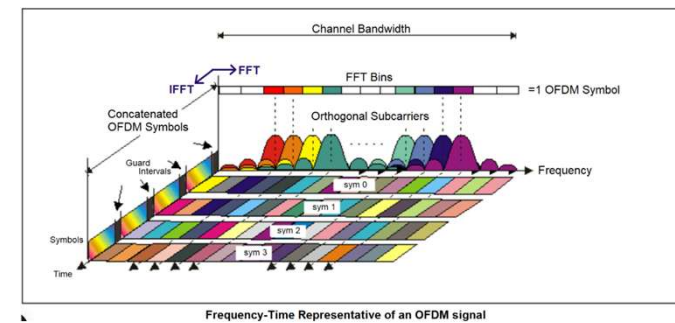
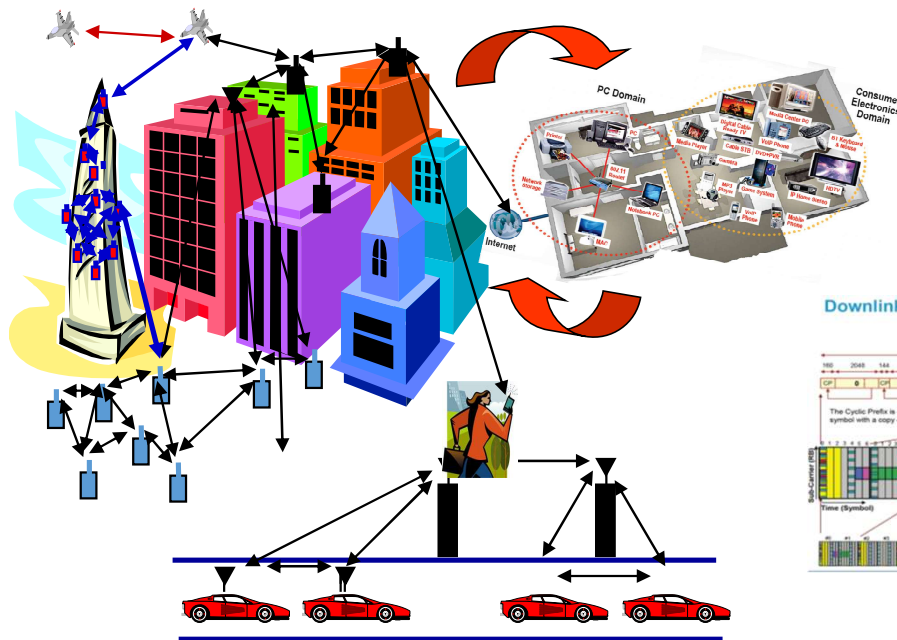
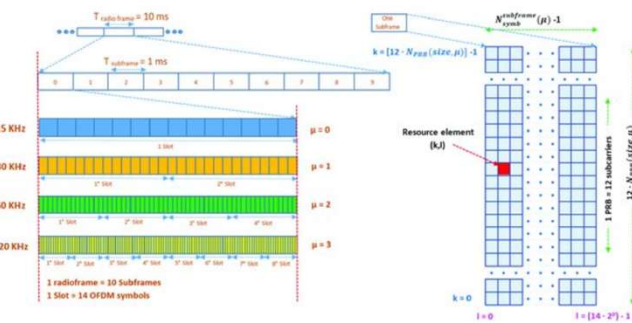
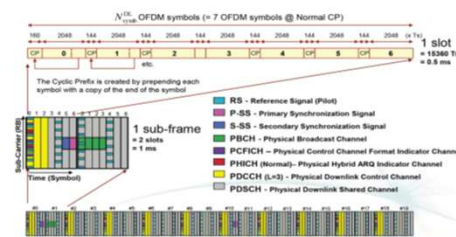


IEE2650: Cellular Communication Technologies

Muhammad Mahtab Alam, Professor



Downlink Frame Structure Type 1



Mobility in Cellular Networks

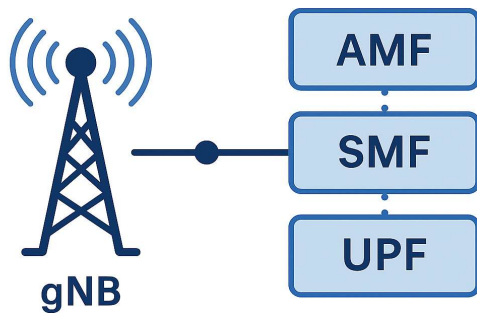
- Mobility management maintains connectivity while users move
- Ensures seamless service during cell transitions
- Critical for voice, video, and data services
- Key function of the radio access and core network

Evolution of Mobility Management

- 2G: Hard handover
- 3G: Soft handover support
- 4G LTE: Fast packet-based handover
- 5G: Beam-level and ultra-low latency mobility

5G System Architecture Diagram Explanation

5G SYSTEM ARCHITECTURE



Control and User Plane Separation

5G architecture separates control and user planes, enabling edge deployment and reduced latency for improved throughput.

Radio Access Network Structure

The gNB replaces LTE eNB with split central and distributed units to allow flexible deployment and performance optimization.

Core Network Functions

Functions like AMF, SMF, PCF, and NRF manage access, sessions, policies, and service discovery in 5G core.

Network Slicing and Multi-Connectivity

Network slicing allows multiple logical networks; multi-connectivity enhances reliability and throughput in 5G services.

Overview of 5G Mobility and Handover Concepts

5G Mobility Architecture

5G mobility integrates service-based core and dual connectivity for flexible and resilient handover mechanisms.

Challenges in High-Frequency Bands

Millimeter wave bands require fast, predictive handover due to shorter coverage and blockage susceptibility.

Advanced Handover Techniques

Conditional handover, multi-beam tracking, and AI models enhance handover efficiency and reduce failures.

Performance and KPIs

Handover success rate and latency metrics help optimize network performance and user experience.



What is Handover?

- Handover transfers an active session from one cell to another
- Triggered when signal quality degrades
- Maintains session continuity
- Happens without interrupting the user experience

Handover Types

- Intra-cell (beam or sector change)
- Inter-cell handover
- Inter-frequency handover
- Inter-RAT handover (5G ↔ LTE)

Portfolio of handover strategies (1/4)

Coverage-based handover

- Intra-frequency
- Inter-frequency
- Inter-RAT

Frequency priority-based handover

- Inter-frequency

Service-based handover

- Inter-frequency
- Inter-RAT

Load-based handover

- Intra-frequency
- Inter-frequency
- Inter-RAT

Distance-based handover

- Inter-frequency
- Inter-RAT

UL-quality-based handover

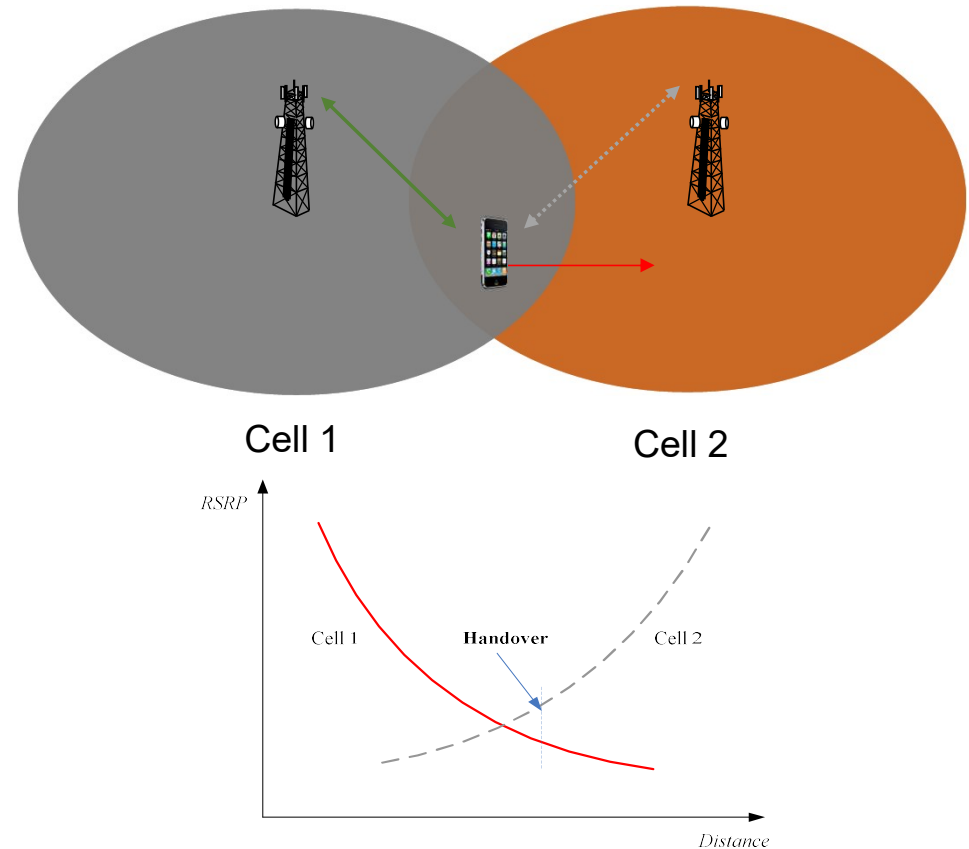
- Inter-frequency
- Inter-RAT

Portfolio of handover strategies (2/4)

▪ Coverage-based handover

- The RSRP of cell 1 becomes weaker and the RSRP of cell 2 becomes stronger when the UE moves from cell 1 to cell 2.
- In the event of a failure for the network to hand over the UE from cell 1 to cell 2:
 - User experience deteriorates due to growing interference.
 - A call drop occurs due to gradually bad signal quality of the serving cell.
- The handover function selects the cell with the best signal quality for the UE, helping improve user experience while the UE moves around in the network.

Coverage-based handover

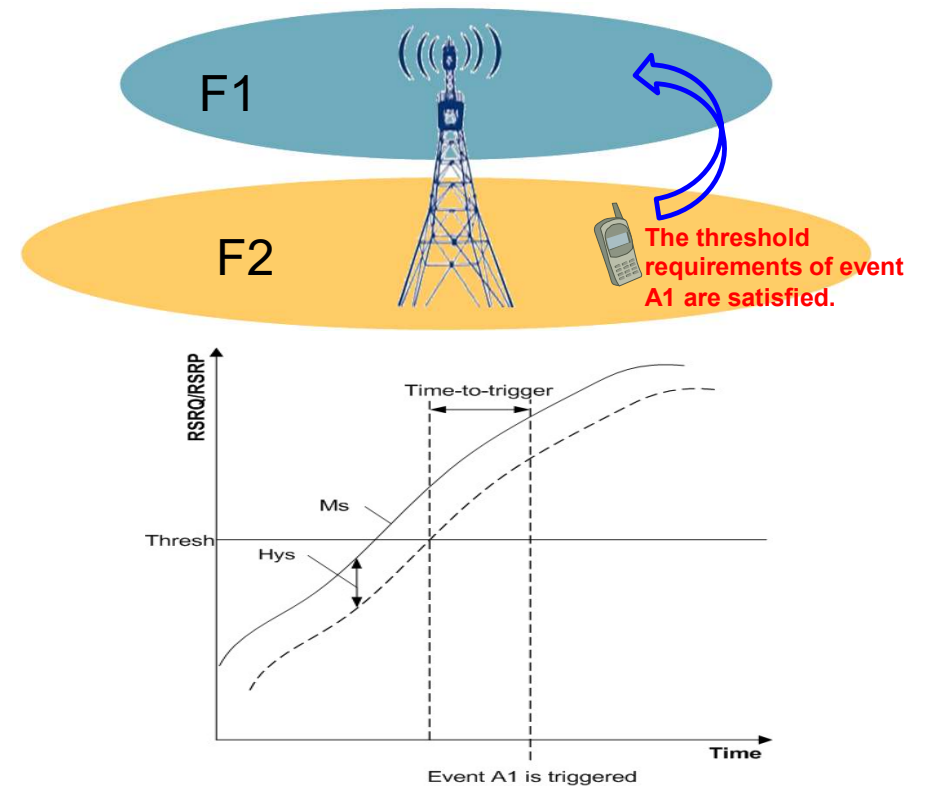


Portfolio of handover strategies (3/4)

- Frequency-priority-based inter-frequency handover

- In multi-frequency networking scenarios, operators prefer the high frequency band to carry services as much as possible to spare the low frequency band for continuous coverage.
 - When the high frequency band is prioritized, the frequency-priority-based handover is performed from the low frequency band to the high frequency band to implement service steering.
 - When the UE served by a low-priority frequency band meets the triggering threshold of event A1, the gNodeB instructs the UE to hand over to a high-priority frequency through an A4 measurement.

Frequency priority-based handover



Portfolio of handover strategies (4/4)

- Other handover strategies (Not Standardized)

- **Load-based handover:** Hand over UEs from a heavy-load cell to a light-load neighboring cell or frequency to balance the loads between cells.
- **Service-based handover:** Configure differentiated handover parameters specific to service QCI to direct the traffic streams of these QCIs to desired target frequencies, thereby fulfilling the service steering requirements.
- **Distance-based handover:** Hand over UEs to a neighboring frequency when their distance to the serving cell is above a certain threshold. This function applies when a severe overshoot coverage causes a coverage-based handover unable to be triggered even when the distance becomes very large, helping prevent call drops.
- **UL-quality-based handover:** Trigger handovers when uplink signals are weak to thereby prevent call drops caused by delayed handovers in the environment of bad uplink signals.

List of Measurement Events

Event	Definition	5G RAN (stand Alone)	5G RAN (Non-Stand Alone)
A1	The RSRP of the serving cell exceeds a specific threshold.	Stop measurements for coverage-based inter-frequency/inter-RAT handover. Start measurements for frequency-priority-based inter-frequency handover.	Supported only for inter-RAT measurements
A2	The RSRP of the serving cell drops below a specific threshold.	Start measurements for coverage-based inter-frequency/inter-RAT handover. Stop measurements for frequency-priority-based inter-frequency handover.	Supported only for inter-RAT measurements
A3	The RSRP of a neighboring cell is higher than that of the serving cell by a certain threshold.	Intra-frequency handover decision	Supported
A4	The RSRP of a neighboring cell exceeds a specific threshold.	Frequency-priority-based inter-frequency handover decision	Not supported
A5	The RSRP of the serving cell drops below threshold 1 and the RSRP of a neighboring cell exceeds threshold 2.	Coverage-based inter-frequency handover decision CA secondary carrier addition	Supported only for CA
A6	The RSRP of a neighboring cell is higher than that of the secondary serving cell by a certain threshold.	CA secondary carrier addition	Supported
B1	The RSRP of an inter-RAT neighboring cell exceeds a specific threshold.	Inter-RAT handover decision	Supported
B2	The RSRP of the serving cell drops below threshold 1 and the RSRP of an inter-RAT neighboring cell exceeds threshold 2.	Inter-RAT handover decision (recommended)	Supported

NR Measurement Events and Mobility Triggering

Measurement Events Overview

Measurement events trigger mobility by evaluating signal metrics like reference signal received power (RSRP), reference signal received quality (RSRQ), and SINR to optimize connectivity.

Key Events A3 and A5

Events A3 and A5 compare serving and neighboring cells to reduce ping-pong handovers and improve handover decisions.

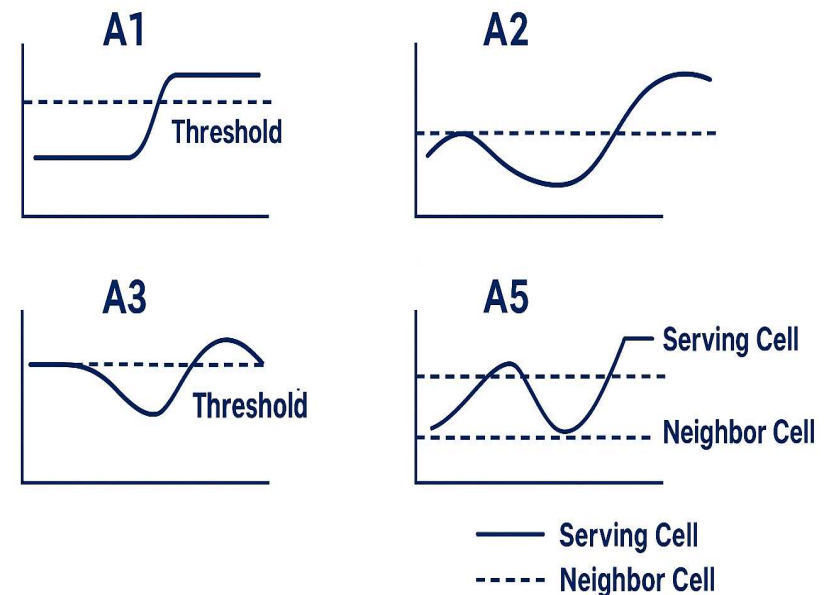
Configuration Parameters

Parameters like, time-to-trigger, and offsets control sensitivity and timing of mobility triggering in UEs.

Advanced Beam-level Reporting

Beam-level measurement supports handovers between beams within the same cell for high-frequency 5G mmWave networks.

NR MEASUREMENT EVENTS



NG-Based Handover Process and Signalling Flow

Handover Coordination by AMF

AMF centrally manages handover when Xn interface is unavailable, ensuring seamless UE transition between gNBs.

UE Measurement and Handover Trigger

UE reports signal quality degradation or improvement to source gNB, triggering handover decision and messages.

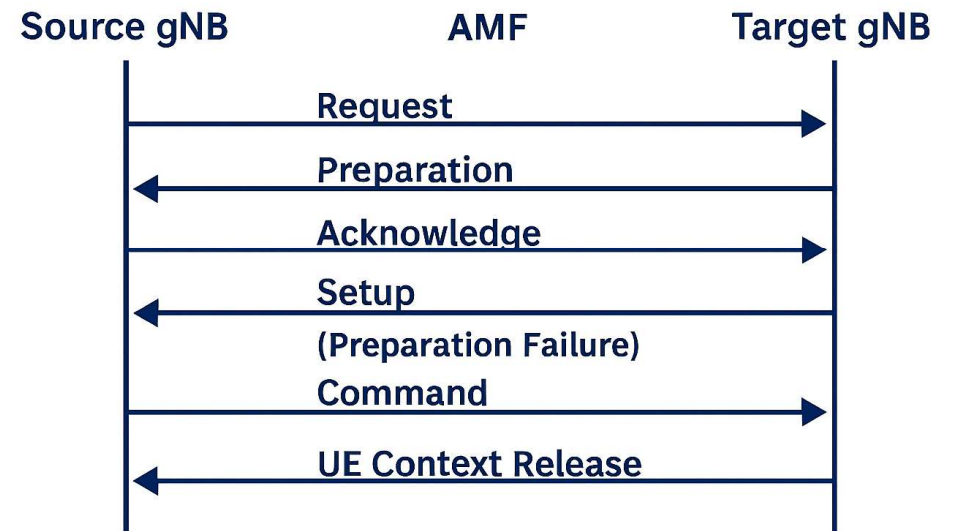
Signalling Flow and Resource Allocation

Source gNB requests handover via AMF; target gNB allocates resources and sends reconfiguration to UE.

Handover Completion and Core Network Update

After UE synchronizes with target gNB, path switch occurs updating user plane routing and maintaining sessions.

NG-BASED HANDOVER



Dual Connectivity in 5G Mobility

Simultaneous LTE and 5G Connections

EN-DC allows user equipment to connect simultaneously to LTE and 5G NR nodes, boosting data throughput and stability.

Improved Mobility and Reliability

Dual Connectivity reduces radio link failures by maintaining active connections during cell transitions, enhancing URLLC reliability.

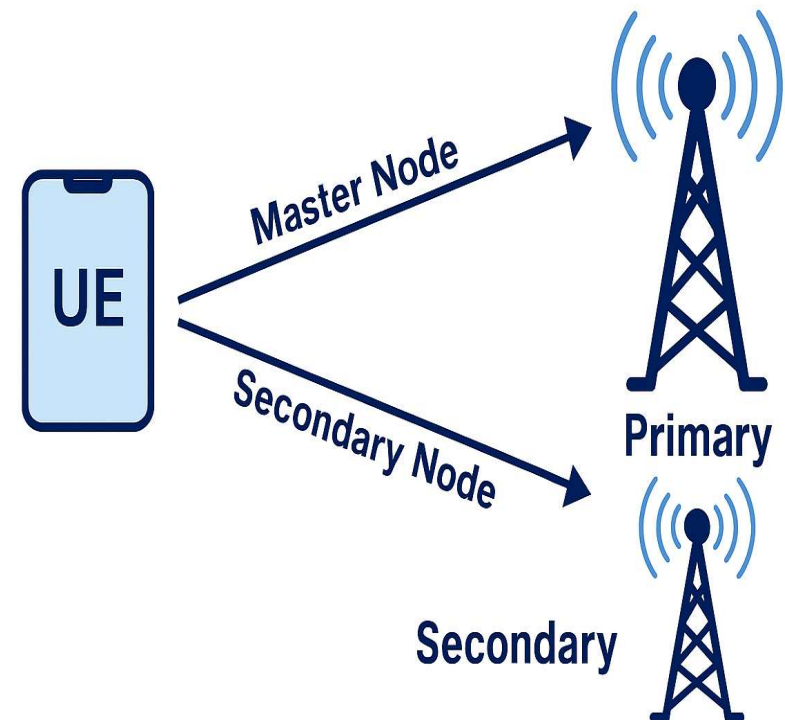
Dynamic Signalling Procedures

Secondary Node Addition, Modification, and Release signaling ensure adaptive connectivity based on radio conditions.

Load Balancing and Throughput Optimization

DC mechanisms steer traffic between LTE and NR to optimize load and maximize throughput in different conditions.

DUAL CONNECTIVITY / EN-DC



Path Switch Call Flow and Core Network Role

Path Switch Procedure Overview

Path switch ensures data traffic reroutes correctly through the target gNB and UPF after handover completion.

Session and Routing Updates

SMF updates session and routing rules to redirect user-plane traffic to the target gNB and UPF.

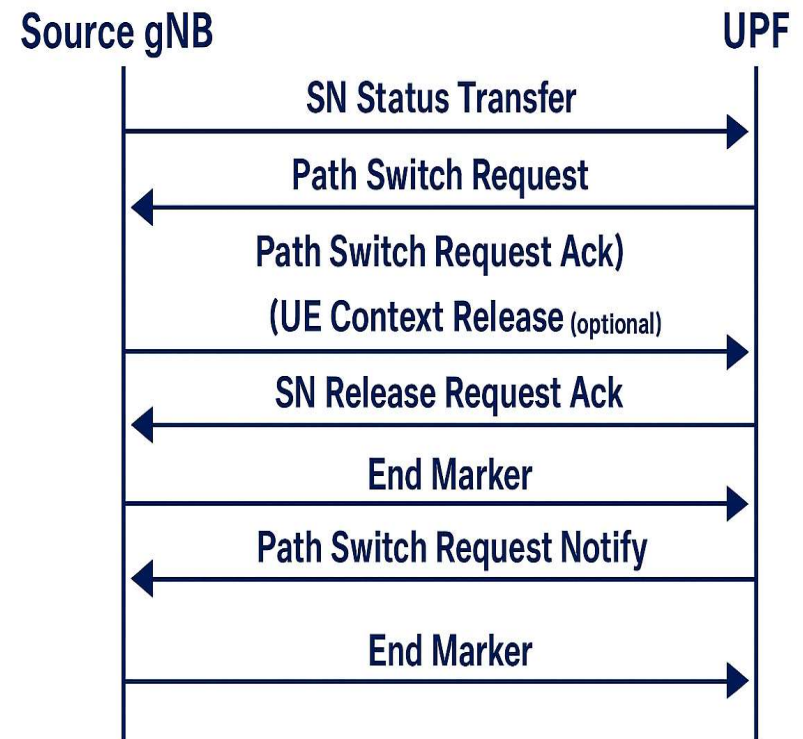
Core Network Role and Efficiency

Efficient path switch minimizes handover interruption time and enhances mobility performance in high-mobility scenarios.

Importance for Network Engineers

Understanding path switch is crucial for diagnosing handover issues like data stalls and latency spikes post-handover.

PATH SWITCH



RRC and NGAP Call Flow in 5G Handover

Handover Signaling Coordination

RRC and NGAP signaling coordinate measurements, decisions, and link transitions during 5G handover execution.

Measurement and Decision Process

UE sends measurement reports; serving gNB uses mobility algorithms to decide on handover necessity.

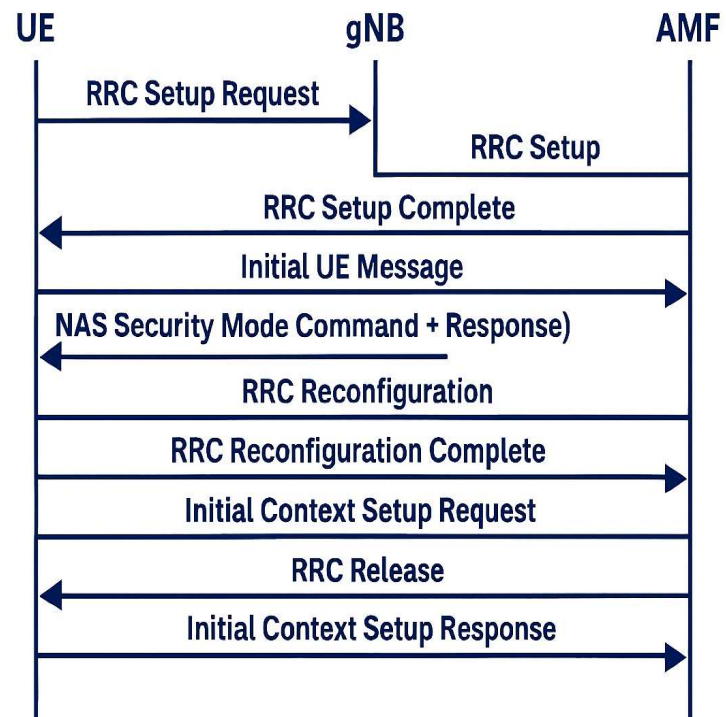
Context Transfer and Core Network Roles

NGAP messages handle context transfer and path switching coordinated by AMF and SMF for seamless handover.

Performance Monitoring and Diagnostics

Operators monitor KPIs like latency and success rate to optimize handover in dense urban settings.

FULL RRC/NGAP SIGNALLING SEQUENCE



Xn-Based Handover and Low-Latency Mobility

Direct gNB Communication

Xn-based handover enables direct communication between source and target gNBs, bypassing core network during preparation.

Reduced Signalling and Latency

This handover process reduces signalling overhead and minimizes latency, crucial for dense and high-frequency deployments.

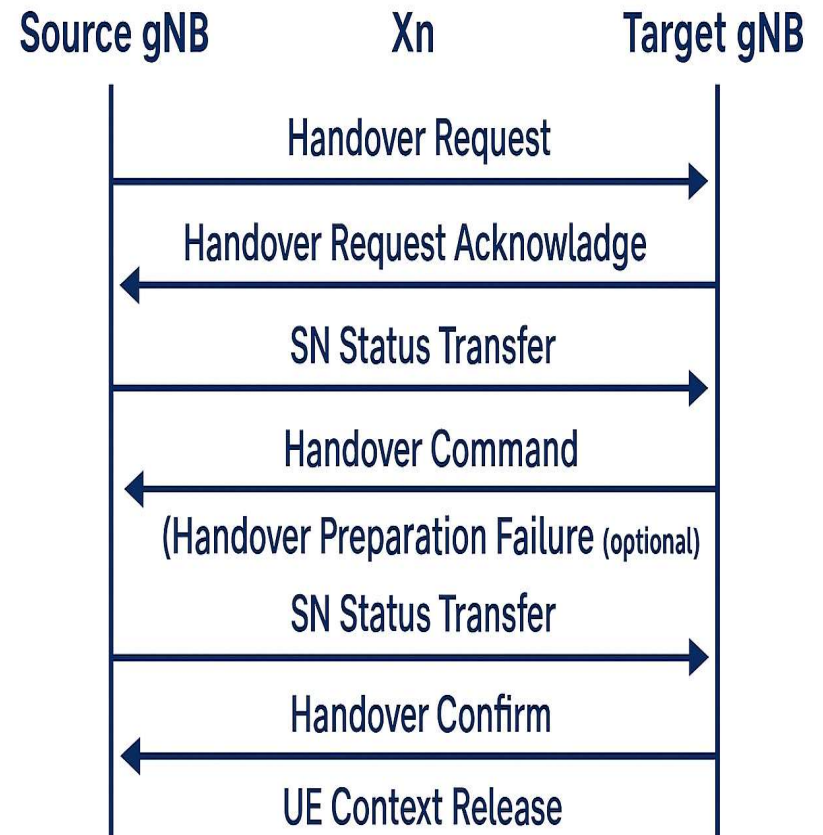
Seamless User Transition

UE performs smooth transition through handover command, random access, and RRC reconfiguration for connectivity.

Core Network Path Update

Target gNB updates user-plane routing via AMF and SMF interaction to ensure correct data forwarding.

Xn-BASED HANDOVER



Cell Selection Criterion

UEs in idle mode select unbarred cells that meet criteria S to camp on.

Criterion S $S_{rxlev} > 0,$
 $S_{rxlev} = Q_{rxlevmeas} - (Q_{rxlevmin} + Q_{rxlevminoffset}) - P_{compensation}$

The meaning of the variables is as follows:

Variable	Definition	Meaning
S_{rxlev}	Cell selection RX level value (dB)	RX level value for cell selection
$Q_{rxlevmeas}$	Measured cell RX level value (RSRP)	Measured RX level value of a cell (namely, SSB RSRP)
$Q_{rxlevmin}$	Minimum required RX level in the cell (dBm)	Minimum receive level of the cell broadcast in SIB1 (specified by NRDUCellSelConfig.MinimumRxLevel)
$Q_{rxlevminoffset}$	Offset to the signaled $Q_{rxlevmin}$	Minimum receive level offset of the cell broadcast in SIB1 (specified by NRCeIIRelation.NCellReselOffset)
$P_{compensation}$	$\max(P_{EMAX1} - P_{PowerClass}, 0)$	P_{EMAX1} : maximum TX power a UE is allowed to use (broadcast in SIB1) $P_{PowerClass}$: maximum power level the UE can output.

2. Solution Overview – SA Intra-RAT Intra-frequency Handover

1. Intra-frequency handover within a gNodeB (in-CU)

- **Key procedures**

1. CU: measurement configuration delivery

- The source DU sends measurement configurations to the CU over the F1 interface and the CU sends them to the UE through RRC connection messages.
- Intra-frequency handover is based on event A3.

2. UE: measurement result reporting

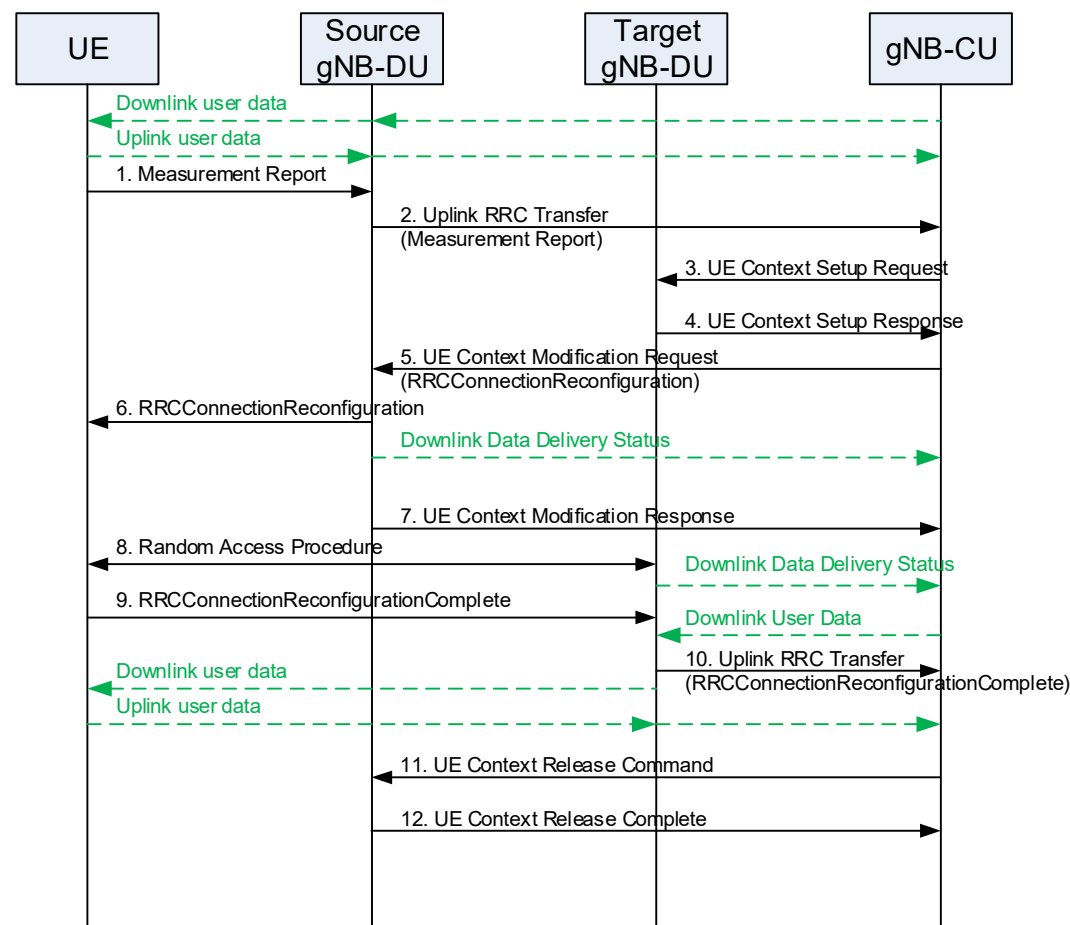
- If the criteria for reporting event A3 are satisfied, the UE reports the measurement results of the serving and neighboring cells.
- In 5G RAN3.0, only SSB RSRP measurements are supported.

3. Source DU: cell handover decision

- The source DU selects the neighboring cell with the best signal quality as the target cell for handover.

4. Handover execution

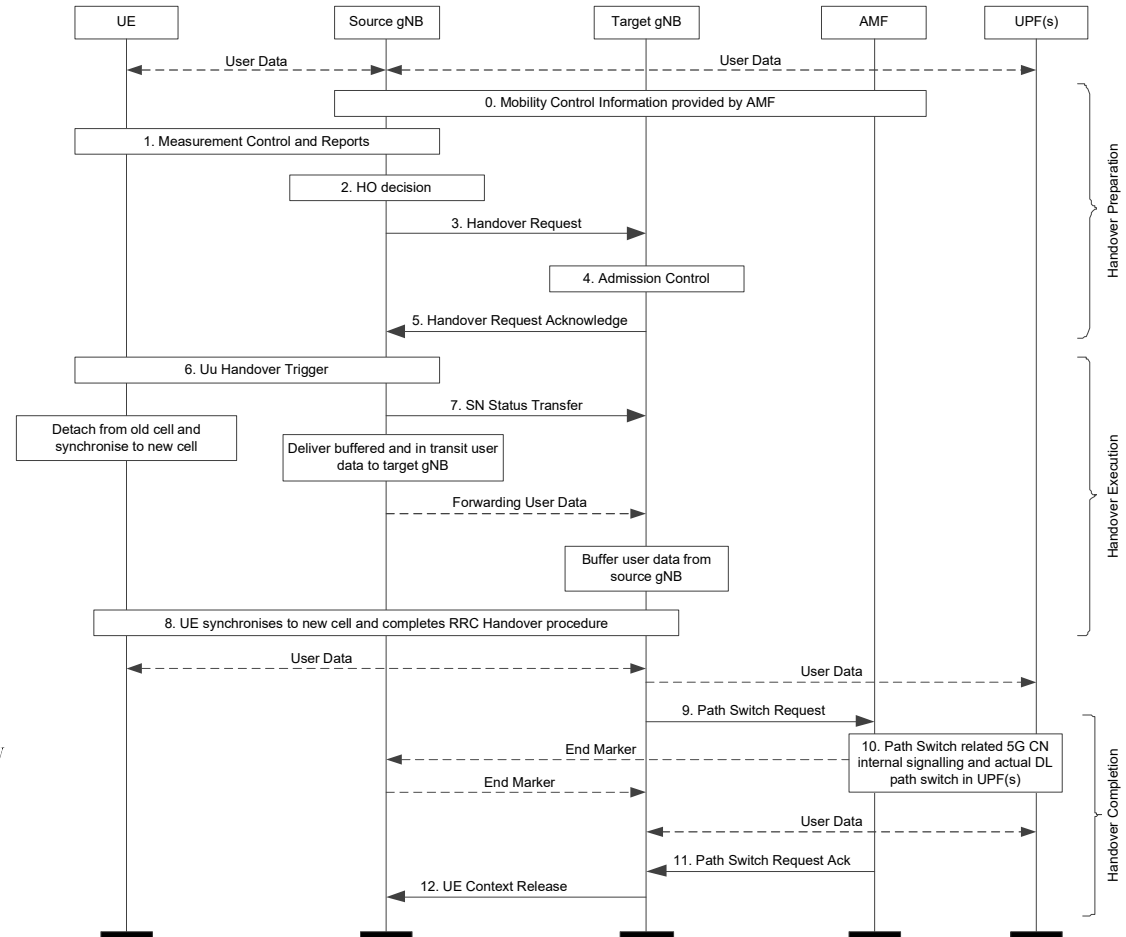
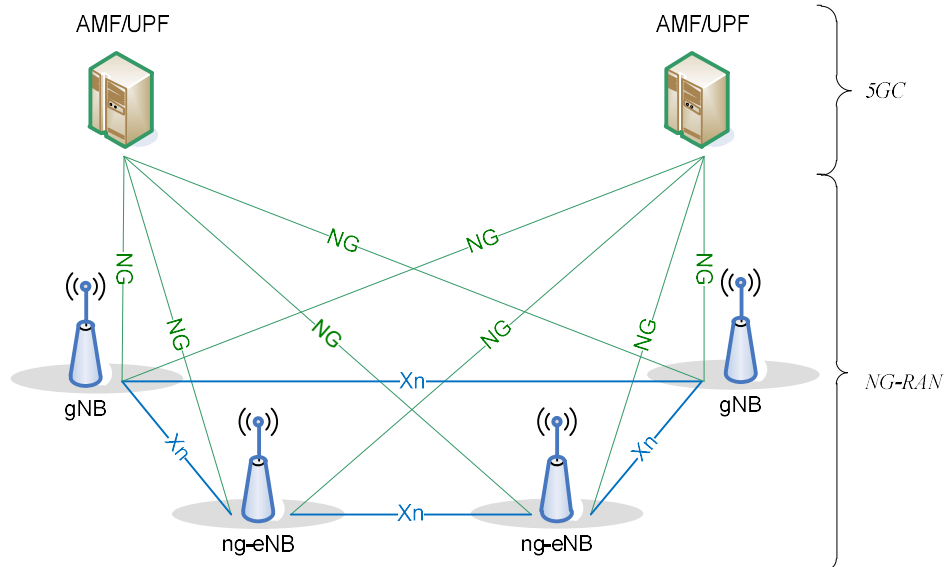
- The source DU sends the RRC connection reconfiguration to the UE.



2. Solution Overview – SA Intra-RAT Intra-frequency Handover

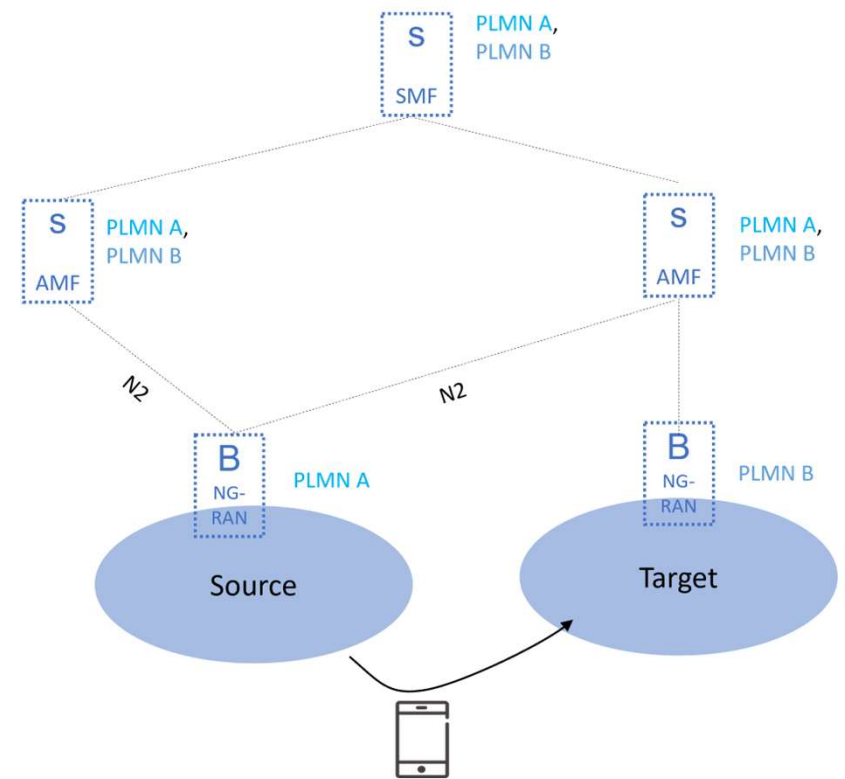
2. Intra-frequency handover between gNodeBs (Xn)

- The procedures are basically the same as for intra-frequency handover within a gNodeB. The difference lies in signaling.
- Inter-gNodeB handover can be based on the Xn and Ng interfaces. The signaling procedures involve the Xn or Ng interface. The entity involved includes gNodeB and AMF.
- Ng-eNB: eNodeB connects to the 5GC over the Ng interface.



Inter-PLMN solution

- The inter-PLMN solution is used to enable the testing of the inter-operator cross-border handover thanks to multi-PLMN network functionality.
- The multi-PLMN enables the core (e.g., AMF) to support up to 12 NR PLMNs
- An illustration of the multi-PLMN solution is shown in the figure, where two PLMNS (PLMN A, and PLMN B) are deployed
- As seen, the multi-PLMN is flexible in the sense that network functions such as AMF, SMF, and NRF can host multiple PLMNs.
- A UE served by PLMN A must perform a handover once it moves from its coverage area to the coverage area of PLMN B.



Inter-PLMN Handover Procedure

- The handover procedure is split into two parts:
 - Preparation: According to the UE measurement, the source gNB makes a HO decision and request HO from the target gNB.
 - Execution: The various messages (e.g., RRC, NSMF) are exchanged between UE, gNBs (source, and target), AMF and SMF. The aim is to start the UL/DL data forwarding to the target gNB and release the UE content from the source gNB.

