5G Mobility Procedures

TP00005-V-1701 V0 - S04M06 Ed1

Learning Objectives

Upon completion of this module, you should be able to:

- Explain UE Mobility Management in the AMF.
- Describe UE Mobility in RRC Idle and RRC Inactive states.
- Describe UE Mobility in Connected Mode.

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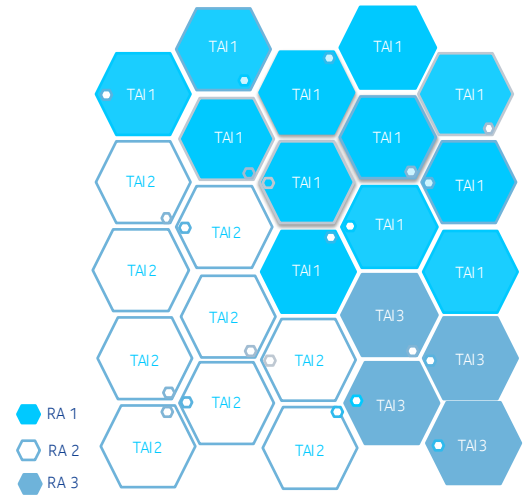
Mobility Management in the AMF

Mobility Management in the AMF
Registration Area Management

- Registration Area consist of one or more Tracking Areas
  - Each Tracking area is defined by TA Identifier (TAI) which is broadcasted in each cell
  - TAI format consisting of MCC, MNC and a 3 -byte TAC only

Registration Area management comprises the functions to allocate (by AMF) and reallocate a Registration area to a UE.

Registration area is managed per access type i.e., 3GPP access or Non-3GPP access.



Registration Area management comprises the functions to allocate and reallocate a Registration area to a UE. Registration area is managed per access type that is to say, 3GPP access or Non-3GPP access.

When a UE registers with the network over the 3GPP access, the AMF allocates a set of tracking areas in TAI List to the UE. **When the AMF allocates registration area, that is to say the set of tracking areas in the TAI List, to the UE it may take into account various information such as Mobility Pattern and Allowed/Non-Allowed Area.

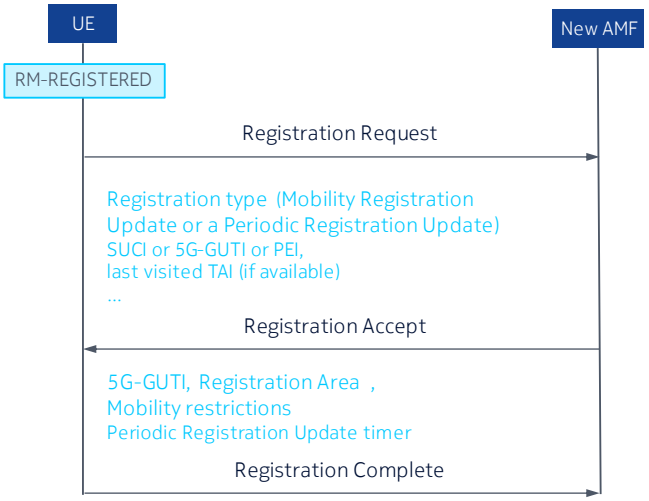
Furthermore, a single TAI dedicated to the Non-3GPP access, the N3GPP TAI, is defined in a PLMN and applies within the PLMN.

When a UE registers with the network over the Non-3GPP access, the AMF allocates a registration area that only includes the N3GPP TAI to the UE.

Mobility Management in the AMF
Mobility Registration Update

Mobility Registration Update
upon changing to a new Tracking Area (TA) outside the UE's Registration Area in both CM-CONNECTED and CM-IDLE state.

Periodic Registration Update
due to a predefined time period of inactivity



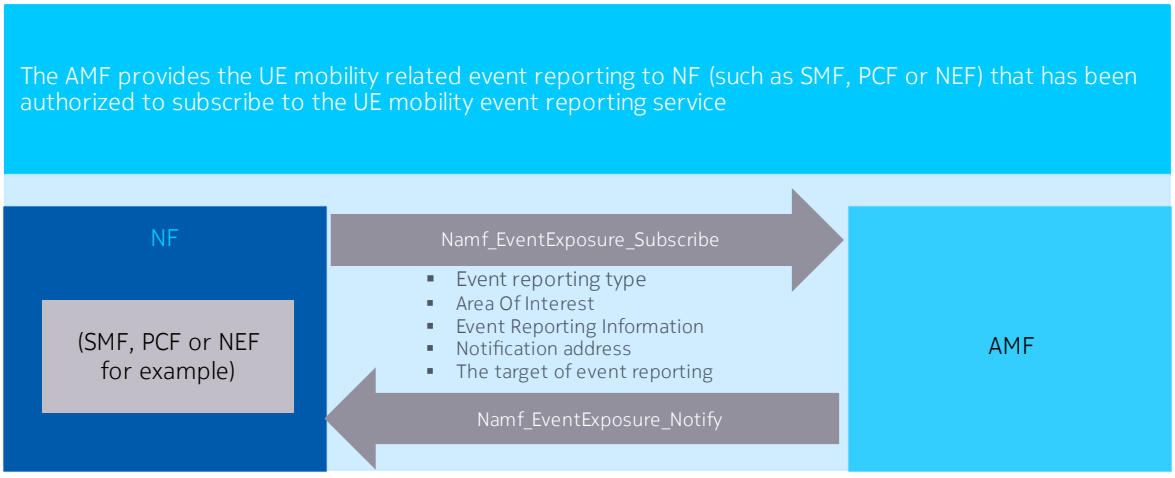
The UE initiates the Registration procedure using one of the following Registration types:

- Initial Registration to the 5GS;
- **Mobility Registration Update** upon changing to a new Tracking Area (TA) outside the UE's Registration Area in both CM-CONNECTED and CM-IDLE state, or when the UE needs to update its capabilities or protocol parameters that are negotiated in Registration procedure with or without changing to a new TA; or when the UE intends to retrieve LADN Information; or
- **Periodic Registration Update** (due to a predefined time period of inactivity); or
- Emergency Registration.

The Registration type indicates if the UE wants to perform an Initial Registration (i.e. the UE is in RM-DEREGISTERED state), a Mobility Registration Update (i.e. the UE is in RM-REGISTERED state and initiates a Registration procedure due to mobility or due to the UE needs to update its capabilities or protocol parameters, or to request a change of the set of network slices it is allowed to use), a Periodic Registration Update (i.e. the UE is in RM-REGISTERED state and initiates a Registration procedure due to the Periodic Registration Update timer expiry.

Mobility Restrictions (Which consist of RAT restriction, Forbidden Area, Service Area Restrictions and Core Network type restriction) restrict mobility handling or service access of a UE. The Mobility Restriction functionality is provided by the UE (only for mobility restriction categories provided to the UE), the radio access network and the core network.

Mobility Management in the AMF
UE Mobility Event Notification



5G System supports the functionality of tracking and reporting UE mobility events.

The UE mobility event notification service is provided by AMF. When NF service consumer (SMF, PCF or NEF for example) subscribes such service, the AMF tracks UE's location considering UE's CM state and using NG-RAN procedures in order to determine the UE presence in the Area Of Interest. Upon detecting the change of the UE presence in the Area Of Interest, the AMF notifies the UE presence in the Area Of Interest and the new UE location to the subscribed NF consumer.

- Event reporting type: what to be reported on UE mobility (e.g. UE location, UE mobility on Area of Interest).
- Area Of Interest that specifies a geographical area within 3GPP system: list of Tracking Areas, list of cells or list of (R)AN node identifiers.
- Event Reporting Information: event reporting mode, number of reports, maximum duration of reporting, event reporting condition (e.g. when the target UE moved into a specified Area Of Interest).
- Notification address: i.e. Endpoint Address of NF service consumer to be notified to.
- The target of event reporting that indicates a specific UE, a group of UE(s) or any UE (i.e. all UEs).

Mobility Management in the AMF
UE Reachability Management

Reachability management is responsible for detecting whether the UE is reachable and providing UE location (i.e., access node) for the network to reach the UE.

UE reachability in CM-IDLE	Allowing Mobile Terminated (MT) data in CM-IDLE state	The UE location is known on a TA List granularity
		Paging procedures apply to this category
		MO and MT data apply for both CM-CONNECTED and CM-IDLE state
	Mobile Initiated Connection Only (MICO) mode:	MO data applies for both CM-CONNECTED and CM-IDLE state
		MT data is only supported in CM-CONNECTED state

UE reachability in CM-CONNECTED	The AMF knows the UE location on a serving (R)AN node granularity
	NG-RAN notifies the AMF when UE becomes unreachable from RAN point of view
	UE RAN reachability management is used by RAN for UEs in RRC Inactive state

Reachability management is responsible for detecting whether the UE is reachable and providing UE location (i.e. access node) for the network to reach the UE. This is done by paging UE and UE location tracking. The UE location tracking includes both UE registration area tracking (i.e. UE registration area update) and UE reachability tracking ((i.e. UE periodic registration area update)). Such functionalities can be either located at 5GC (in the case of CM-IDLE state) or NG-RAN (in the case of CM-CONNECTED state).

UE and AMF negotiate UE reachability characteristics for CM-IDLE state during registration procedures.

Two UE reachability categories:

1. allowing Mobile Terminated data in CM-IDLE state
2. Mobile Initiated Connection Only (MICO) mode:
    - Mobile originated data applies for both CM-CONNECTED and CM-IDLE state.
    - Mobile terminated data is only supported in CM-CONNECTED state.

UE indicate preference for MICO mode during Registration Procedure. AMF based on local configuration, UE indicated preferences, UE subscription information and network policies to determine whether allow MICO mode for UE and indicates to UE during Registration procedure

MICO mode UE in CM-IDLE status: AMF considers UE always unreachable and UE need not listen to paging.

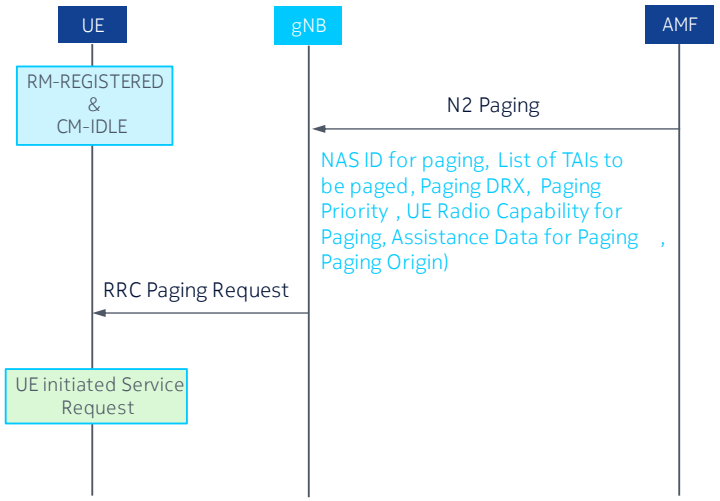
UE reachability in CM-CONNECTED:

UE RAN reachability management is used by RAN for UEs in RRC Inactive state. The location of a UE in RRC Inactive state is known by the RAN on a RAN Notification area granularity. A UE in RRC Inactive state is paged in cells of the RAN Notification area. UE in RRC Inactive state performs RAN Notification Area Update when entering a cell that is not part of the RAN Notification area that is assigned to the UE.

Mobility Management in the AMF
Paging Procedure

- UE is in RM-Registered State
- UE is in CM-IDLE state

- This can be triggered by AMF itself or other NF (e.g. SMF or SMSF).
- AMF requests the paging if UE is in CM-IDLE state
- UE initiates service request with PDU



1. AMF to gNB: N2 Paging (Paging priority: 5G-TMSI)

   If the UE is in RM-REGISTERED state and CM-IDLE and reachable in 3GPP access, the AMF sends a Paging message (NAS ID for paging, List of TAIs to be paged, Paging DRX, Paging Priority, UE Radio Capability for Paging, Assistance Data for Paging, Paging Origin) to (R)AN node(s) belonging to the Tracking Area(s) in which the UE is registered, then the eNB pages the UE.

   When supporting Paging Policy Differentiation, paging strategies may be configured in the AMF for different combinations of Paging Priority, DNN, ARP and 5QI.
2. gNB to UE: RRC Paging Request
3. At the reception of the PAGING message, the NG-RAN node shall perform paging of the UE in cells which belong to tracking areas as indicated in the TAI List for Paging IE.
4. The UE is in CM-IDLE state in 3GPP access, upon reception of paging request for a PDU Session associated to 3GPP access, the UE shall initiate the UE Triggered Service Request with PDU procedure

- Paging policy differentiation is an optional feature that allows the AMF, based on operator configuration, to apply different paging strategies for different traffic or service types provided within the same PDU Session.
- Paging Priority is a feature that allows the AMF to include an indication in the Paging Message sent to NG-RAN that the UE be paged with priority. The decision by the AMF whether to include Paging Priority in the Paging Message is based on the ARP value in the message received from the SMF for an IP packet waiting to be delivered in the UPF.
- The paging assistance information contains UE radio related information that assists the RAN for efficient paging. The Paging assistance information contains:
  - UE radio capability for paging information: It contains information derived by the NG-RAN node (e.g. band support information) from the UE Radio Capability information.
  - Information On Recommended Cells And RAN nodes For Paging: The RAN provides this information during N2 release.
    - It is used by the AMF when paging the UE to help determining the NG RAN nodes to be paged as well as to provide the information on recommended cells to each of these RAN nodes, in order to optimize the probability of successful paging while minimizing the signaling load on the radio path.

Mobility Management in the AMF
Quiz 1

1. When does the UE initiate a Mobility Registration Update?
    a. upon changing to a new Tracking Area (TA) outside the UE's Registration Area in CM -IDLE state only
    b. upon changing to a new Tracking Area (TA) outside the UE's Registration Area in CM -CONNECTED state only
    c. upon changing to a new Tracking Area (TA) outside the UE's Registration Area in both CM -CONNECTED and CM-IDLE state
2. Which NF supports the functionality of tracking and reporting UE mobility events?
    a. UPF
    b. UDM
    c. AMF
    d. SMF

Mobility in RRC Idle and RRC Inactive states

Mobility in RRC Idle and RRC Inactive states
Review of RRC States

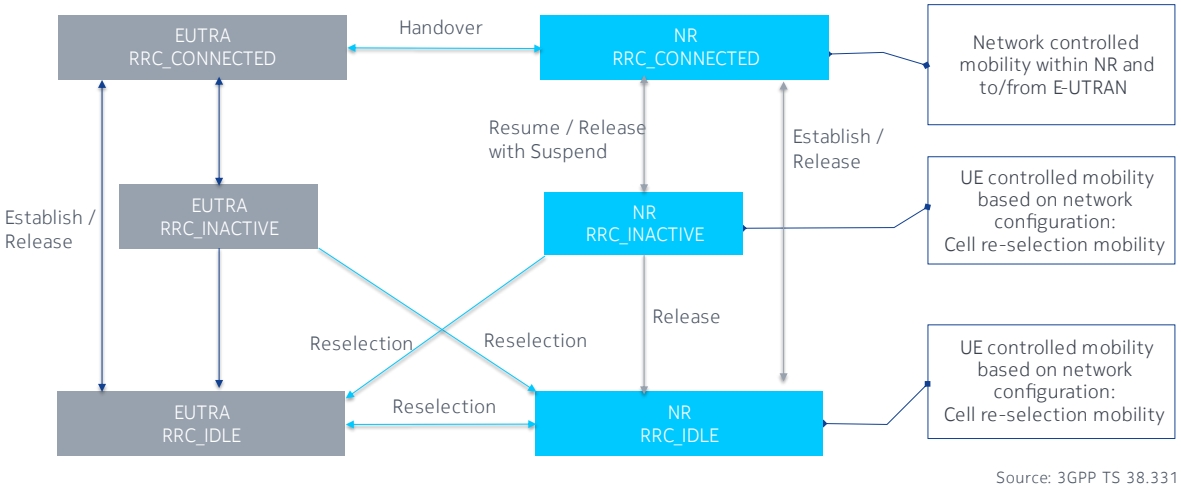
RRC State	Mobility procedure	Monitoring dedicated physical channels	Allowed mode for DL channel monitoring	UE location known on	Paging	Uplink activity allowed	Storage of RAN context information
RRC Idle	Cell selection & reselection	No	Discontinuous with DRX	Tracking area list level	CN paging using 5G-S-TMSI	No	No
RRC Inactive	Cell selection & reselection	No	Discontinuous with DRX	RAN Notification Area level	RAN paging using I-RNTI	No	Yes, UE and at least one gNB
RRC Connected	Network controlled handover	Yes	Both continuous and discontinuous with DRX	Cell level	Paging channel associated with the shared data channel	Yes	UE and gNB(s)

A UE is either in RRC_CONNECTED state or in RRC_INACTIVE state when an RRC connection has been established. If this is not the case, i.e. no RRC connection is established, the UE is in RRC_IDLE state. Note that IDLE mode refers to a UE state similar to LTE IDLE state and RRC_INACTIVE state is a new RRC state introduced in NR.

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

- **RRC_IDLE**:
  - PLMN selection;
  - Broadcast of system information;
  - Cell re-selection mobility;
  - Paging for mobile terminated data is initiated by 5GC;
  - 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 AS context is stored in NG-RAN and the UE;
  - NG-RAN knows the RNA which the UE belongs to.
- **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;
  - Network controlled mobility including measurements.

Mobility in RRC Idle and RRC Inactive states
NR Mobility



Source: 3GPP TS 38.331

In 5G NR (same as other 3GPP Radio access networks) the term handover refers to the process of transferring an ongoing user connection from one radio channel to another. If active UE due to its movement can be served in a more efficient manner in another cell – a handover is performed.

There are two categories of 5G NR handovers: network controlled and UE controlled:

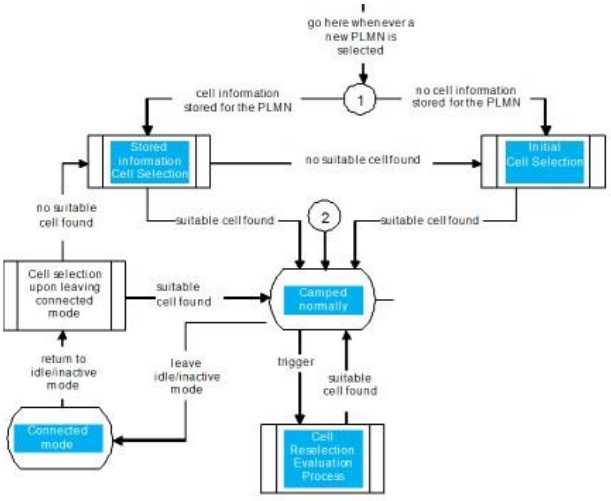
- Network controlled handover is applied to 5G NR UEs in RRC CONNECTED mode. This network controlled handover is categorized into two types : Cell level and beam level.
- UE controlled mobility based on network configuration is applied in 5G NR UEs is RRC Idle or RRC Inactive state.

Remember, RRC protocol is responsible for mobility mechanisms in 5G NR (same as LTE eUTRAN).

Mobility in RRC Idle and RRC Inactive states

RRC_IDLE and RRC_INACTIVE Cell Selection and Reselection

PLMN selection, cell (re)selection procedures, and location registration are common for both RRC_IDLE state and RRC_INACTIVE state.



In both RRC Idle and RRC INACTIVE Modes, UE controlled mobility based on network configuration is performed.

In RRC Idle Mode: during cell selection procedure, 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:

The UE makes measurements of attributes of the serving and neighbor cells to enable the reselection process

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 neighbor cells. In multi-beam operations, the cell quality is derived amongst the beams corresponding to the same cell .

A UE in RRC_INACTIVE performs cell reselection. The principles of the procedure are as for the RRC IDLE state.

In RRC Connected state Network controlled mobility including measurements is performed. This can be within NR and to or from E-UTRAN; Intra-System handover or Inter System handover.

Cell selection is based on the following principles:

- The UE NAS layer identifies a selected PLMN (and equivalent PLMNs, if any);
- The UE searches the supported frequency bands and for each carrier frequency it searches and identifies the strongest cell. It reads cell broadcast information to identify PLMN(s) and other relevant parameters (e.g. related to cell restrictions);
- 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.
- A cell is “suitable” if: the measured cell attributes satisfy the cell selection criteria (based on DL radio signal strength/quality); the cell belongs to the selected/equivalent PLMN; cell is not restricted (e.g. cell is not barred/reserved or part of "forbidden" roaming areas);
- An “acceptable” cell is one for which the measured cell attributes satisfy the cell selection criteria and the cell is not barred.
- Among the identified suitable (or acceptable) cells, the UE selects the strongest cell, (technically it “camps” on that cell).
- As signaled/configured by the radio network, certain frequencies could be prioritized for camping.

Mobility in RRC Idle and RRC Inactive states
RAN Notification Area

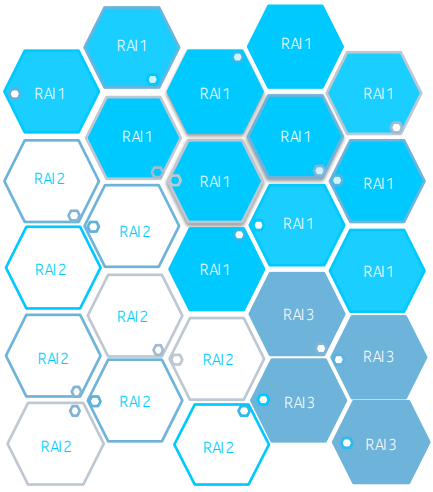
RRC_INACTIVE is a state where a UE remains in CM-CONNECTED and can move within an area configured by NG-RAN (the RNA) without notifying NG-RAN.

RNA can cover a single or multiple cells and shall be contained within the CN Registration Area.

On initial NR specification (Release 15), Xn connectivity is assumed to be available within the RNA.

A RAN-based Notification Area Update (RNAU) is sent by the UE both

- Periodically,
- and when the cell reselection procedure of the UE selects a cell that does not belong to the configured RNA.



Key principles of the RAN Notification Area (RNA):

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.

RNA can cover a single or multiple cells, and shall be contained within the CN Registration Area.

In Rel-15, Xn connectivity is assumed to be available within the RNA.

A RAN-based Notification Area Update (RNAU) is sent by the UE both Periodically, and 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 more RAN area IDs in the system information.

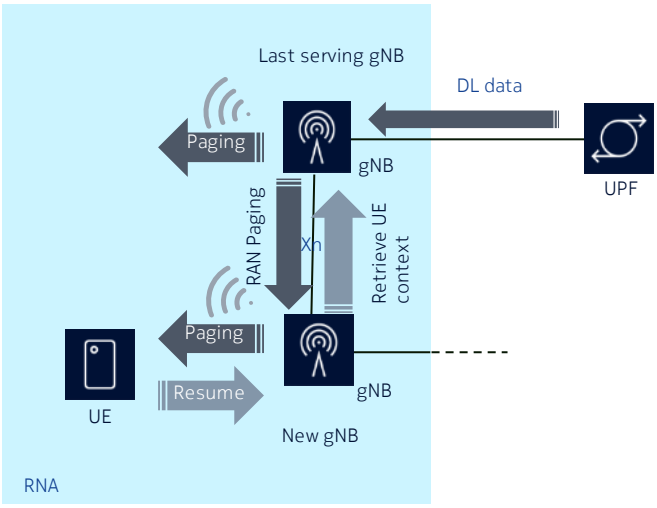
NG-RAN may provide different RNA definitions to different UEs but not mix different definitions to the same UE at the same time. UE shall support all RNA configuration options listed above.

Mobility in RRC Idle and RRC Inactive states
RRC Inactive State Mobility

The last serving gNB node keeps the UE context and the UE-associated NG connection with the serving AMF and UPF

If the last serving NG-RAN node receives DL data from the UPF or DL signaling from the AMF while the UE is in RRC_INACTIVE, it pages in the cells corresponding to the RNA

If the UE accesses an NG-RAN node other than the last serving NG-RAN node, the receiving NG-RAN node triggers the XnAP Retrieve UE Context procedure to get the UE context from the last serving NG-RAN node



In RRC_INACTIVE, the last serving gNB node keeps the UE context and the UE-associated NG connection with the serving AMF and UPF.

If the last serving gNB receives DL data from the UPF or DL signaling from the AMF while the UE is in RRC_INACTIVE, it pages in the cells corresponding to the RNA and may send XnAP RAN Paging to neighbor gNB(s) if the RNA includes cells of neighbor gNB(s).

The AMF provides to the NG-RAN node the RRC Inactive Assistant Information to assist the NG-RAN node's decision whether the UE can be sent to RRC_INACTIVE. The RRC Inactive Assistant Information includes:

- the registration area configured for the UE,
- the UE specific DRX,
- Periodic Registration Update timer,
- an indication if the UE is configured with Mobile Initiated Connection Only (MICO) mode by the AMF,
- and UE Identity Index value.

The UE registration area is taken into account by the NG-RAN node when configuring the RAN-based notification area.

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 RAN Notification Area Update timer.

The I-RNTI provides the new NG-RAN node a reference to the UE context in the old NG-RAN node:

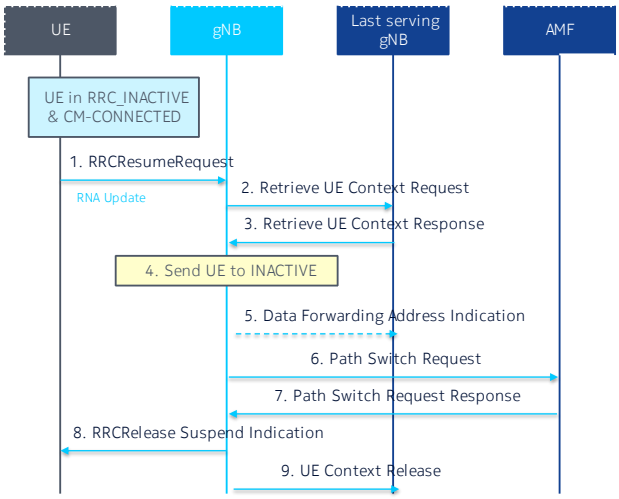
40bit I-RNTI = <20 bits UE specific reference>+<20 bits NG-RAN node address index (e.g., gNB ID, eNB ID)>.

Mobility in RRC Idle and RRC Inactive states
RAN-based Notification Area Update

Procedure starts from state where UE is in RRC_INACTIVE and in CM-CONNECTED.

- UE does cell reselection outside from RAN Notification Area.

- When the UE moves out of the RNA or at expiry of the periodic RNA Update timer, the UE triggers an RNA Update procedure.
- In the nominal scenario, the UE context is relocated if UE has moved to a new gNB (involving Xn Retrieve UE Context procedure).



1. The UE resumes from RRC_INACTIVE, providing the I-RNTI allocated by the last serving gNB. Cause value, e.g., RAN notification area update.
2. The gNB resolves the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context.
3. The last serving gNB provides the UE context response.

The last serving gNB may provide the UE context.

The last serving gNB may decide to move the UE to RRC_IDLE.

The last serving gNB may decide keep the UE context in the last serving gNB and to keep the UE in RRC_INACTIVE.

4. The gNB may move the UE to RRC_CONNECTED, or send the UE back to RRC_IDLE (RRCRelease), or send the UE back to RRC_INACTIVE.
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.

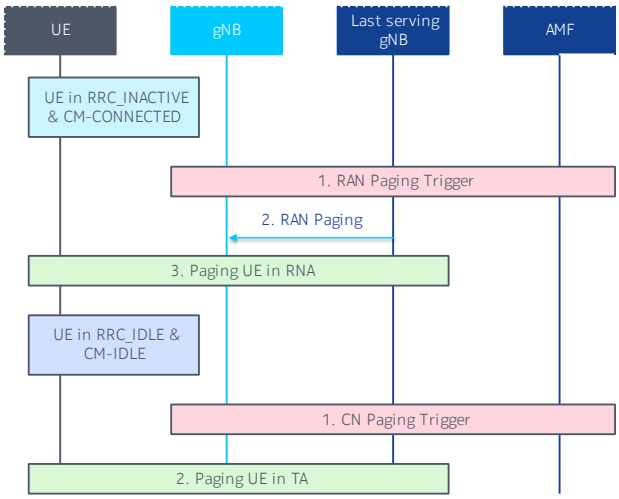
8. The gNB keeps the UE in RRC_INACTIVE state by sending RRCRelease with suspend indication.
9. The gNB triggers the release of the UE resources at the last serving gNB.

Mobility in RRC Idle and RRC Inactive states
Paging for UEs in RRC Idle and in RRC Inactive

NR Paging allows the network to reach UEs in RRC_IDLE and in RRC_INACTIVE state:

- RRC_IDLE: UE monitors the paging channels for CN initiated paging (5GS-TMSI).
- RRC_INACTIVE: UE also monitors paging channels for RAN-initiated paging (I-RNTI).

- Paging DRX is defined where the UE in RRC_IDLE or RRC_INACTIVE is only required to monitor paging channels during one Paging Occasions (PO) per DRX cycle.
- The UE uses the shortest of the DRX cycles applicable.
- The POs of a UE for CN-initiated and RAN-initiated paging are based on the same UE ID: overlapping POs.



NR Paging allows the network to reach UEs in RRC_IDLE and in RRC_INACTIVE state:

Reach the low activity UE for incoming data.

Used to notify UEs in RRC_IDLE, RRC_INACTIVE and RRC_CONNECTED state of system information change.

Used to notify UEs about ETWS/CMAS.

RRC_IDLE: UE monitors the paging channels for CN-initiated paging (5G-S-TMSI).

RRC_INACTIVE: UE *also* monitors paging channels for RAN-initiated paging (I-RNTI).

Paging DRX is defined where the UE in RRC_IDLE or RRC_INACTIVE is only required to monitor paging channels during one Paging Occasions (PO) per DRX cycle.

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 signaling;
3) For RAN-initiated paging, a UE-specific cycle is configured via RRC signaling.

The UE uses the shortest of the DRX cycles applicable.

The POs of a UE for CN-initiated and RAN-initiated paging are based on the same UE ID : overlapping POs.

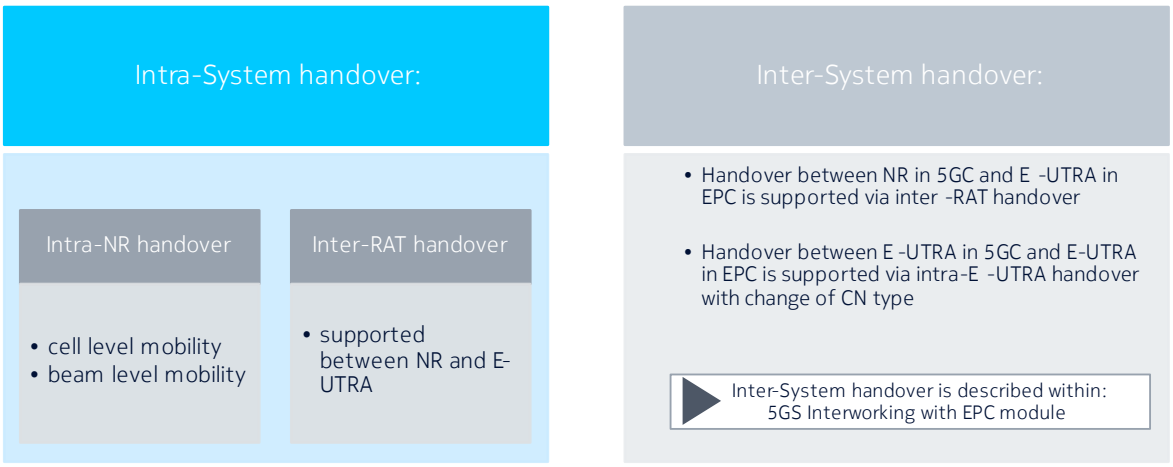
At RAN Paging, the serving NG-RAN node provides RAN Paging area information. The serving NG-RAN node may also provide RAN Paging attempt information. Each paged NG-RAN node receives the same RAN Paging attempt information during a paging attempt with the following content: Paging Attempt Count, the intended 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.

Mobility in RRC Idle and RRC Inactive states
Quiz 2

1. Which of the following can be considered as the RRC Inactive Assistant Information the AMF provides to the NG -RAN node?
    a. the registration area configured for the UE
    b. the UE specific DRX
    c. Periodic Registration Update timer
    d. an indication if the UE is configured with MICO mode by the AMF
    e. UE Identity Index value
2. Which of the following apply to MICO mode?
    a. MO and MT data apply for both CM -CONNECTED and CM -IDLE state
    b. MO data applies for both CM -CONNECTED and CM -IDLE state
    c. MT data is only supported in CM -CONNECTED state
    d. MO data is only supported in CM -CONNECTED state

Mobility in Connected Mode

Mobility in Connected Mode
Intra-NR and Inter-RAT Handover



5G Intra-System handover are Intra-NR handover and Inter-RAT handover; Intra 5GC inter RAT mobility is supported between NR and E-UTRA: Inter RAT measurements in NR are limited to E-UTRA and the source RAT should be able to support and configure Target RAT measurement and reporting.

Intra-NR handover: Network controlled mobility applies to UEs in RRC_CONNECTED and is categorized into two types of mobility: Cell level mobility and Beam level mobility.

Data forwarding, in-sequence delivery and duplication avoidance at handover can be guaranteed between target gNB and source gNB.

Inter-system handovers are supported between 5G Core Network (5GC) and EPC.

- Handover between NR in 5GC and E-UTRA in EPC is supported via inter-RAT handover.
- Handover between E-UTRA in 5GC and E-UTRA in EPC is supported via intra-E-UTRA handover with change of CN type. The source eNB/ng-eNB decides handover procedure to trigger (e.g. via the same CN type or to the other CN type). UE has to know the target CN type from the handover command during intra-LTE inter-system HO, intra-LTE intra-system HO.

Mobility in Connected Mode
Intra-NR Handover

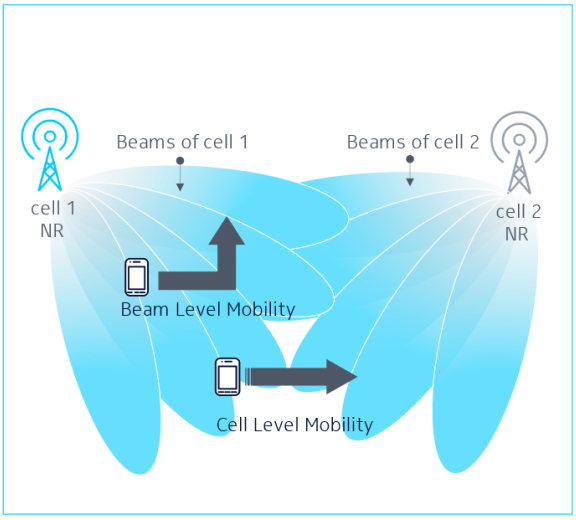
Beam level mobility

- Beam level mobility in same cell with minimum or no RRC involvement
- UE moves inside the cell : handled by beam management
- Based on beam feedback provided by UE
- Network controlled

Cell level mobility

- RRC level mobility between different cells
- Cell quality level evaluation is based on the beam quality measurements
- Network controlled

In 5G NR not only inter -cell, but also intra -cell mobility (i.e. UE mobility between beams) needs to be considered



Network controlled mobility applies to UEs in RRC_CONNECTED and is categorized into two types of mobility: cell level mobility and beam level mobility:

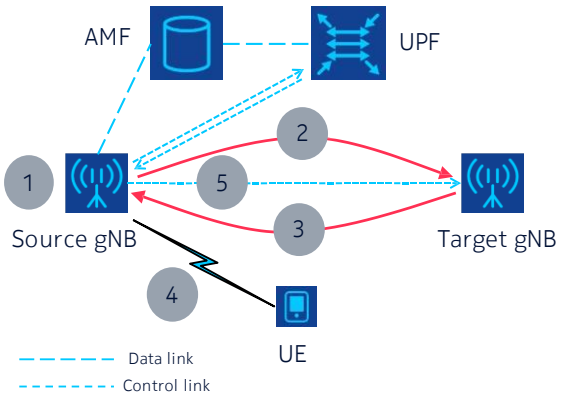
- Cell level mobility requires explicit RRC signaling to be triggered, i.e. handover. For inter-gNB handover, handover request, handover acknowledgement, handover command, handover complete procedure are supported between source gNB and target gNB. The release of the resources at the source gNB during the handover completion phase is triggered by the target gNB.

- Beam level mobility does not require explicit RRC signaling to be triggered - it is dealt with at lower layers - and RRC is not required to know which beam is being used at a given point in time.

Keep in mind, in 5G NR not only inter-cell, but also intra-cell mobility (i.e. UE mobility between beams) needs to be considered.

Mobility in Connected Mode
Intra-NR Handover

Handover procedure in NR



Handover Preparation	1.Handover decision 2.Handover Request (reservation of radio resources) 3.Handover ACK

Similar to LTE handover with three phases:

- Handover Preparation
- Handover Execution
- Handover Completion.

Measurement reports:

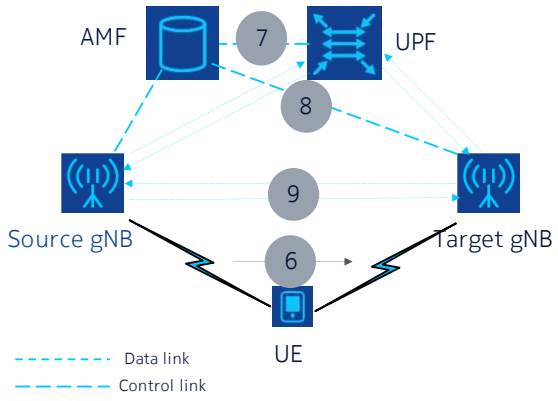
triggered using cell quality measurements derived based on beam measurements: Average of the measurements of N strongest beams above certain threshold T.

This Figure depicts the preparation phase of 5G Inter gNB handover type.

1. The source gNB initiates handover
2. and issues a Handover Request over the Xn interface.
3. The target gNB performs admission control and provides the RRC configuration as part of the Handover Acknowledgement.
4. The source gNB provides the RRC configuration to the UE in the Handover Command. The Handover Command 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 Handover Command message. The access information to the target cell may include beam specific information, if any.
5. Data forwarding, in-sequence delivery and duplication avoidance at handover can be guaranteed between target gNB and source gNB.

Mobility in Connected Mode
Intra-NR Handover

Handover procedure in NR



Handover Execution

4. Handover Command
5. Data forwarding
6. Handover
7. Path switch request
8. Path switch ACK
9. UE Context Release

Then, The UE synchronizes to the target cell and completes the RRC handover procedure.

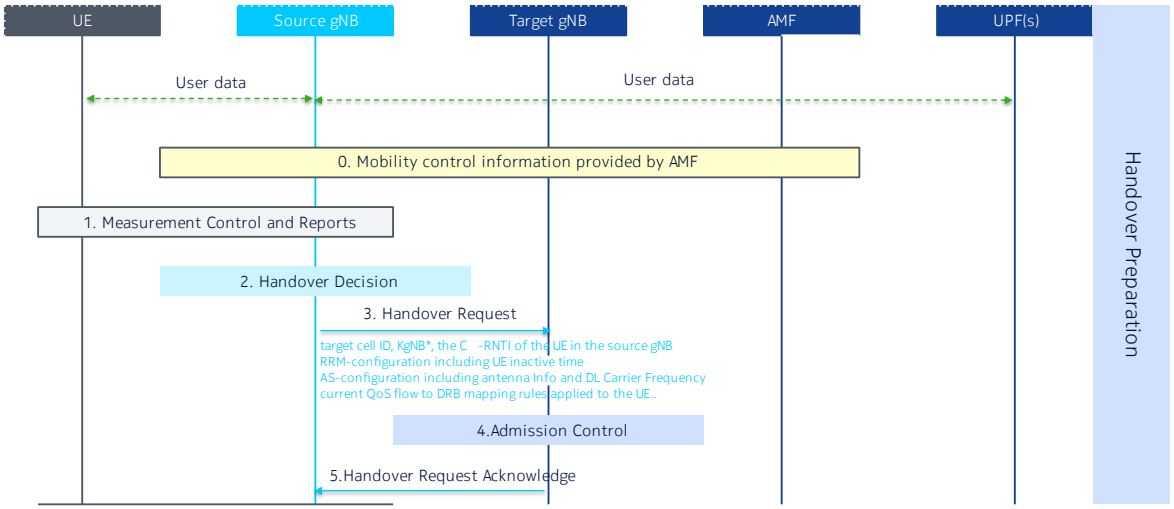
The target gNB sends a PATH SWITCH REQUEST message to AMF to trigger 5G Core to switch the DL data path towards the target gNB and to establish an NG-C interface instance towards the target gNB.

5GC switches the DL data path towards the target gNB and the AMF confirms the PATH SWITCH REQUEST message with the PATH SWITCH REQUEST ACKNOWLEDGE message.

By sending the UE CONTEXT RELEASE message, the target gNB informs the source gNB about the success of handover and triggers the release of resources by the source gNB.

Note finally that Timer based handover failure procedure is supported in NR and RRC connection re-establishment procedure is used for recovering from handover failure.

Mobility in Connected Mode
Intra-NR Handover



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.

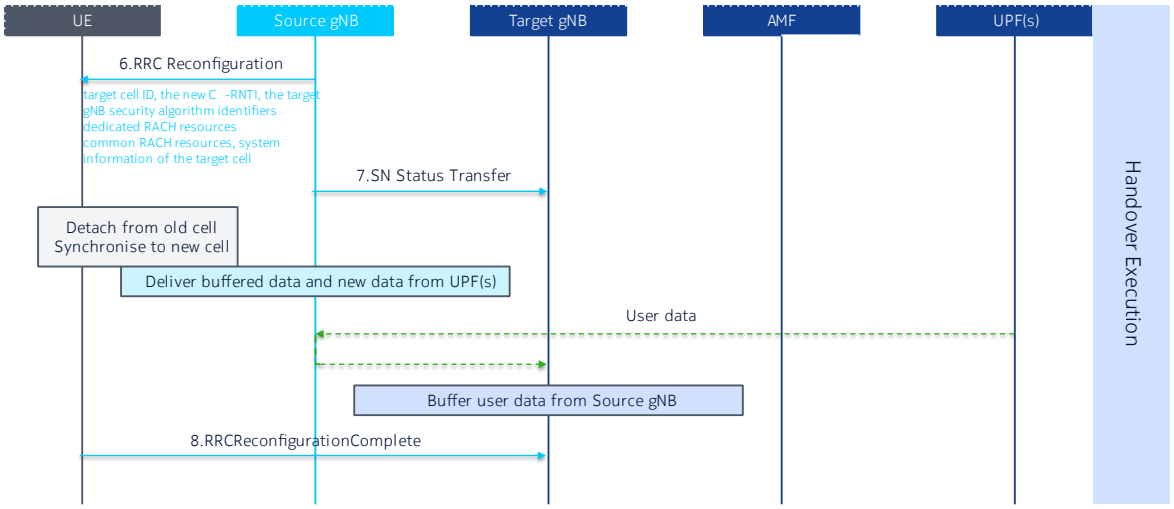
This slide and 2 coming slides display the basic intra-NR RAN handover scenario where neither the AMF nor the UPF changes.

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

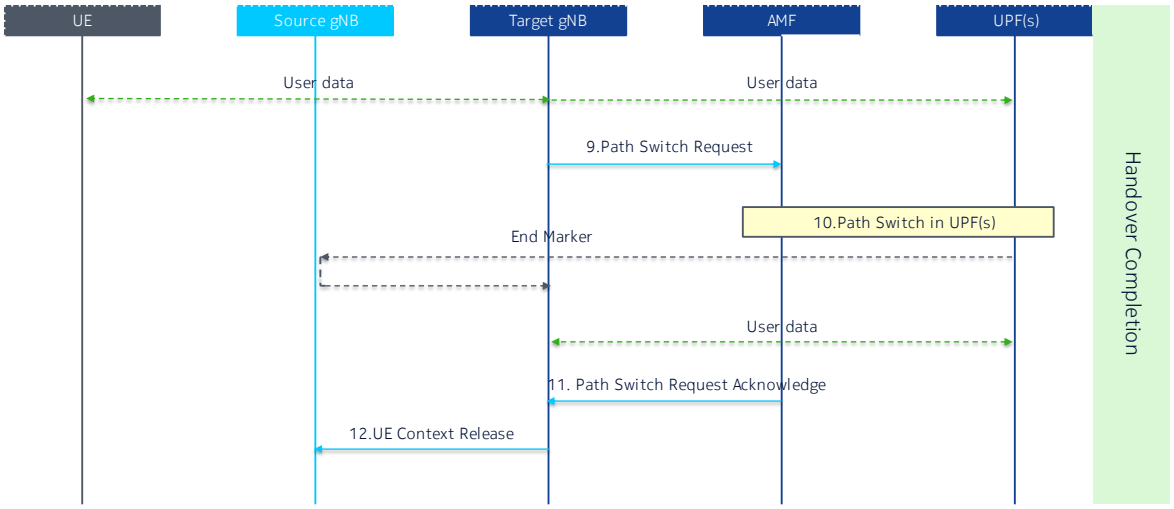
3. The source gNB issues a Handover Request message to the target gNB passing a transparent RRC container with necessary information to prepare the handover at the target side. The information includes at least the target cell ID, KgNB*, the C-RNTI of the UE in the source gNB, RRM-configuration including 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 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 (if supported) and QoS flow level QoS profile(s).
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.

Mobility in Connected Mode
Intra-NR Handover



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.
7. The source gNB sends the SN STATUS TRANSFER message to the target gNB.
8. The UE synchronizes to the target cell and completes the RRC handover procedure by sending RRCReconfigurationComplete message to target gNB.

Mobility in Connected Mode
Intra-NR Handover

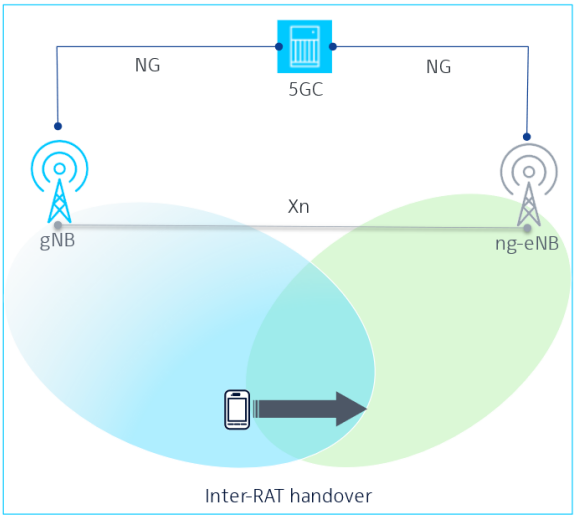


9. The target gNB sends a PATH SWITCH REQUEST message to AMF to trigger 5GC to switch the DL data path towards the target gNB and to establish an NG-C interface instance towards the target gNB.
10. 5GC switches the DL data path towards the target gNB. The UPF sends one or more "end marker" packets on 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.

Mobility in Connected Mode
Intra-NR Handover

Intra-System handover:

- Inter-RAT handover: gNB ⇔ ng-eNB
  - Supported between NR and E-UTRA
  - Both Xn and NG based inter -RAT handover (via core network) are supported.
    - Transparent for the UE.
  - In-sequence and lossless handovers are supported.



These procedures are used to hand over a UE from a source NG-RAN node to a target NG-RAN node using the Xn or N2 reference points. This can be triggered, for example, due to new radio conditions, load balancing or due to specific service e.g. in the presence of QoS Flow for voice, the source NG-RAN node being NR may trigger handover to E-UTRA connected to 5GC;

Xn & N2 handovers are similar to X2 & S1 handovers, with a few key differences:

- Admission at target NG-RAN node is based on PDU session & QoS flow level for the signaling (instead of E-RABs)
- However, resource admission is done at DRB level & Slice level
- Flow re-mapping by target NG-RAN node can happen at handover.

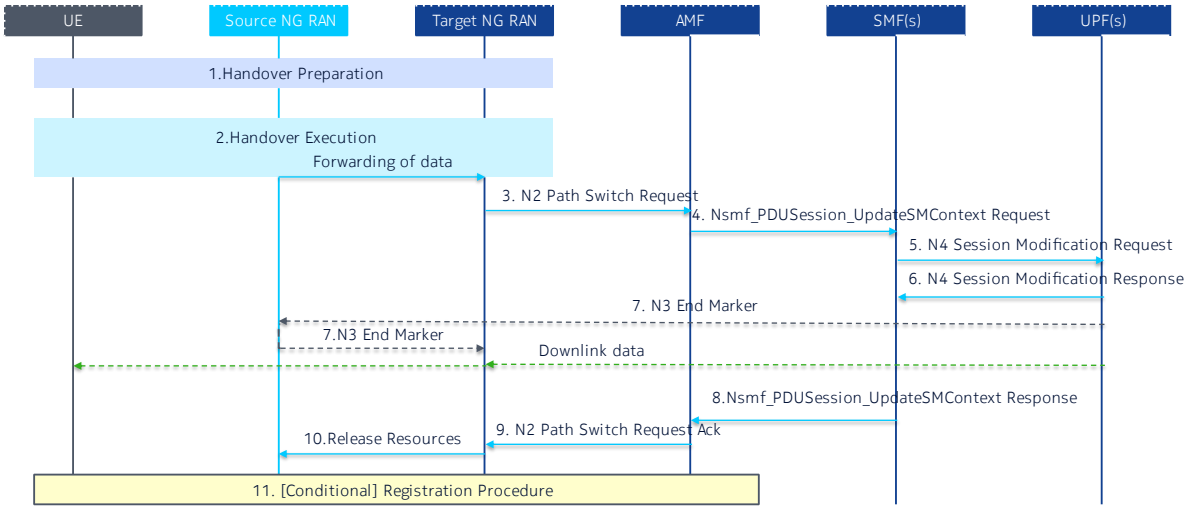
Xn based inter NG-RAN handover:

This procedure is used to hand over a UE from a source NG-RAN to target NG-RAN using Xn.

Inter NG-RAN node N2 based handover:

The source NG-RAN decides to initiate an N2-based handover to the target NG-RAN. This can be triggered, for example, due to new radio conditions or load balancing, if there is no Xn connectivity to the target NG-RAN, an error indication from the target NG-RAN after an unsuccessful Xn-based handover (i.e. no IP connectivity between T-RAN and S-UPF), or based on dynamic information learnt by the S-RAN.

Mobility in Connected Mode
Xn-based inter NG-RAN Nodes Handover



This signaling flow shows Xn based inter NG-RAN handover without UPF re-allocation:

1. Handover Prepration (refer to Intra-NR Handover slides)
2. Handover Execution (refer to Intra-NR Handover slides)
3. The Target NG-RAN sends an N2 Path Switch Request message to an AMF to inform that the UE has moved to a new target cell and provides a List Of PDU Sessions To Be Switched. The selected PLMN ID is included in the message. The target NG-RAN shall include the PDU Session in the PDU Sessions Rejected list (because none of the QoS Flows of a PDU Session are accepted by the Target NG-RAN; or the corresponding network slice is not supported in the Target NG-RAN)
4. The AMF sends N2 SM information by invoking the Nsmf_PDUSession_UpdateSMContext request service operation for each PDU Session in the lists of PDU Sessions received in the N2 Path Switch Request. The Nsmf_PDUSession_UpdateSMContext Request contains either an indication that the PDU Session Is To Be Switched (together with information on the N3 addressing to use and on the transferred QoS flows) or an indication that the PDU Session is to be Rejected (together with a rejection cause).
5. For PDU Sessions that are modified by the Target NG-RAN, the SMF sends an N4 Session Modification Request message to the UPF. The SMF may notify the UPF that originated the Data Notification to discard downlink data for the PDU Sessions and/or to not provide further Data Notification messages.
6. For the PDU Sessions that are switched, the UPF returns an N4 Session Modification Response message to the SMF after requested PDU Sessions are switched
7. The UPF sends one or more "end marker" packets for each N3 tunnel on the old path immediately after switching the path (In order to assist the reordering function in the Target NG-RAN). The UPF starts sending downlink packets to the Target NG-RAN
8. The SMF sends an Nsmf_PDUSession_UpdateSMContext response (CN Tunnel Info) to the AMF for PDU Sessions which have been switched successfully. The CN Tunnel Info of UPF send to AMF is used to setup N3 tunnel
9. Once the Nsmf_PDUSession_UpdateSMContext response is received from all the SMFs, the AMF aggregates received CN Tunnel Info and sends this aggregated information as a part of N2 SM Information along with the Failed PDU Sessions in N2 Path Switch Request Ack to the Target NG-RAN
10. The Target NG-RAN confirms success of the handover, by sending a Release Resources message to the Source NG-RAN. It then triggers the release of resources with the Source NG-RAN
11. The UE may initiate Mobility Registration Update procedure if one of the triggers of registration procedure applies.

Mobility in Connected Mode
Xn-based inter NG-RAN Nodes Handover

Data forwarding

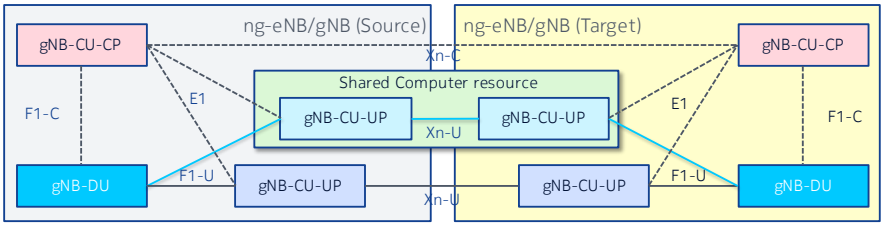
UP compute resources can be shared between source and target NG -RAN nodes

1. At Xn handover the source NG-RAN node includes the NG-U TEID for identification of UP resources that can be reused by target NG-RAN node

2. Target NG-RAN node indicates the reuse to SMF to avoid useless signaling to the UPF

Benefits include:

- Minimization of packet transfer and latency during handover
- Traffic pooling of UP compute resources leading to network cost reduction.

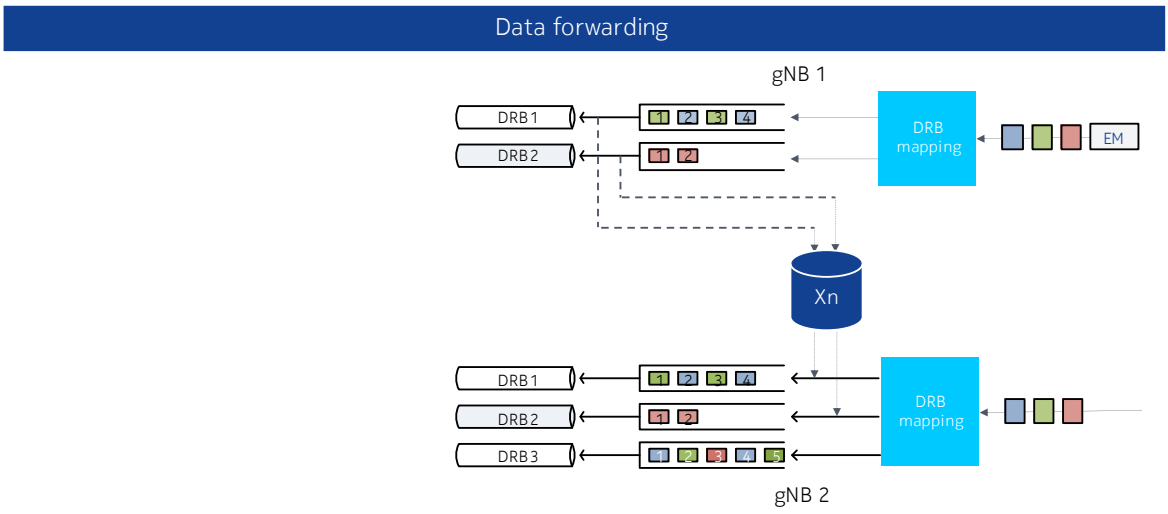


The source NG-RAN node may suggest downlink data forwarding per QoS flow established for a PDU session and may provide information how it maps QoS flows to DRBs. The target NG-RAN node decides data forwarding per QoS flow established for a PDU Session.

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.

Mobility in Connected Mode
Xn-based inter NG-RAN Nodes Handover



Lossless Handover: DRB level forwarding similar to 4G E-RAB forwarding tunnels.

When lossless handover is required, source DRB configuration is replicated at the target NG-RAN node, at least during the forwarding phase.

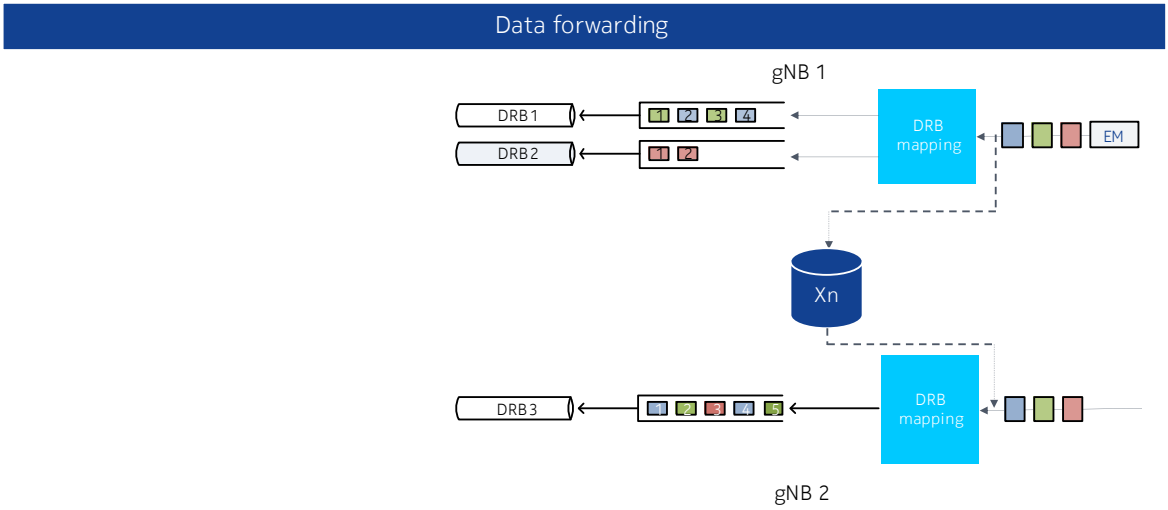
Forwarding DRB tunnels are setup end-to-end between the source and target NG-RAN nodes to forward PDCP SDU(s).

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.

Flow remapping can happen for the new NG-U packets after the forwarding phase

- 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.

Mobility in Connected Mode
Xn-based inter NG-RAN Nodes Handover

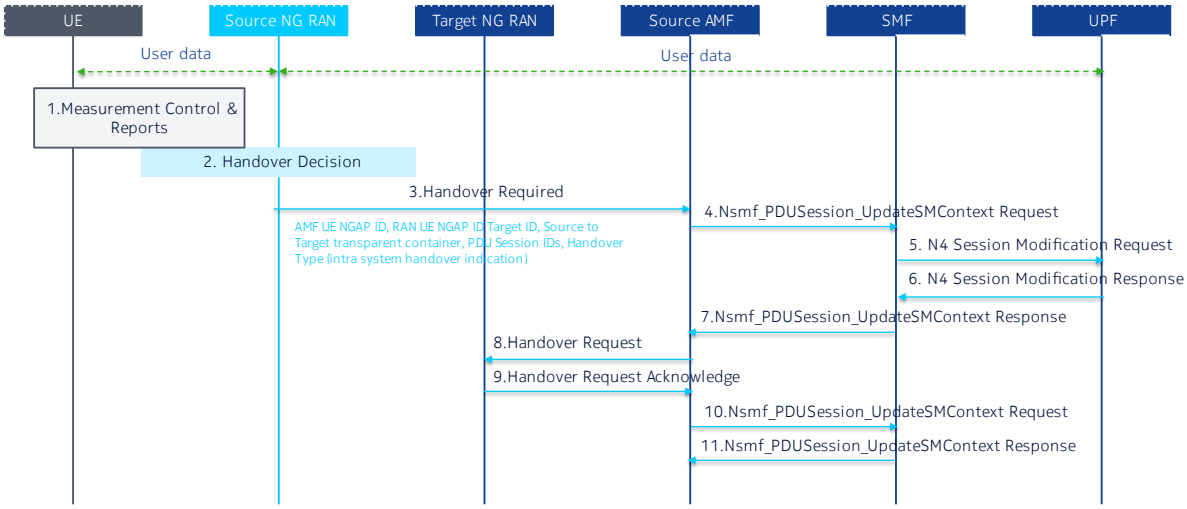


Non Lossless: PDU session forwarding tunnel (new)

- When the handover is not lossless (e.g. RRC full configuration), a single PDU session tunnel can instead be setup for the forwarding phase
- All SDAP SDUs are then forwarded over this PDU session tunnel.

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.

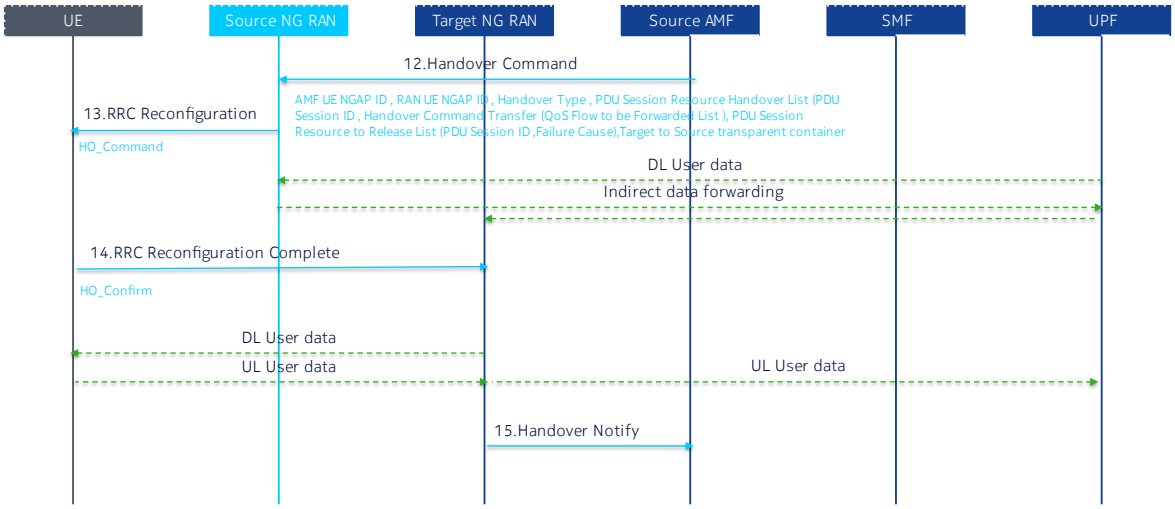
Mobility in Connected Mode
N2-based inter NG-RAN Nodes Handover



The inter NG-RAN node N2 based handover without Xn interface. This call flow is for the scenario without AMF change, without intermediate UPFs with indirect Data Transfer:

1. The source gNB configures the UE measurement procedures and the UE reports accordingly
2. The source gNB decides to handover the UE, based on MeasurementReport and RRM information
3. Source gNB to Source-AMF: Handover Required
4. For each PDU Session indicated by Source-NG RAN, the AMF invokes the Nsmf_PDUSession_UpdateSMContext Request ((PDU Session ID, Target ID, S-AMF ID, SM N2 Info) to the associated SMF
5. SMF to UPF: N4 Session Modification Request (AN Tunnel Info, CN Tunnel Info). If the CN Tunnel Info (on N3) of UPF need be re-allocated and CN Tunnel Info is allocated by the SMF, the SMF provides the CN Tunnel Info (on N3) to the UPF.
6. The UPF sends an N4 Session Modification Response message to the SMF with DL CN Tunnel Info and UL CN Tunnel Info (i.e. N3 tunnel info).
7. If N2 handover for the PDU Session is accepted, the SMF includes in the Nsmf_PDUSession_UpdateSMContext response the N2 SM Information containing the N3 UP address and the UL CN Tunnel ID of the UPF and the QoS parameters indicating that the N2 SM Information is for the Target NG-RAN. If the Direct Forwarding Path Availability indicates direct forwarding is not available and the SMF knows that there is no indirect data forwarding connectivity between source and target, the N2 SM Information also includes a Data forwarding not possible indication
8. S-AMF to Target gNB, Handover Request (AMF UE NGAP ID , Handover Type ,Cause, Source to Target transparent container, UE Aggregate Maximum Bit Rate , UE Security Capabilities , Security Context , PDU Session Resource Setup List (PDU Session ID , S-NSSAI , Handover Request Transfer (UL NG-U UP TNL Information, PDU Session Type, QoS Flow Setup Request List),Allowed NSSAI , GUAMI).
9. Target gNB to S-AMF: Handover Request Acknowledge
10. For each N2 SM response received from the T-RAN (N2 SM information included in Handover Request Acknowledge), AMF sends the received N2 SM response to the SMF indicated by the respective PDU Session ID
11. SMF to S-AMF: Nsmf_PDUSession_UpdateSMContext Response (N2 SM Information).

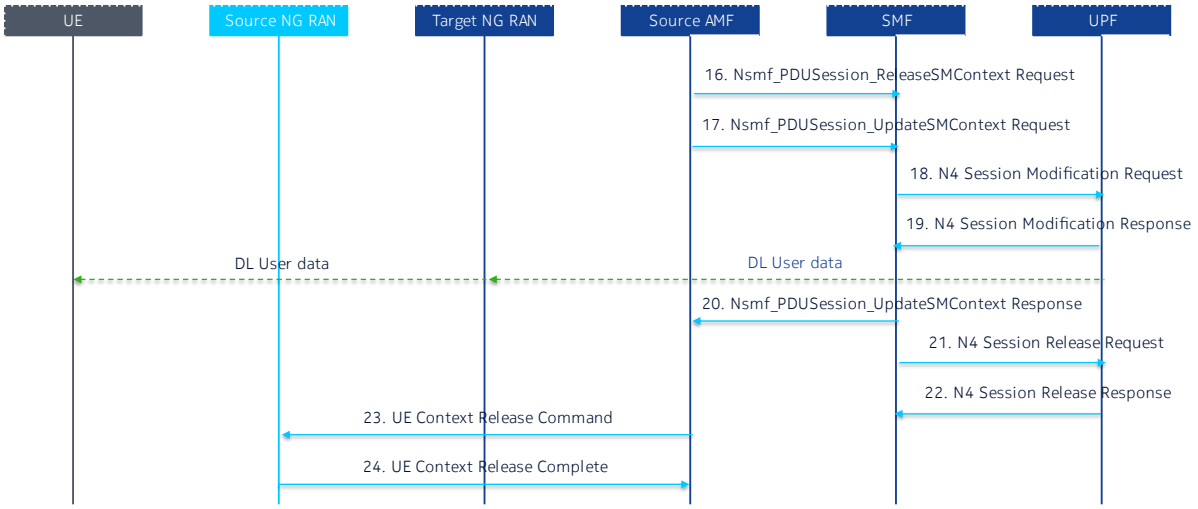
Mobility in Connected Mode
N2-based inter NG-RAN Nodes Handover



12. Source-AMF to Source gNB: Handover Command
13. The source gNB triggers the Uu handover and sends the RRCReconfiguration message containing Handover Command message to the UE. The Handover Command message carries the information required to access the target cell, which includes at least the target cell ID, the new C-RNTI, the target gNB security algorithm identifiers for the selected security algorithms, can include a set of dedicated RACH resources, the association between RACH resources and SS blocks, the association between RACH resources and UE-specific CSI-RS configuration(s), common RACH resources, and target cell SIBs, etc.
14. The UE synchronizes to the target cell and completes the RRC handover procedure by sending RRCReconfigurationComplete message to target gNB
15. Target-NGRAN to Source-AMF: Handover Notify. Handover is by this message considered as successful in Target gNB.

Note that uplink packets are sent from Target-NGRAN to UPF. Downlink packets are sent from UPF to Source-NGRAN. The Source-NGRAN should start forwarding of downlink data from the Source-NGRAN towards the Target-NGRAN for QoS Flows or DRBs subject to data forwarding. This may be either direct or indirect forwarding (Indirect forwarding is shown on the slide).

Mobility in Connected Mode
N2-based inter NG-RAN Nodes Handover



16. Source-AMF to SMF: Nsmf_PDUSession_ReleaseSMContext Request (SUPI, PDU Session ID).
17. T-AMF to SMF: Nsmf_PDUSession_UpdateSMContext Request (Handover Complete indication for PDU Session ID, UE presence in LADN service area). Handover Complete indication is sent per each PDU Session to the corresponding SMF to indicate the success of the N2 Handover.
18. SMF to UPF: N4 Session Modification Request (AN Tunnel Info, CN Tunnel Info). Depending on the network deployment, the CN Tunnel Info of UPF used for connection to Target NG-RAN and connection to Source NG-RAN may be different, e.g. due to Source and Target NG-RAN are in different IP domains. If the CN Tunnel Info (on N3) of UPF need be re-allocated and CN Tunnel Info is allocated by the SMF, the SMF provides the CN Tunnel Info (on N3) to the UPF.
19. The UPF acknowledges by sending N4 Session Modification Response message to SMF.
20. SMF to AMF: Nsmf_PDUSession_UpdateSMContext Response (PDU Session ID). SMF confirms reception of Handover Complete
21. SMF to UPF : N4 Session Release Request
22. UPF to SMF: N4 Session Release Response
23. Source AMF to Source gNB: UE Context Release Command to release UE context at Source gNB
24. The source NG-RAN releases its resources related to the UE and responds with a UE Context Release Complete message.

Mobility in Connected Mode
Quiz 3

1. Which NR mobility mode does not require explicit RRC signaling?
   a. Cell Level Mobility
   b. Beam Level Mobility
   c. Inter-RAT Handover
   d. Inter-System Handover
2. Which of the following is a correct statement?
   a. UE initiates intra-NR handover and issues a Handover Request over the Uu interface
   b. gNB initiates intra-NR handover and issues a Handover Request over the Xn interface
   c. gNB initiates intra-NR handover and issues a Handover Request over the NG-C interface
3. Which of the following can be considered as the message sent by the source gNB to the UE to trigger the Uu handover?
   a. Handover Request
   b. Handover Required
   c. RRC Reconfiguration
   d. Handover Notify

Wrap-up

In this module we have covered the following items:

- Explain UE Mobility Management in the AMF.
- Describe UE Mobility in RRC Idle and RRC Inactive states.
- Describe UE Mobility in Connected Mode.