to perform measurements and detect E-UTRA cells connected to EPC.:

1 The NG-RAN node instructs a UE to look for neighbour cells in the target system. To do so the NG-RAN node may need to schedule appropriate idle periods to allow the UE to scan all cells in the target system.

2 The UE reports the PCI and carrier frequency of the detected cells in the target system.

NOTE: The NG-RAN node may use different policies for instructing the UE to do measurements, and when to report them to the NG-RAN node.

When the NG-RAN node receives the UE reports containing PCIs of cell(s), the following sequence may be used:

3 The NG-RAN node instructs the UE, using the newly discovered PCI as parameter, to read the ECGI, the TAC and all available PLMN ID(s) of the newly detected cell in case of E-UTRA detected cells. The UE ignores transmissions from the serving cell while finding the requested information transmitted in the broadcast channel of the detected inter-system/inter-frequency neighbour cell. To do so, the NG-RAN node may need to schedule appropriate idle periods to allow the UE to read the requested information from the broadcast channel of the detected inter-system neighbour cell.

4 After the UE has read the requested information in the new cell, it reports the detected ECGI, TAC, and available PLMN ID(s) to the serving cell NG-RAN node.

5 The NG-RAN node updates its inter-system NCRT.

### 15.3.4 Xn-C TNL address discovery

If the NG-RAN node is aware of the RAN node ID of the candidate NG-RAN node (e.g. via the ANR function) but not of a TNL address suitable for SCTP connectivity, then the NG-RAN node can utilize the 5GC (an AMF it is connected to) to determine the TNL address as follows:

- The NG-RAN node sends the UPLINK RAN CONFIGURATION TRANSFER message to the AMF to request the TNL address of the candidate NG-RAN node, and includes relevant information such as the source and target RAN node ID;

- The AMF relays the request by sending the DOWNLINK RAN CONFIGURATION TRANSFER message to the candidate NG-RAN node identified by the target RAN node ID;

- The candidate NG-RAN node responds by sending the UPLINK RAN CONFIGURATION TRANSFER message containing one or more TNL addresses to be used for SCTP connectivity with the initiating NG-RAN node, and includes other relevant information such as the source and target RAN node ID;

- The AMF relays the response by sending the DOWNLINK CONFIGURATION TRANSFER message to the initiating NG-RAN node identified by the target RAN node ID.

NOTE: Void.

The NG-RAN node may determine the gNB ID length of the candidate gNB based on, e.g. OAM configuration or UE reporting in ANR function. If the NG-RAN node is not able to make this determination, it may include the NR cell identifier in the UPLINK RAN CONFIGURATION TRANSFER message to the AMF. The AMF may, if supported, determine the target gNB ID by matching the NR cell identifier with a gNB ID of a gNB it connects to.

## 15.4 Support for Energy Saving

### 15.4.1 General

The aim of this function is to reduce operational expenses through energy savings.

The function allows, for example in a deployment where capacity boosters can be distinguished from cells providing basic coverage, to optimize energy consumption enabling the possibility for an E-UTRA or NR cell providing additional capacity via single or dual connectivity, to be switched off when its capacity is no longer needed and to be re-activated on a need basis, or to support various adaptation techniques in time, frequency, spatial and power domains.

### 15.4.2 Solution description

#### 15.4.2.1 Intra-system energy saving

The solution builds upon the possibility for the NG-RAN node owning a capacity booster cell to autonomously decide to switch-off such cell to lower energy consumption (inactive state). The decision is typically based on cell load information, consistently with configured information. The switch-off decision may also be taken by O&M.

The NG-RAN node may initiate handover actions in order to off-load the cell being switched off and may indicate the reason for handover with an appropriate cause value to support the target node in taking subsequent actions, e.g. when selecting the target cell for subsequent handovers.

All neighbour NG-RAN nodes are informed by the NG-RAN node owning the concerned cell about the switch-off actions over the Xn interface, by means of the NG-RAN node Configuration Update procedure.

All informed nodes maintain the cell configuration data, e.g., neighbour relationship configuration, also when a certain cell is inactive. If basic coverage is ensured by NG-RAN node cells, NG-RAN node owning non-capacity boosting cells may request a re-activation over the Xn interface if capacity needs in such cells demand to do so. This is achieved via the Cell Activation procedure. During switch off time period of the boost cell, the NG-RAN node may prevent idle mode UEs from camping on this cell and may prevent incoming handovers to the same cell.

The NG-RAN node receiving a request should act accordingly. The switch-on decision may also be taken by O&M. All peer NG-RAN nodes are informed by the NG-RAN node owning the concerned cell about the re-activation by an indication on the Xn interface.

The solution also builds upon the possibility for the NG-RAN node owning a coverage cell to request neighbouring NG-RAN node(s) owning a capacity booster cell to switch on some SSB beams within the cell which are deactivated. The receiving NG-RAN node should act accordingly.

The solution also builds upon the possibility for an NG-RAN node to page certain UEs (e.g., stationary UEs) in RRC\_INACTIVE state on a limited set of beams, instead of paging on all the beams within the cell. It is up to the gNB's implementation to select the UEs in RRC\_INACTIVE for which paging in limited set of beams applies. If the paging over the limited set of beams fails, the gNB performs subsequent paging by implementation, e.g., by ensuring the same paging message is repeated in all the transmitted SSB beams.

#### 15.4.2.2 Inter-system energy saving

The solution builds upon the possibility for the NG-RAN node owning a capacity booster cell to autonomously decide to switch-off such cell to dormant state. The decision is typically based on cell load information, consistently with configured information. The switch-off decision may also be taken by O&M. The NG-RAN node indicates the switch-off action to the eNB over NG interface and S1 interface. The NG-RAN node could also indicate the switch-on action to the eNB over NG interface and S1 interface.

The eNB providing basic coverage may request a NG-RAN node's cell re-activation based on its own cell load information or neighbour cell load information, the switch-on decision may also be taken by O&M. The eNB requests a NG-RAN node's cell re-activation and receives the NG-RAN node's cell re-activation reply from the NG-RAN node over the S1 interface and NG interface. Upon reception of the re-activation request, the NG-RAN node's cell should remain switched on at least until expiration of the minimum activation time. The minimum activation time may be configured by O&M or be left to the NG-RAN node's implementation.

#### 15.4.2.3 Cell DTX/DRX

To facilitate reducing gNB downlink transmission/uplink reception active time, UE can be configured with a periodic cell DTX/DRX pattern (i.e. active and non-active periods). The pattern configuration for cell DTX/DRX is common for the UEs configured with this feature in the cell. The cell DTX and cell DRX patterns can be configured and activated separately. A maximum of two cell DTX/DRX patterns can be configured per MAC entity for different serving cells. When cell DTX is configured and activated for the concerned cell, the UE may not monitor PDCCH in selected cases or does not monitor SPS occasions during cell DTX non-active duration. When cell DRX is configured and activated for the concerned cell, the UE does not transmit on CG resources or does not transmit a SR during cell DRX non-active duration. This feature is only applicable to UEs in RRC\_CONNECTED state and it does not impact Random Access procedure, SSB transmission, paging, and system information broadcasting. Cell DTX/DRX operation is only supported for single TRP scenario. Cell DTX/DRX can be activated/deactivated by RRC signalling or L1 group common signalling. Cell DTX/DRX is characterized by the following:

- **active duration**: duration that the UE waits for to receive PDCCHs or SPS occasions, and transmit SR or CG. In this duration, the gNB transmission/reception of PDCCH, SPS, SR, CG, periodic and semi-persistent CSI report are not impacted for the purpose of network energy saving;

- **cycle**: specifies the periodic repetition of the active-duration followed by a period of non-active duration.

Active duration and cycle parameters are common between cell DTX and cell DRX, when both are configured;

Once the gNB recognizes there is an emergency call or public safety related service, the network should ensure that there is no impact to that service (e.g. it may release or deactivate cell DTX/DRX configuration). The network should also ensure that there is at least partial overlapping between UE's connected mode DRX on-duration and cell DTX/DRX active duration, i.e. the UE's connected mode DRX periodicity is a multiple of cell DTX/DRX periodicity or vice versa.

#### 15.4.2.4 Conditional Handover

The same principle as described in 9.2.3.4 applies to conditional handover in case the source cell is using a network energy saving solution (e.g., the cell is activating cell DTX/DRX or turning off), unless hereunder specified. In this case, the following additional triggering conditions are supported, upon which UE may use NES-specific CHO event for executing CHO to a candidate cell, as defined in TS 38.331 [12]:

- The UE may be notified via DCI to enable CHO conditions(s) configured with NES event indication.

#### 15.4.2.5 Camping Restrictions

If a cell is activating or going to activate NES cell DTX/DRX, the cell can allow the access of UEs capable of NES cell DTX/DRX via a single bit in SIB1 but prevent the access of UEs not capable of cell DTX/DRX using barring mechanisms described in clause 7.4.

If a cell provides SIB1 on-demand, the cell can allow the access of UEs capable of OD-SIB1 but prevent the access of UEs not capable of OD-SIB1 based on no SIB1 indication in MIB using FFS as described in clause X.Y.

#### 15.4.2.6 SSB-less SCell

For an intra-band or inter-band CA SCell, a UE may obtain timing reference and AGC source from another serving cell in case the UE is not provided with SSB nor SMTC configuration for this SCell, as described in TS 38.331 [12].

#### 15.4.2.7 Spatial and power domain adaptation

To assist the gNB on muting transceivers and/or adapting transmission power, the UE can be configured to report multiple CSI entries in a CSI report based on two or more sub-configurations, as specified in clause 5.2.1.6 in TS 38.214 [56]. Each sub-configuration corresponds to a spatial domain adaptation pattern (subsets of available spatial elements) and/or a power offset between PDSCH and CSI-RS.

#### 15.4.2.x1 On-demand SSB SCell

The functionality supports on-demand SSB-based SCell operations for UEs in RRC\_CONNECTED configured with carrier aggregation (CA), applicable to both intra-band and inter-band CA configurations. On-demand SSB transmissions facilitated through serving cell indications enable UEs to perform at least SCell activation, and are supported for FR1 and FR2 in non-shared spectrum. This solution is supported in the following scenarios:

* + - The SCell is configured to a UE but before the UE receives SCell activation command
    - When UE receives SCell activation command

The following signals can be used to indicate the activation/deactivation state of OD-SSB configuration:

* + - RRC based OD-SSB transmission indication
    - MAC-CE for OD-SSB transmission indication

Editor’s note: FFS whether to merge OD-SSB and SSB adaptation into one section.

#### 15.4.2.x2 On-demand SIB1

To facilitate reducing gNB downlink transmissions, the gNB can provide SIB1 on-demand, i.e., upon receiving OD-SIB1 request from the UE. On-demand SIB1 is supported for UEs in RRC\_IDLE, RRC\_INACTIVE and RRC\_CONNECTED when T311 is running. A request for SIB1 triggers a random access procedure, in which case MSG1 is used for indicating OD-SIB1 request and the gNB acknowledges the request in MSG2. UL-WUS configurations of one or more cells are included in SIBxx, which can be broadcasted in any cell, including cell’s own UL-WUS configuration. While the UE is camped on a cell, it can use the UL-WUS configuration of another cell from SIBxx valid in the camped cell to acquire OD-SIB1 of that cell for cell reselection or it can apply the UL-WUS configuration of the camped cell from SIBxx valid in the camped cell to acquire OD-SIB1 of the camped cell.

#### 15.4.2.x3 Common signal/channel transmissions adaptation

For adaptation of paging occasions in time domain, the values range for parameter N is extended to make it possible to have increased interval between PFs. The value range for Ns, which is the number of paging occasions within one paging frame, is increased to compensate the decrease in the number of PFs.

Adaptation of SSB in time domain is supported for SCells for UEs in RRC\_CONNECTED configured with carrier aggregation (CA).

Adaptation of PRACH configurations in time domain is supported for 4-step RACH CBRA.

Editor’s note: FFS further details of adaptation of SSB and PRACH in time domain.

### 15.4.3 O&M requirements

Operators should be able to configure the energy saving function.

The configured information should include:

- The ability of an NG-RAN node to perform autonomous cell switch-off;

- The ability of an NG-RAN node to request the re-activation of a configured list of inactive cells owned by a peer NG-RAN node.

O&M may also configure:

- policies used by the NG-RAN node for cell switch-off decision;

- policies used by peer NG-RAN nodes for requesting the re-activation of an inactive cell;

- The minimum time an NG-RAN node's cell should remain activated upon reception of a re-activation request from an eNB.

## 15.5 Self-optimisation

### 15.5.1 Support for Mobility Load Balancing

#### 15.5.1.1 General

The objective of mobility load balancing is to distribute load evenly among cells and among areas of cells, or to transfer part of the traffic from congested cell or from congested areas of cells, or to offload users from one cell, cell area, carrier or RAT to achieve network energy saving. This can be done by means of optimization of cell reselection/handover parameters and handover actions. The automation of such optimisation can provide high quality user experience, while simultaneously improving the system capacity and also to minimize human intervention in the network management and optimization tasks.

Intra-RAT, intra-system inter-RAT and inter-system load balancing scenarios are supported.

In general, support for mobility load balancing consists of one or more of following functions:

- Load reporting for intra-RAT and intra-system inter-RAT load balancing;

- Load balancing action based on handovers;

- Adapting handover and/or reselection configuration;

- Load reporting for inter-system load balancing.

#### 15.5.1.2 Load reporting for intra-RAT and intra-system inter-RAT load balancing

The load reporting function is executed by exchanging load information over the Xn/X2/F1/E1 interfaces.

The following load related information should be supported which consists of:

- Radio resource usage (per-cell and per SSB area PRB usage: DL/UL GBR PRB usage, DL/UL non-GBR PRB usage, DL/UL total PRB usage, and DL/UL scheduling PDCCH CCE usage; PRB usage for slice(s): DL/UL GBR PRB usage, DL/UL non-GBR PRB usage, and DL/UL Total PRB allocation);

- TNL capacity indicator (UL/DL TNL offered capacity and available capacity);

- Cell Capacity Class value (UL/DL relative capacity indicator);

- Capacity value (per cell, per SSB area and per slice: UL/DL available capacity);

- HW capacity indicator (offered throughput and available throughput over E1, percentage utilisation over F1);

- RRC connections (number of RRC connections, and available RRC Connection Capacity);

- Number of active UEs;

- NR-U channel load (DL/UL channel occupancy time percentage, DL/UL energy detection threshold, radio resource usage).

To achieve load reporting function, Resource Status Reporting Initiation & Resource Status Reporting procedures are used.

15.5.1.3 Load balancing action based on handovers

The source cell may initiate handover due to load. The target cell performs admission control for the load balancing handovers. A handover preparation related to a mobility load balancing action is distinguishable from other handovers, so that the target cell is able to apply appropriate admission control.

#### 15.5.1.4 Adapting handover and/or reselection configuration

This function enables requesting of a change of handover and/or reselection parameters at target cell. The source cell that initialized the load balancing estimates if it is needed to change mobility configuration in the source and/or target cell. If the amendment is needed, the source cell initializes mobility negotiation procedure toward the target cell.

The source cell informs the target cell about the new mobility setting and provides cause for the change (e.g. load balancing related request). The proposed change is expressed by the means of the difference (delta) between the current and the new values of the handover trigger. The handover trigger is the cell specific offset that corresponds to the threshold at which a cell initialises the handover preparation procedure. Cell reselection configuration may be amended to reflect changes in the HO setting. The target cell responds to the information from the source cell. The allowed delta range for HO trigger parameter may be carried in the failure response message. The source cell should consider the responses before executing the planned change of its mobility setting.

All automatic changes on the HO and/or reselection parameters must be within the range allowed by OAM.

#### 15.5.1.5 Load reporting for inter-system load balancing

The load reporting function for inter-system load balancing is executed by exchanging load information between NG-RAN and E-UTRAN. Both event-triggered and periodic inter-system load reporting are supported. Event-triggered inter-system load reports are sent when the reporting node detects crossing of cell load thresholds.

The following load related information should be supported:

- Cell Capacity Class value (UL/DL relative capacity indicator);

- Capacity value (per cell: UL/DL available capacity);

- RRC connections (number of RRC connections, and available RRC Connection Capacity);

- Number of active UEs;

- Radio Resource Status (per cell PRB usage: UL/DL GBR PRB usage for MIMO, DL/UL non-GBR PRB usage for MIMO, DL/UL total PRB usage for MIMO).

NGAP procedures used for inter-system load balancing are Uplink RAN Configuration Transfer and Downlink RAN Configuration Transfer.

S1AP procedures used for inter-system load balancing are eNB Configuration Transfer and MME Configuration Transfer.

### 15.5.2 Support for Mobility Robustness Optimization

#### 15.5.2.1 General

Mobility Robustness Optimisation aims at detecting and enabling correction of following problems:

- Connection failure due to intra-system or inter-system mobility;

- Inter-system Unnecessary HO (too early inter-system HO from NR to E-UTRAN with no radio link failure);

- Inter-system HO ping-pong;

- PSCell change failure;

- Inter-system voice fallback failure;

- Fast MCG recovery failure or a sub-optimal Fast MCG recovery.

MRO provides means to distinguish the above problems from NR coverage related problems and other problems, not related to mobility.

For detection of a sub-optimal successful handovers, MRO additionally enables observability of:

- Successful HO due to intra-NR mobility;

- Successful HO due to inter-RAT mobility.

For detection of a sub-optimal successful PSCell addition/change, MRO additionally enables observability of:

- Successful PSCell addition/change.

#### 15.5.2.2 Connection failure

##### 15.5.2.2.1 General

For analysis of connection failures, the UE makes the RLF Report available to the network.

The UE stores the latest RLF Report, including both LTE and NR RLF report until the RLF report is fetched by the network or for 48 hours after the connection failure is detected.

The UE only indicates RLF report availability and only provides the RLF report to the network if the current RPLMN is a PLMN that was present in the UE's EPLMN List or was the RPLMN at the time the connection failure was detected. In case RLF happens in an E-UTRA cell, the UE makes the LTE RLF Report available to NG-RAN nodes and eNB(s), and in case RLF happens in an NR cell the UE makes the NR RLF Report available to gNB(s).

If the LTE RLF Report is reported to a NG-RAN node, and the last serving node is an E-UTRAN node, the NG-RAN node may transfer it to the E-UTRAN node by triggering the Uplink RAN configuration transfer procedure over NG and the E-UTRAN node can take this into account as defined in TS 36.300 [2].

##### 15.5.2.2.2 Connection failure due to intra-system mobility

One of the functions of Mobility Robustness Optimization is to detect connection failures that occur due to Too Early or Too Late Handovers, or Handover to Wrong Cell. These problems are defined as follows:

- Intra-system Too Late Handover: an RLF occurs after the UE has stayed for a long period of time in the cell; the UE attempts to re-establish the radio link connection in a different cell.

- Intra-system Too Early Handover: an RLF occurs shortly after a successful handover from a source cell to a target cell or a handover failure occurs during the handover procedure; the UE attempts to re-establish the radio link connection in the source cell.

- Intra-system Handover to Wrong Cell: an RLF occurs shortly after a successful handover from a source cell to a target cell or a handover failure occurs during the handover procedure; the UE attempts to re-establish the radio link connection in a cell other than the source cell and the target cell.

In the definition above, the "successful handover" refers to the UE state, namely the successful completion of the RA procedure.

In case of CHO, the Too Late Handover, Too Early Handover and Handover to Wrong Cell in the definition above means Too Late CHO Execution, Too Early CHO Execution and CHO Execution to Wrong Cell.

**Detection mechanism**

A failure indication may be initiated after a UE attempts to re-establish the radio link connection at NG-RAN node B after a failure at NG-RAN node A. NG-RAN node B may initiate the Failure Indication procedure towards multiple NG-RAN nodes if they control cells which use the PCI signalled by the UE during the re-establishment procedure. The NG-RAN node receiving this selects the UE context that matches the received Failure Cell ID and C-RNTI, and, if available, uses the shortMAC-I to confirm this identification, by calculating the shortMAC-I and comparing it to the received IE.

A failure indication may also be sent to the node last serving the UE when the NG-RAN node fetches the RLF REPORT from UE by triggering:

- The Failure Indication procedure over Xn;

- The Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

The detailed detection mechanisms for too late handover, too early handover and handover to wrong cell are carried out through the following in the NG-RAN node that served the UE before the reported connection failure:

- Intra-system Too Late Handover: there is no recent handover for the UE prior to the connection failure e.g. the UE reported timer is absent or larger than the configured threshold (e.g. Tstore\_UE\_cntxt), or if CHO is configured but the CHO execution is not initiated for the UE prior to the connection failure, e.g. the UE reported timer is absent or larger than the configured threshold (e.g. Tstore\_UE\_cntxt).

- Intra-system Too Early Handover: there is a recent handover for the UE prior to the connection failure e.g. the UE reported timer is smaller than the configured threshold (e.g. Tstore\_UE\_cntxt), and the first re-establishment attempt cell/the successful re-connect cell is the cell that served the UE at the last handover initialisation or fall back to the source cell configuration in case of DAPS HO.

- Intra-system Handover to Wrong Cell: there is a recent handover for the UE prior to the connection failure e.g. the UE reported timer is smaller than the configured threshold (e.g. Tstore\_UE\_cntxt), and the first re-establishment attempt cell/ the cell UE attempts to re-connect/the cell UE attempts CHO recovery is neither the cell that served the UE at the last handover initialisation nor the cell that served the UE where the RLF happened or the cell that the handover was initialized toward.

The "UE reported timer" above indicates the time elapsed since the last handover initialisation until connection failure or the time elapsed since the CHO execution until connection failure.

In case of Too Early Handover or Handover to Wrong Cell, the NG-RAN node receiving the failure indication may inform the NG-RAN node controlling the cell where the mobility configuration caused the failure by means of the Handover Report procedure over Xn or the Uplink RAN Configuration Transfer procedure over NG. This may include the RLF report.

For MRO analysis, in case of RLFs or handover failures, the source gNB may take into account the information regarding the LBT failures occurred in UL and DL for a specific UE. For UL, the information may be collected and provided by the UE to the network in the RLF report. For DL, the information may be collected at the source and target gNBs. The target gNB may provide the information to the source gNB via the Access and Mobility Indication procedure over Xn, if requested by the source gNB during the handover preparation.

**Retrieval of information needed for problem analysis**

In order to retrieve relevant information collected at the network side as part of the UE context, the UE provides C-RNTI used in the last serving cell. If the cause for the failure is identified as a "Too Early HO" or a "HO to Wrong Cell", the NG-RAN node controlling the last serving cell shall, include in the HANDOVER REPORT message the C-RNTI used in the source cell of the last completed handover before the failure. If the NG RAN node controlling that source cell provided the Mobility Information, it is also included in the HANDOVER REPORT message. If used, the Mobility Information is prepared at the source NG RAN node of a handover and may refer to or identify any handover-related data at this NG RAN node. In the Handover Preparation procedure, the source gNB can request the target gNB to provide information on DL LBT failures at the target gNB during handover execution.

**Handling multiple reports from a single failure event**

In case the RRC re-establishment fails and the RRC connection setup succeeds, MRO evaluation of intra-RAT mobility connection failures may be triggered twice for the same failure event. In this case, only one failure event should be counted.

##### 15.5.2.2.3 Connection failure due to inter-system mobility

One of the functions of Mobility Robustness Optimization is to detect connection failures that occurred due to Too Early or Too Late inter-system handovers or inter-system Mobility Failure for Voice Fallback. These problems are defined as follows:

- Inter-system/ Too Late Handover: an RLF occurs after the UE has stayed in a cell belonging to an NG-RAN node for a long period of time; the UE attempts to re-connect to a cell belonging to an E-UTRAN node.

- Inter-system/ Too Early Handover: an RLF occurs shortly after a successful handover from a cell belonging to an E-UTRAN node to a target cell belonging to an NG-RAN node or a handover failure occurs during the handover procedure; the UE attempts to re-connect to the source cell or to another cell belonging to an E-UTRAN node.

- Inter-system Mobility Failure for Voice Fallback: an RLF occurs shortly after a successful handover triggered due to Voice Fallback, or a failure occurs during an handover triggered due to Voice Fallback, from a cell belonging to an NG-RAN node to a cell belonging to an E-UTRAN node; the UE attempts to re-connect to a cell belonging to an E-UTRAN node, or an NG-RAN node.

**Detection mechanism**

A failure indication may be sent to the node last serving the UE when the NG-RAN node fetches the RLF REPORT from UE by triggering:

- The Failure Indication procedure over Xn;

- The Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

In case the last serving node is an E-UTRAN node, the detection mechanism proceeds as defined in TS 36.300 [2].

In case the last serving node is an NG-RAN node, the detection mechanisms for Too Late Inter-system Handover, Too Early Inter-system Handover, and Inter-system Mobility Failure for Voice Fallback are carried out through the following:

- Too Late Inter-system Handover: the connection failure occurs while being connected to a NG-RAN node, and there is no recent handover for the UE prior to the connection failure i.e., the UE reported timer is absent or larger than the configured threshold, e.g., *Tstore\_UE\_cntxt*, and the first node where the UE attempts to re-connect is a E-UTRAN node.

- Too Early Inter-system Handover: the connection failure occurs while being connected to a NG-RAN node, and there is a recent inter-system handover for the UE prior to the connection failure i.e., the UE reported timer is smaller than the configured threshold, e.g., *Tstore\_UE\_cntxt*, and the first cell where the UE attempts to re-connect and the node that served the UE at the last handover initialisation are both E-UTRAN node.

- Inter-system Mobility Failure for Voice Fallback: in case the connection failure occurs during an inter-system handover for voice fall back from NR, the RLF Report from the UE includes a voice fallback indication, as defined in TS 38.331 [12].

The "UE reported timer" above indicates the time elapsed since the last handover initialisation until connection failure. The UE may make the RLF Report available to an NG-RAN node. The NG-RAN node may forward the information using the FAILURE INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer over NG to the node that served the UE before the reported connection failure.

In case the failure is a Too Early Inter-system Handover, the NG-RAN node receiving the failure indication may inform the E-UTRAN node by means of the Uplink RAN Configuration Transfer procedure over NG. This may include the RLF report.

#### 15.5.2.3 Inter-system Unnecessary HO

One of the purposes of inter-system Mobility Robustness Optimisation is the detection of a non-optimal use of network resources. In particular, in case of inter-system operations and when NR is considered, the case known as Unnecessary HO to another system is identified. The problem is defined as follows:

- UE is handed over from NR to E-UTRAN even though quality of the NR coverage was sufficient for the service used by the UE. The handover may therefore be considered as unnecessary HO to another system (i.e. EPS) (too early inter-system HO without connection failure).

In inter-system HO, if the serving cell threshold (NR cell) is set too high, and cell in another system (i.e. EPS) with good signal strength is available, a handover to another system may be triggered unnecessarily, resulting in an inefficient use of the networks. With a lower threshold the UE could have continued in the source system (5GS).

To be able to detect the Unnecessary HO to another system, a gNB node may choose to put additional coverage and quality condition information into the HANDOVER REQUIRED message in the Handover Preparation procedure when an inter-system HO from gNB to another system occurs. The RAN node in the other system, upon receiving this additional coverage and quality information, may instruct the UE to continue measuring the cell(s) in source system during a period of time, while being connected to another system, and send periodic or single measurement reports to the node in other system. When the period of time indicated by the node in source system expires, the RAN node in the other system, may evaluate the received measurement reports with the coverage/quality condition received during the inter-system HO procedure and decide if an inter-system unnecessary HO report should be sent to the gNB in the source system.

The inter-system unnecessary HO report shall only be sent in cases where, in all UE measurement reports collected during the measurement period, any cells in the source system exceed the radio coverage and/or quality threshold (the radio threshold RSRP, RSRQ or/and SINR and the measurement period are indicated in the additional coverage and quality information in the Handover Preparation procedure). If an inter-system handover towards 5GS is executed from EPS within the indicated measurement period, the measurement period expires. In this case, the eNB in EPS may also send the HO Report. No HO Report shall be sent in case no NR cell could be included, or if the indicated period of time is interrupted by an inter-system handover to a system different than 5GS.

The RAN node in the source system (5GS) upon receiving of the report, can decide if/how its parameters (e.g., threshold to trigger Inter-system HO) should be adjusted.

#### 15.5.2.4 Inter-system Ping-pong

One of the functions of Mobility Robustness Optimization is to detect ping-pongs that occur in inter-system environment. The problem is defined as follows:

- A UE is handed over from a cell in a source system (e.g. 5GS) to a cell in a target system different from the source system (e.g. EPS), then within a predefined limited time the UE is handed over back to a cell in the source system, while the coverage of the source system was sufficient for the service used by the UE. The event may occur more than once.

The solution for the problem may consist of the following steps:

1) Statistics regarding inter-system ping-pong occurrences are collected by the responsible node;

2) Coverage verification is performed to check if the mobility to other system was inevitable.

The statistics regarding ping-pong occurrence may be based on evaluation of the *UE History Information* IE in the HANDOVER REQUIRED message. If the evaluation indicates a potential ping-pong case and the source NG\_RAN node of the 1st inter-system handover is different than the target NG-RAN node of the 2nd inter-system handover, the target NG-RAN node may use the HANDOVER REPORT message or the UPLINK RAN CONFIGURATION TRANSFER message to indicate the occurrence of potential ping-pong cases to the source NG-RAN node.

If NG-RAN coverage during the potential ping-pong event needs to be verified for the purpose of determining corrective measures, the Unnecessary HO to another system procedure may be used.

NOTE: Inter-system mobility triggered by Voice Fallback is not considered as inter-system ping-pong.

#### 15.5.2.5 O&M Requirements

All automatic changes of the HO and/or reselection parameters for mobility robustness optimisation shall be within the ranges allowed by OAM and specified below.

The following control parameters shall be provided by OAM to control MRO behaviour:

- Maximum deviation of Handover Trigger: this parameter defines the maximum allowed absolute deviation of the Handover Trigger, from the default point of operation defined by the parameter values assigned by OAM.

- Minimum time between Handover Trigger changes: this parameter defines the minimum allowed time interval between two Handover Trigger change performed by MRO. This is used to control the stability and convergence of the algorithm.

Furthermore, in order to support the solutions for detection of mobility optimisation, the parameter *Tstore\_UE\_cntxt* shall be configurable by the OAM system.

#### 15.5.2.6 PSCell addition/change failure

For analysis of PSCell addition/change failures, the UE makes the SCG Failure Information available to the MN. If the MN can perform an initial analysis, it transfers the SCG Failure Information together with the analysis results to the relevant SN as defined in TS 37.340 [21].

#### 15.5.2.7 Successful HO

One of the functions of Mobility Robustness Optimization is to detect a sub-optimal successful handover event. The aim is to identify underlying conditions during successful ordinary handovers, successful DAPS handovers, or successful Conditional handovers.

For analysis of successful handover, the UE may collect Successful Handover Report (SHR) based on configuration by network, if stored, and makes the SHR available to the network as specified in TS 38.331 [12]. The UE stores the SHR until it is fetched by the network or for 48 hours after the SHR is recorded.

For SHR collected during intra-NR handover, if the target NR node fetches the SHR from the UE and the trigger of SHR is T310/T312, it may forward the information to the source NR node, i.e. the node handling the cell reported as source cell in this SHR, by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

If the NG-RAN node that fetches the SHR from the UE is neither the source node nor the target node of the handover, it forwards the information to the node(s) which configured the SHR trigger causing the SHR to be generated, by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer procedure over NG.

In case of failure shortly after successful Handover, the same mobility event may generate both a SHR and a RLF report. In this case, the node(s), which configured the SHR trigger causing the SHR, may take the duplication into account e.g. ignore the SHR.

Upon retrieval of an SHR, the receiving node may analyse whether its mobility configuration needs adjustment.

The SHR report can be used to detect one case of Intra-system Too Late Handover, namely when DAPS HO is configured but an RLF is detected in the source cell during a successful DAPS HO.

The SHR report can be collected for intra-NR handover and for handover from NR to E-UTRA.

#### 15.5.2.8 Successful PSCell Addition/Change Report

For the analysis of successful PSCell addition/change, the UE may collect Successful PSCell Addition/Change Report (SPR) based on the configuration by network, if received, and makes the SPR available to the network as specified in TS 38.331 [12].

The UE stores the SPR until the SPR is fetched by the network or for 48 hours after the SPR is recorded.

The UE makes the SPR available to gNB(s).

When a gNB fetches the SPR from UE, it forwards the SPR to the MN that was serving the UE at the time the SPR was generated by using the ACCESS AND MOBILITY INDICATION message over Xn or by means of the Uplink RAN configuration transfer procedure and Downlink RAN configuration transfer over NG.

### 15.5.3 Support for RACH Optimization

RACH optimization is supported by UE reported information made available at the NG RAN node as specified in TS 38.331 [12] and by PRACH parameters exchange between NG RAN nodes.

The contents of the RA Report comprise of the following:

- Contention detection indication per RACH attempt;

- Indexes of the SSBs and number of RACH preambles sent on each tried SSB listed in chronological order of attempts;

- Indication whether the selected SSB is above or below the configured RSRP threshold per RACH attempt;

- 2-step RACH information as specified in clause 5.7.10.4 of TS 38.331 [12];

- Indication of LBT failures detected during the random access.

**SN RA Reports**

The UE may also support collection of SN RA Reports.

The SN RA report retrieval and forwarding is specified in TS 37.340 [21].

### 15.5.4 UE History Information from the UE

The source NG-RAN node collects and stores the UE History Information for as long as the UE stays in one of its cells.

The UE may report the UE history information when connecting to a cell of the NG-RAN node, consisting of PCell and PSCell mobility history information, as specified in TS 38.331 [12].

When information needs to be discarded because the list is full, such information will be discarded in order of its position in the list, starting with the oldest cell record. If the list is full, and the UE history information from the UE is available, the UE history information from the UE should also be discarded.

The resulting information is then used in subsequent handover preparations by means of the Handover Preparation procedures over the NG and XN interfaces, which provide the target NG-RAN node with a list of previously visited cells and associated (per-cell) information elements. The Handover Preparation procedures also trigger the target NG-RAN node to start collection and storage of UE history Information and thus to propagate the collected information.

In case of CHO, the target NG-RAN node updates the time UE stayed in cell of the latest PCell entry (i.e. the source cell) when the UE successfully accesses a candidate cell of the target NG-RAN node. The updated value of the time UE stayed in the source cell is equal to the value received from the source NG-RAN node during the Handover Preparation plus the time from receiving the Handover Request message from the source NG-RAN node to receiving the RRC Reconfiguration Complete message from the UE. When the target NG-RAN node receives the SCG UHI from the source NG-RAN node via the Handover Request message, the target NG-RAN node also updates the time UE stayed in cell of the latest PSCell entry (i.e. the source PSCell) as specified in TS 37.340 [21].

### 15.5.5 Support for Coverage and Capacity Optimisation

#### 15.5.5.1 General

The objective of NR Coverage and Capacity Optimization (CCO) function is to detect and resolve or mitigate CCO issues, e.g. coverage and cell edge interference issues.

#### 15.5.5.2 OAM requirements

Each NG-RAN node may be configured with *alternative coverage configurations* by OAM. The alternative coverage configurations contain relevant radio parameters and may also include a range for how each parameter is allowed to be adjusted.

#### 15.5.5.3 Dynamic coverage configuration changes

An NG-RAN node may autonomously adjust within and switch between coverage configurations. When a change is executed, a NG-RAN node may notify its neighbour NG-RAN nodes using the NG-RAN NODE CONFIGURATION UPDATE message with the list of cells and SSBs with modified coverage included. The list contains the CGI of each modified cell with its coverage state indicator and optionally the SSB index of each modified SSB with its coverage state indicator.

The coverage state indicator may be used at the receiving NG-RAN node to adjust the functions of the Mobility Robustness Optimisation, e.g. by using the coverage state indicator to retrieve a previously stored Mobility Robustness Optimisation state. The coverage state indicator may also be used at the receiving NG-RAN node to adopt coverage configurations matching with neighbouring cells coverage configurations.

If the list includes indication about planned reconfiguration and possibly a list of replacing cells, the receiving NG-RAN node may use this to avoid connection or re-establishment failures during the reconfiguration. Also, if the sending NG-RAN node adds cells in inactive state, the receiving NG-RAN node may use this information to avoid connection or re-establishment failures. The receiving NG-RAN node may also use the notification to reduce the impact on mobility. The receiving NG-RAN node should avoid triggering handovers towards cell(s) that are indicated to be inactive.

### 15.5.6 Support for PCI Optimisation

The PCI Optimization Function in split gNB case is specified in TS 38.401 [4].

#### 15.5.6.1 Centralized PCI Assignment

For centralized PCI assignment in gNB, the OAM assigns a single PCI for each NR cell in the gNB, and the gNB selects this value as the PCI of the NR cell.

#### 15.5.6.2 Distributed PCI Assignment

For distributed PCI assignment in gNB, the OAM assigns a list of PCIs for each NR cell in the gNB, and the gNB selects a PCI value from the list of PCIs. The gNB may restrict this list by removing some PCIs that are reported by UEs, reported over the Xn interface by neighbouring gNBs, and/or acquired through other methods, e.g. detected over the air using a downlink receiver.

*End of changes*

# Annex: RAN2 Agreements

## RAN2#125bis

on-demand SIB1

**Agreements on on-demand SIB1:**

1. At least RAN2 starts scenario 1a (Cell A SIB assisted intra-cell WUS. And WUS and SIB1 is sent to/from NES cell). Other scenarios are not excluded.
2. RAN2 assume that RACH procedure is reused for UE to request on-demand SIB1.
3. UL WUS configuration includes at least RACH configuration.
4. A UE needs to know a UL WUS configuration to request SIB1 of which cell.
5. Existing Msg 1 based on-demand procedure is reused for on-demand SIB1 acquisition procedure. FFS on Msg 3. FFS if / when the UE monitors the OD-SIB1 upon reception of RAR. FFS: whether introduce specified UE behavior if RACH failure of OD-SIB1 request.
6. The UE first should acquire valid SIB1 (e.g. via SIB1 request) for camping to NES cell (if the UE knows the cell doesn’t broadcast SIB1 and supports on-demand SIB1).

Adaptation of common signal channel transmissions

**Agreements on paging adaptation:**

1. From the UE point of view, UE will monitor one PEI/PO every paging DRX cycle, i.e. the UE doesn’t skip PO in paging DRX cycle.
2. For adaptation of paging occasions in time domain, RAN2 to study a) bundle paging frames and b) extend the values of N to have increased interval between PFs (e.g. T/64, T/128 ...) and compensating decrease in number of PFs by increasing POs per PF.
3. For Paging adaptation, R2 discusses the following options on compatibility of legacy RRC\_IDLE/RRC\_INACTIVE UE:

- Option 1: Prevent the access of legacy UE via barring;

- Option 2: Separate paging resources for legacy UEs and Rel-19 NES UEs (assuming there are legacy UEs)

## RAN2#126

on-demand SIB1

**Agreements on on-demand SIB1:**

**Further clarification**

1. Study on-demand SIB1 provisioning for NES Cell(s) in versions of Scenario 1a with multiple Cells A and/or NES Cells:

- More than one Cell A may provide configuration for the same NES cell.

- The same Cell A may assist more than one NES Cells.

1. RRC release message assisted intra-cell WUS can be discussed as option of signaling details in stage 3.

**Information of WUS configuration**

1. Can use the PCI and frequency of a NES Cell to associate the UL WUS configuration with a NES Cell.
2. For Message 1 based on-demand SIB1 request, the on-demand SI request configuration that currently included in SIB1 may be used as the design baseline.

**Transmission of WUS configuration**

1. Cell A’s SIB can be used to configure on-demand SIB1 related configuration for neighbour NES cells, e.g., via new SIB or the existing SIB.

**Triggering condition of WUS transmission**

1. If the UE chooses the NES cell using legacy intra-F/inter-F cell re-selection procedure (as baseline), the UE triggers WUS transmission.
2. After UE successfully receives OD-SIB1 for that NES Cell and if it is a suitable cell, UE camps in the NES Cell “similar” to a legacy Cell.

**UE request SIB1 to perform initial access in NES cell**

1. RAN2 not to support on-demand SIB1 request that is combined with an initial access to perform RRC connection establishment/resume on the NES cell.

**Legacy UE impact**

1. NW need to bar the legacy UE from accessing the on-demand SIB1 cell (e.g. based on the existing barring mechanism)
2. How to avoid/deprioritize the legacy UE camping at the Cell A attempting to switch to the NES Cell (but allowing the R19 NES UE to do that).

**Barring for R19 NES UE**

1. If the NES UE is unable to acquire the SIB1 of NES Cell before UE initiates OD-SIB1 procedure, it will not consider it as barred at that moment. R19 NES UE bars the cell if the UE fails to acquire SIB1 via on-demand SIB1 for NES cell.

**Paging and SIB1 update in NES cell**

1. After Rel-19 NES UEs camp in NES cell, the UE behaviour is same as the one defined as legacy normal camped state, e.g. paging reception, SIB1 update, etc.

**RAR monitoring for MSG1 based OD-SIB1 REQ**

1. RAN2 assumes the UE is expected to receive the RAR responding to the preamble transmission for Msg1-based on-demand SIB1 procedure, as the baseline.

**UE behaviour on RACH failure of OD-SIB1 REQ**

1. As baseline, upon random access procedure failure of OD-SIB1 request, UE regards OD-SIB1 can’t be acquired in the NES cell and considers it as barred. It doesn’t exclude the option to leave the determination to the UE implementation.

**SIB1 acquisition upon SIB change notification in NES cell**

1. Once the NES UE camps on the NES cell, if the UE receives SIB change notification, the UE is expected to receive SIB1 from NES cell.

**Scenario 3 (case 1 in RAN1)**

1. RAN2 to wait for RAN1’s progress whether to support scenario 3.

Adaptation of common signal channel transmissions

**RACH adaptation in spatial domain**

1. RAN2 counts on RAN1 evaluation and conclusion.

## RAN2#127

On-demand SSB SCell operation

**Agreements on OD-SSB**

Scenarios on OD-SSB:

1. RAN2 start the discussion from Scenario 2/2A and wait for RAN1 conclusion on Scenario 3A/3B.

OD-SSB transmission indication:

1. RRC based OD-SSB transmission indication is used to indicate at least the initial activation/deactivation state of OD-SSB configuration. FFS on reconfiguration.
2. New MAC-CE for OD-SSB transmission indication is introduced. We will not change legacy SCell activation/deactivation MAC CE. FFS if we need further optimization for scenario 2A.

Measurement on OD-SSB:

1. Measurement based on OD-SSB in both case 1 and case 2 will be considered. (case 1 and case 2 defined in RAN1).
2. For Case #1, the UE does not expect to measure SSB when on-demand SSB transmission is deactivated. In other words, the UE expects to measure SSB when on-demand SSB transmission is activated.
3. RAN2 does not handle the issue raised in R2-2407414 in OD-SSB based measurements.
4. RAN2 study how the UE to perform L3 measurement according to OD-SSB L3 RRM configuration.

on-demand SIB1

**Agreements on OD-SIB1**

Scenarios:

1. No consensus for RAN1 case 3 in RAN2.

OD-SIB1 Validity:

1. We can rely on legacy UE behaviour to ensure UE has valid SIB1 for the cell (i.e. UE reacquire SIB1 whenever (re)selecting cell).
2. Further UE keeps SIB1 updated while on cell via regular SI modification procedure (confirmation of earlier RAN2 agreement).

WUS configuration of NES cell from NES cell:

1. Once Rel-19 NES UE camps on the NES cell, the UE expects to receive UL WUS configuration updates from the NES Cell, e.g., via legacy SI modification procedures.

MSG3 based OD-SIB1 REQ:

1. Msg 3 based OD-SI procedure is not supported for on-demand SIB1 request in case 2 (for requesting to the NES Cell).

Access restriction for legacy UEs:

1. Following example options to handle legacy UEs (i.e. UEs not supporting OD-SIB1) can be considered in normative work. Details and further analysis need to be further discussed in normative work. Other existing options are not excluded.

- Option 1: Legacy UEs bar the OD-SIB1 cell based on cellBarred bit set to barred in MIB.

- Option 2: Legacy UEs bar the OD-SIB1 cell based on no SIB1 indication via ssb-SubcarrierOffset in MIB.

- Option 3: Network includes cells supporting OD-SIB1 to list of excluded cells.

Impacts to RRC connected UEs:

1. RAN2 understands the NW can avoid impact on legacy RRC connected UE and R19 RRC connected UE due to on-demand SIB1 (e.g. NES cell with OD-SIB1 is measured by legacy RRC\_CONNECTED UE and can be configured as its PSCell/SCells/target cell).

OD-SIB1 SI conclusion:

1. RAN2 conclude that on-demand SIB1 is feasible from RAN2 perspective and recommend normative work of case 2 for on-demand SIB1.

Adaptation of common signal channel transmissions

**Agreements on paging adaptation**

1. Option-a) is about the bundling of PF for R19 NES UEs.
2. RAN2 observe that the option-a) and option-b) can be designed to configure the POs at same time position.

## RAN2#127bis

On-demand SSB SCell operation

**Agreements on OD-SSB SCell**

1. No need to restrict the OD-SSB activation/deactivation state indication in RRC to initial configuration. No special specification effort is required.
2. Don’t introduce further new MAC CE that combines SCell activation/deactivation and OD-SSB indication for scenario 2A.
3. NW should be able to send OD-SSB indication for multiple SCells simultaneously by a MAC CE.

on-demand SIB1

**Agreements on OD-SIB1**

1. We will inherit all agreements made during SI phase to WI phase.
2. A NES cell can include neighbouring NES cell’s WUS configuration.
3. NES cell’s WUS configuration, it is included in a new SIB (including its own WUS configuration).
4. In on-demand SIB1 procedure, the UE considers RACH failure when PREAMBLE\_TRANSMISSION\_COUNTER = preambleTransMax + 1.
5. The MAC layer will indicate the RACH failure for SI request to upper layers. FFS: after that the UE upper layer will consider the cell as barred.
6. The legacy UE behaviour can be reused upon on-demand SIB1 acquisition failure, i.e., the NES UE should follow the intraFreqReselection in MIB of NES cell.
7. A cell for which SIB1 request configuration is available, can periodically broadcast SIB1.
8. If UE has SIB1 request configuration of a cell, UE needs to check if SIB1 is currently being broadcasted or provided on demand for that cell before requesting SIB1 of that cell.
9. Legacy UEs bar the OD-SIB1 cell based on no SIB1 indication in MIB e.g. via ssb-SubcarrierOffset. Detailed solution is up to RAN1. If this works, no separate barring bit for R19 NES UEs is introduced.
10. NES UEs should be allowed to reselect to cells that are prevented from legacy UEs (e.g. by excluded cell list, reselection priorities).
11. RAN2 will not start the discussion on the issue when the UL WUS configuration update in Cell A is not synchronised with the UL WUS configuration update in the NES cell, unless we’re asked to do that by other WG, e.g. RAN3.

Adaptation of common signal channel transmissions

**Agreements on paging adaptation**

1. Select option-b as baseline for R19 NES paging enhancement.
2. R2 should aim at signaling overhead minimization (e.g., Ns=8 and FFS for other larger values)
3. Allowing legacy and R19 UEs to co-ex in the same PF/PO is possible, based on NW configuration.
4. Legacy UE is not barred.
5. Rel-19 UEs only monitor the PO(s) according to Rel-19 paging configuration.

## RAN2#128

On-demand SSB SCell operation

on-demand SIB1

**Agreements on OD-SIB1**

1. NES UE with SIB1 request configuration of a NES cell assumes that a NES cell, with SSB containing K\_SSB < 24 for FR1 and K\_SSB < 12 for FR2, will acquire SIB1 as in legacy.
2. New NES-specific reselection priority parameters for NES UEs are defined for the purpose of prioritizing/deprioritizing a NES frequency.
3. Introduce new IntraFreqExcludedCellList-NES / InterFreqExcludedCellList-NES IEs enable proper reselection behaviour of legacy and NES UEs.
4. Reuse legacy cell reselection criterion as trigger condition of OD-SIB1 acquisition. No need to specify other conditions (e.g. a new RSRP threshold).
5. The existing 1-second rule in the cell reselection criteria is still applied to the triggering condition of UL WUS transmission.
6. The UE considers the cell as barred after MAC indicates max number of preamble transmission for the OD-SIB1 request.
7. If MSG2 (ACK) is received, but UE fails to receive SIB1 then the UE may consider this cell as barred, no spec impact.
8. A UE bars the NES/SIB1 less cell and/or excludes it as a candidate for reselection since the UE had no corresponding UL WUS configuration, the UE would treat this cell as if cell status is “not barred” and consider it as candidate for cell reselection once it has received a UL-WUS configuration to request SIB1 for this cell.
9. UE considers WUS configuration only valid in directly succeeding cell reselection from cell where UE acquired WUS configuration. FFS on SI validity area rather than cell level.
10. Working assumption: UL-WUS configuration in RRC release is not supported.

Adaptation of common signal channel transmissions

**Agreements on paging adaptation**

1. Introduce value for Ns=8. FFS on 16.
2. Introduce value for N= T/32. FFS on T/64, T/128, T/256.

## RAN2#129

On-demand SSB SCell operation

**Agreements on OD-SSB**

1. RAN2 leave it to RAN4 to conclude whether always-on SSB and/or OD-SSB are measured when both are transmitted in OD-SSB case 2.

on-demand SIB1

**Agreements on OD-SIB1**

1. There is no need for additional barring mechanisms (in addition to the k\_ssb signaling “no SIB1” indication in MIB) to handle legacy to be able to bar cell using OD-SIB1.
2. Specify the following UE behavior to allow the UEs in RRC\_CONNECTED state to acquire OD-SIB1 when T311 is running:

- When T311 is running, the UE can trigger the OD-SIB1 acquisition procedure with stored UL WUS configuration in SIB-X, if it is still valid.

- The legacy cell selection criteria are reused as the trigger condition of OD-SIB1 acquisition.

- The OD-SIB1 acquisition behavior is same as that of RRC\_IDLE/IANCTIV UEs.

1. The UE follows the legacy validity principle of stored SIB.
2. For Rel-19 NES UE in RRC\_CONNECTED, rely on the NW dedicated RRC for SIB1 delivery if searchSpaceSIB1 is not configured. It is legacy UE behavior and no spec change is expected.
3. SIB-x can be cell specific or area specific, as legacy.
4. Upon reception of RAR, the UE monitors OD-SIB1 in the window agreed by RAN1.

Adaptation of common signal channel transmissions

**Agreements on paging adaptation**

1. For N, values smaller than T/32 are not supported.
2. The maximum possible value for Ns is 8.
3. Introduce a separate PEI configuration.
4. Paging adaptations are configured semi-statically and updated via system information update notification.
5. A new UE capability is added for R19 NES paging enhancement, and the new capability is included in UE-RadioPagingInfo. FFS on whether we have a common capability for all NES features.

**Agreements on SSB adaptation**

1. RAN2 confirms SSB adaptation in time domain is not supported for RRC idle/inactive UEs and Rel-19 NES-capable UE’s PCell.
2. RAN2 preference is to keep SMTC based L3 RRM framework and to introduce additional SMTC configuration according to SSB adaptation for L3 RRM measurement on SCell with SSB adaptation.
3. For L3 measurement, RAN2 assumes the adapted SSB on neighbor cell is measured based on legacy SMTC.

**Agreements on RACH adaptation**

1. Legacy UEs and UEs non-capable of time domain PRACH adaptation are expected to use legacy PRACH resources per legacy configuration and procedures. No barring is needed.

2a. RAN2 starts CBRA for RACH adaptation.

2b. RAN2 starts 4-step RACH adaptation.

3. From R2 perspective, not apply time-domain RACH adaptation to RACH resources for MSG1-based SI request.

1. From R2 perspective, not apply time-domain RACH adaptation to IAB RACH resources.

5a. From R2 perspective, RACH adaptation is not modelled as RA feature(s).

5b. From R2 perspective, RACH partitioning with all the features, i.e. RedCap, SDT, and Slicing, and feature combinations, are supported for PRACH adaption in time domain.

1. Will follow legacy mechanism regarding how to select RACH resource.