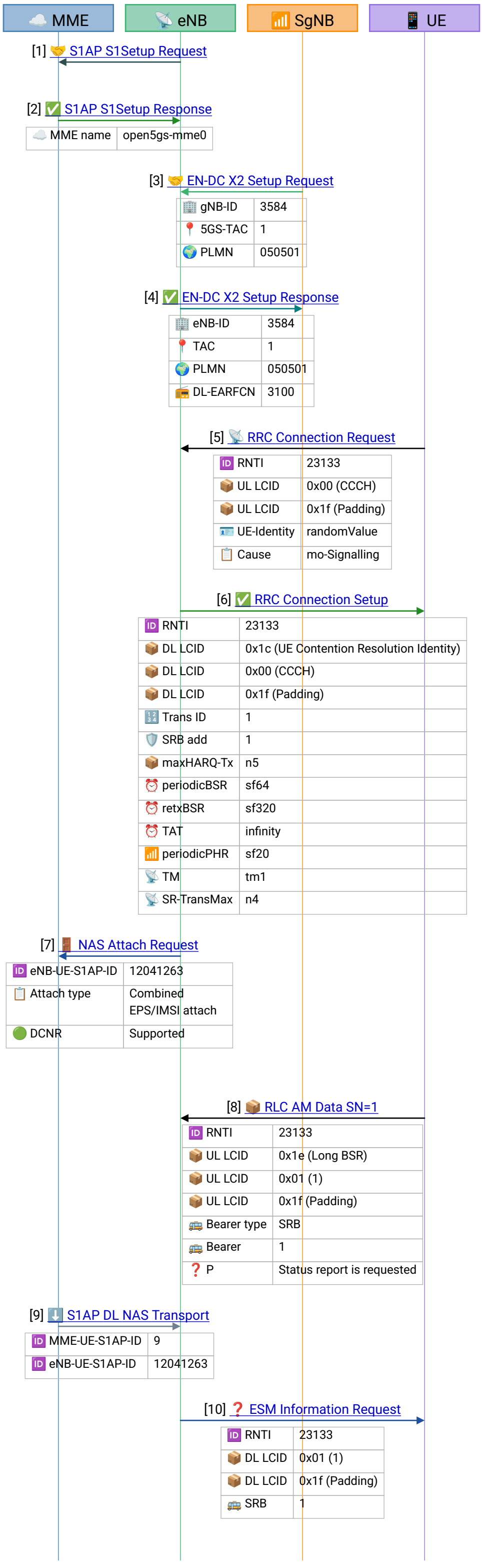
nsa-en-dc-attach.annotated



[Frame 1] Phase 1 — Interface bring-up (no UE yet). S1 Setup Request: the eNB introduces itself to the MME over SCTP, advertising its Global eNB ID, supported TAs and PLMN before any UE can be served (TS 36.413). Nothing UE-specific can happen until S1 is up.

[Frame 2] S1 Setup Response. The MME (`open5gs-mme0`) accepts the eNB onto S1 and returns its served GUMMEIs and relative capacity. The S1-MME control link is now operational.

[Frame 3] EN-DC X2 comes up. X2 Setup Request, but the EN-DC variant: the secondary gNB introduces itself to the master eNB, advertising Global gNB-ID 3584, the 5GS-TAC and PLMN 505/01, plus its served NR cells (TS 36.423). This is the NSA-specific X2 that must exist before any UE can be given a 5G leg.

[Frame 4] EN-DC X2 Setup Response. The eNB accepts the association and returns its served E-UTRA cell config, including DL-EARFCN 3100 (Band 7, ~2630 MHz). The eNB<->gNB X2 is now ready for per-UE SgNB Addition.

[Frame 5] Phase 2 — RRC connection setup (random access). RRC Connection Request on CCCH — this is Msg3 of contention-based random access (TS 36.331). The UE picks C-RNTI 23133, presents a `randomValue` UE-Identity, and gives establishment cause `mo-Signalling`. Everything after this rides on that C-RNTI.

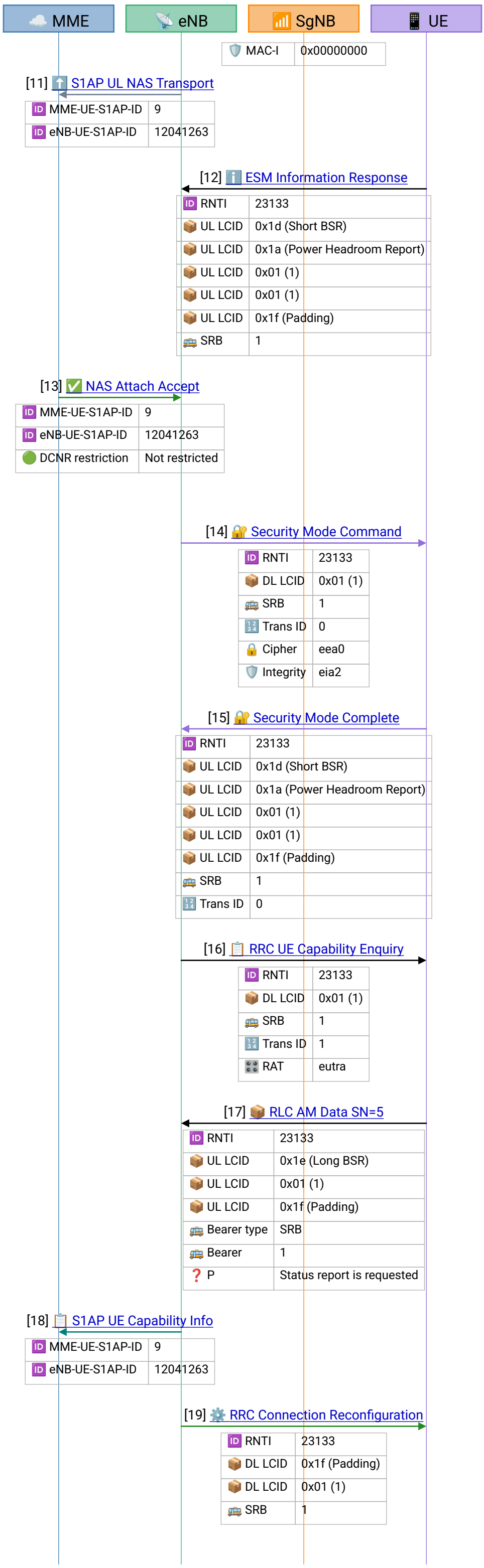
[Frame 6] RRC Connection Setup — Msg4. The DL MAC carries the UE `Contention Resolution Identity` control element (LCID 0x1c) that resolves the Msg3 contention, and the RRC payload sets up SRB1. On receiving it the UE enters RRC_CONNECTED.

[Frame 7] Phase 3 — Attach and default-bearer setup begins. First S1 message for this UE: S1AP `InitialUEMessage` (procedure 12) carrying a NAS Attach Request. The attach type is `Combined EPS/IMSI attach`, and a PDN Connectivity Request (ESM) is piggybacked to establish the default bearer. This message also carries the first EN-DC signal of the trace: the UE Network Capability sets the DCNR bit (`Dual connectivity with NR: Supported`), telling the core the UE can run EN-DC — the precondition for everything the flow later does to add a gNB. The eNB tags the UE with eNB-UE-S1AP-ID 12041263. Note this trace shows no NAS authentication or NAS security-mode exchange — a lab configuration; only the ESM information exchange sits between Request and Accept.

[Frame 8] Radio leg of the initial NAS. This is the uplink RLC AM Data PDU on SRB1 (the RRC Connection Setup Complete that carried the Attach Request over the air), acknowledged mode with the poll bit set so the eNB will return a Status PDU. The Long BSR (LCID 0x1e) tells the eNB how much more uplink the UE has buffered.

[Frame 9] S1AP `DownlinkNASTransport` (procedure 11): the MME tunnels a NAS ESM Information Request down to the eNB. The network is asking the UE to supply the APN and protocol configuration options for the PDN connection.

[Frame 10] Radio leg of that ESM Information Request — a downlink PDCP PDU on SRB1. Note the MAC-I is `0x00000000`: AS security is not active yet, so this PDU is neither ciphered nor integrity-protected. Compare with frame 16, the first PDU after security activation.



[Frame 11] S1AP `UplinkNASTransport` (procedure 13): the eNB tunnels the UE's NAS ESM Information Response up to the MME, carrying the APN and PCO the network asked for. Mirror of frame 9.

[Frame 12] The radio leg of the ESM Information Response — the UE returns the APN and protocol configuration options inside an RRC UL Information Transfer, the over-the-air twin of the S1AP UplinkNASTransport in frame 11. The frame also carries an RLC AM Status PDU (ARQ): the UE acknowledges the downlink up to ACK_SN=1 with no NACKs, and piggybacks a Short BSR and a Power Headroom Report as MAC control elements.

[Frame 13] The pivotal S1 message. S1AP `InitialContextSetupRequest` (procedure 9). The MME delivers, in one shot: the NAS Attach Accept + Activate Default EPS Bearer Context Request, the default bearer E-RAB 5 (QCI 9), the K_eNB security key the eNB will use to activate AS security, and the UE security capabilities. Crucially it includes the UE's `NRUESecurityCapabilities` (NEA1/2/3) — the network now knows this UE can do NR security, which is what makes the later EN-DC leg possible. The Attach Accept in the same message closes the loop the DCNR bit opened in frame 7: it marks dual connectivity with NR `Not restricted`, the core's explicit go-ahead for this UE to use a 5G secondary RAT.

[Frame 14] AS security activation. RRC Security Mode Command. The eNB turns on Access Stratum security keyed from K_eNB: ciphering `EEA0` (null, a lab choice) and integrity `EIA2` (TS 36.331, TS 33.401). From the UE's acknowledgement onward every SRB/DRB PDCP PDU is integrity-protected.

[Frame 15] RRC Security Mode Complete. The UE confirms AS security is active. This is the boundary: subsequent PDCP PDUs carry a real MAC-I and (with a non-null cipher) ciphered payload.

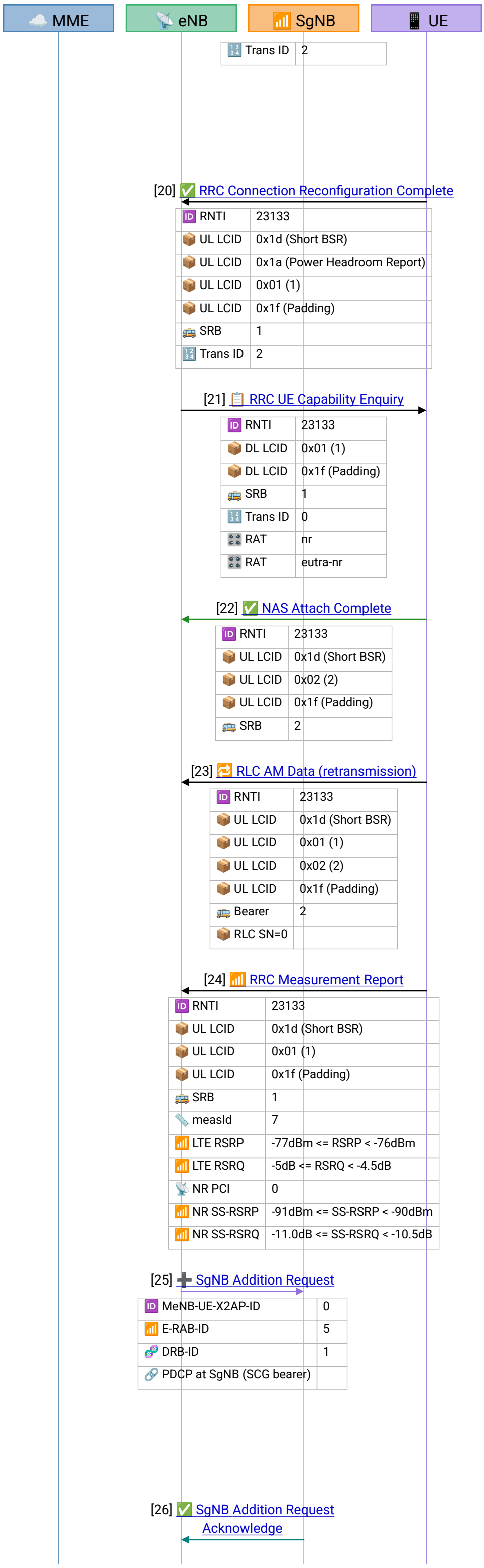
[Frame 16] First downlink PDCP PDU *after* security activation — the security context now shows `EEA0/EIA2` and the MAC-I is a real value `0x76596de5` (PDCP COUNT 2), not the `0x00000000` seen in frame 10. That contrast is AS security taking effect on the wire. This first secured PDU is the RRC UE Capability Enquiry (transaction 1), requesting `RAT-Type: eutra` — the LTE capabilities. The UE answers in frames 17-18, and those E-UTRA capabilities already carry its supported NR bands (`supportedBandListNR`). The EN-DC-specific enquiry for `eutra-nr` / `nr` follows separately in frame 21.

[Frame 17] A large uplink RLC AM segment: a 2331-byte SDU granted 2385 bytes in one TTI. This is the UE Capability Information travelling over the air — big because it enumerates every supported band, band combination and feature. The eNB forwards it on S1 in the next frame.

[Frame 18] S1AP `UECapabilityInfoIndication` (procedure 22). The eNB relays the UE's RAT capabilities — including its NR bands (n78) and EN-DC band combinations — up to the MME for storage. The eNB keeps its own copy to drive measurement configuration and SgNB Addition.

[Frame 19] The reconfiguration that arms the whole flow. RRC Connection Reconfiguration carrying three things at once: the piggybacked NAS Attach Accept; the radio bearers (SRB2 plus DRB1 for EPS bearer 5); and the full `measConfig`. That measConfig defines two measurement objects — E-UTRA at EARFCN 3100 and **NR n78 at NR-ARFCN 640000 (~3600 MHz)** — and seven measIds:

measId	Object	Report config	Purpose



1	E-UTRA 3100	periodic (RSRP+RSRQ)	serving-cell heartbeat
2	E-UTRA 3100	event A1	serving above threshold
3-6	E-UTRA 3100	events A2/A3/A4/A5	intra-LTE mobility (unused here)
7	**NR n78**	**event B1-NR**	detect an NR cell -> trigger EN-DC

measId 7 is the one to watch: its B1-NR threshold is set to the RSRP floor, so it fires as soon as the UE sees any NR cell.

[Frame 20] RRC Connection Reconfiguration Complete — the UE has applied the bearers, security and measurement config from frame 19; SRB2 and DRB1 are now usable. (This same uplink frame also bundles the first two measurement reports, measId 1 and measId 2 — both LTE-only; the diagram renders the completion.)

[Frame 21] A second RRC UE Capability Enquiry (transaction 0), and the EN-DC-relevant one: where frame 16 asked for `eutra`, this requests `RAT-Type: eutra-nr` and `nr` — the NR and MR-DC capabilities proper. Secured on SRB1 (`EEA0/EIA2`). Its response is not in this capture.

[Frame 22] First uplink traffic on SRB2 (bearer 2), now that frame 19 created it. It carries the NAS Attach Complete + Activate Default EPS Bearer Context Accept — the UE confirming both the attach and the default bearer. NAS moves to SRB2 once it exists.

[Frame 23] RLC retransmission / continuation of that SRB2 uplink (RLC SN=8 and SN=0 segments in one grant). RLC-AM stitching the Attach Complete delivery back together after a poll.

[Frame 24] The 5G trigger. This is the first measurement report carrying NR. Event B1-NR (measId 7) has fired: alongside the LTE PCell result the UE reports a detected NR neighbour — PCI 0, SS-RSRP in the -91 to -90 dBm bucket, SS-RSRQ around -11 dB — inside `measResultNeighCellListNR`. Crossing the B1 threshold is exactly what tells the eNB "this UE can see 5G", and it reacts immediately in the next frame. Only the measId-7 sub-reports ever carry 5G measurements; measId 1 and 2 are LTE-only.

[Frame 25] Phase 4 — SgNB Addition (adding the 5G leg). X2AP SgNB Addition Request (procedure id-sgNBAdditionPreparation). The master eNB, which owns the UE, asks the secondary gNB to allocate NR radio resources for E-RAB 5 / DRB 1. It hands over the S-KgNB security key (derived from K_eNB), the UE's NR security capabilities, and the `en-DC-ResourceConfiguration`. The UE-association is one-sided so far: the request carries only the `MeNB-UE-X2AP-ID` — the gNB mints its own ID in the Acknowledge. Watch the bearer shape: `resource-configuration` here is `sgNBPDCPpresent`, so PDCP is placed at the gNB — an SgNB-terminated (SCG) bearer, not the MCG-anchored split bearer (PDCP kept at the MeNB) shown in the companion X2AP walkthrough. Because the bearer now terminates at the gNB, the request also carries the S-GW's uplink S1-U endpoint (`s1-UL-GTPtunnelEndpoint, 0x00000010`), so the gNB can send this bearer's uplink straight to the core. The `MeNBtoSgNBContainer` carries the LTE-side RRC context as a `CG-ConfigInfo`.

[Frame 26] X2AP SgNB Addition Request Acknowledge — a `successfulOutcome` of the same procedure. Where the Request was the eNB's ask, this is the gNB's admit, and two things complete here:

MME | eNB | SgNB | UE

MeNB-UE-X2AP-ID	0
SgNB-UE-X2AP-ID	1779
E-RAB-ID (admitted)	5
PDCP at SgNB (SCG bearer)	
SCG DL TEID	0x649-bacbf

- **The UE-association becomes a pair.** The gNB mints its own `SgNB-UE-X2AP-ID` (1779) to sit beside the `MeNB-UE-X2AP-ID` — the two IDs both nodes now use for every later X2AP message about this UE.
- **The user-plane endpoint is set.** The gNB returns its downlink GTP-TEID for the SCG leg, `0x649bacbf` — where the serving gateway's downlink data for E-RAB 5 must now be sent. Frame 31's E-RAB Modification hands exactly this TEID to the MME.

The `SgNBtoMeNBContainer` carries the NR `RRCReconfiguration` as an RRC `CG-Config` — the reply container, distinct from the `CG-ConfigInfo` the eNB sent outbound in frame 25. The eNB forwards it to the UE in frame 27; the EN-DC secondary cell group is now prepared.

[27] RRC Connection Reconfiguration

RNTI	23133
DL LCID	0x01 (1)
DL LCID	0x1f (Padding)
SRB	1
Trans ID	1

[Frame 27] RRC Connection Reconfiguration, this time carrying the SCG. The eNB forwards the gNB's NR config to the UE: `nr-SecondaryCellGroupConfig` (band n78, p-NR-FR1 20 dBm, SSB and CSI reporting) plus `nr-RadioBearerConfig1`. It also releases LTE DRB 1 (`drb-ToReleaseList`) — the bearer the attach had set up for EPS bearer 5 in frame 19 — and re-adds that bearer on the SCG, so the default bearer's radio leg and its PDCP migrate from the eNB to the gNB. This is the message that actually tells the UE to add the 5G secondary cell.

[28] SgNB Reconfiguration Complete

UE-X2AP-ID	0

[Frame 28] X2AP SgNB Reconfiguration Complete. The eNB tells the gNB the UE is applying the SCG configuration, so the gNB can consider the secondary cell group active (TS 36.423).

[29] RRC Connection Reconfiguration Complete

RNTI	23133
UL LCID	0x1d (Short BSR)
UL LCID	0x18 (Dual Connectivity Power Headroom Report)
UL LCID	0x01 (1)
UL LCID	0x01 (1)
UL LCID	0x1f (Padding)
DC-PHR type	Based on real transmission
DC-PHR level	PH >= 40
SRB	1
Trans ID	1

[Frame 29] RRC Connection Reconfiguration Complete — and this uplink message embeds the NR `RRCReconfigurationComplete` (the SCG-complete) inside the LTE completion. Note the MAC now carries a `Dual Connectivity Power Headroom Report` (LCID 0x18): concrete on-air evidence that the UE is now operating two cell groups. EN-DC is established.

[30.1] RRC Measurement Report

RNTI	23133
UL LCID	0x1d (Short BSR)
UL LCID	0x01 (1)
UL LCID	0x1f (Padding)
SRB	1
measId	1
LTE RSRP	-77dBm <= RSRP < -76dBm
LTE RSRQ	-5dB <= RSRQ < -4.5dB

[Frame 30.1] Periodic measurement reports resume: measId 1 (the RSRP+RSRQ heartbeat on the LTE serving cell). RSRP sits in the -77 to -76 dBm bucket. This sub carries no NR — it is an E-UTRA-only object.

[30.2] RRC Measurement Report

SRB	1
measId	2
LTE RSRP	-77dBm <= RSRP < -76dBm
LTE RSRQ	-5dB <= RSRQ < -4.5dB

[Frame 30.2] measId 2 — the event-A1 report (serving cell above its RSRP threshold). Also E-UTRA-only; no 5G measurement here.

[31] NAS Attach Complete

eNB-UE-S1AP-ID	12041263

[Frame 31] Phase 5 — user-plane rehoming. This S1AP frame bundles three PDUs: `InitialContextSetupResponse`, the uplink NAS Attach Complete, and — the NSA-specific one — an `E-RABModificationIndication` (procedure 50). That last PDU tells the MME the downlink S1-U endpoint for E-RAB 5 has moved: user data should now go to the gNB's GTP-TEID from frame 26, not the eNB. Only the downlink needs this step — the uplink endpoint reached the gNB in the SgNB Addition Request (frame 25) — so both directions of E-RAB 5 now bypass the eNB.

[32] S1AP E-RAB Modification Confirm

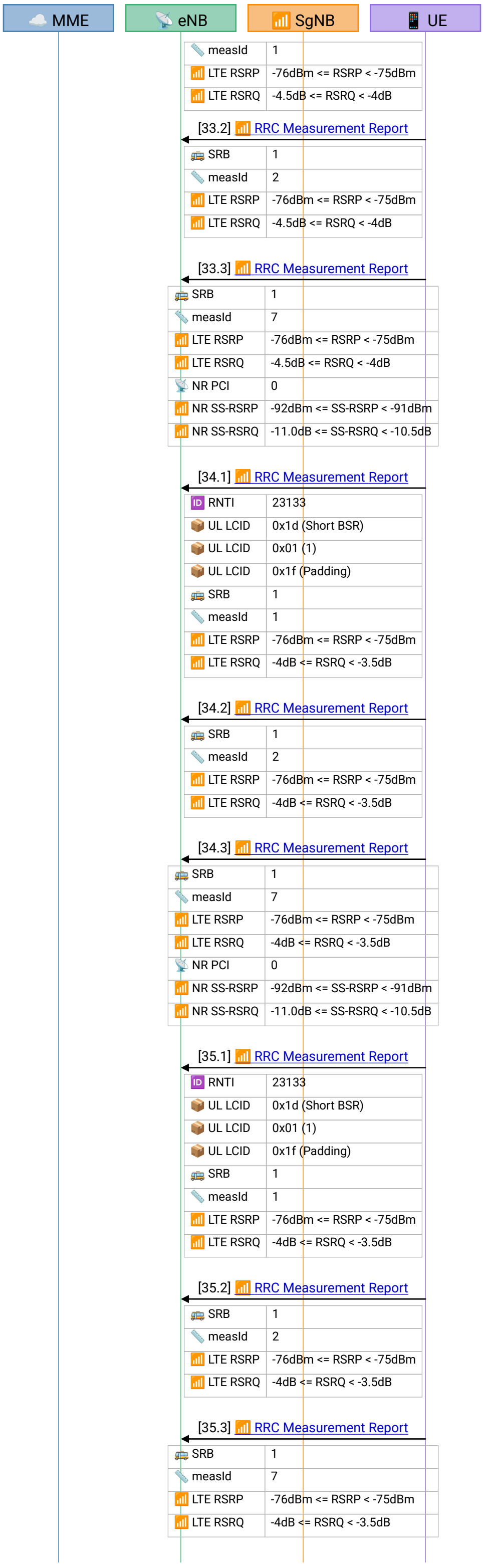
MME-UE-S1AP-ID	9
eNB-UE-S1AP-ID	12041263

[Frame 32] S1AP `E-RABModificationConfirm`. The MME confirms the rehoming, so the S-GW starts sending this bearer's downlink user data to the gNB. With the control plane (attach) and the user plane (E-RAB moved to NR) both in place, the EN-DC data path is fully live.

[33.1] RRC Measurement Report

RNTI	23133
UL LCID	0x1d (Short BSR)
UL LCID	0x01 (1)
UL LCID	0x1f (Padding)
SRB	1

[Frame 33.1] Phase 6 — steady-state measurement reporting. From here the UE emits a periodic bundle roughly every 120 ms, each frame carrying three sub-reports: measId 1, measId 2 and measId 7. This is sub 1 (measId 1) — the LTE serving-cell heartbeat, RSRP now improving into the -76 to -75 dBm bucket.



[Frame 33.2] measId 2 (event A1) — LTE serving above threshold. E-UTRA-only.

[Frame 33.3] measId 7 (event B1-NR) — **the only sub that carries 5G.** The NR neighbour (PCI 0) is reported at SS-RSRP around -92 to -91 dBm. These recurring measId-7 reports are how the eNB keeps confirming the NR leg is still viable while EN-DC is up.

[Frame 34.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat (RSRP -76 to -75 dBm). E-UTRA-only.

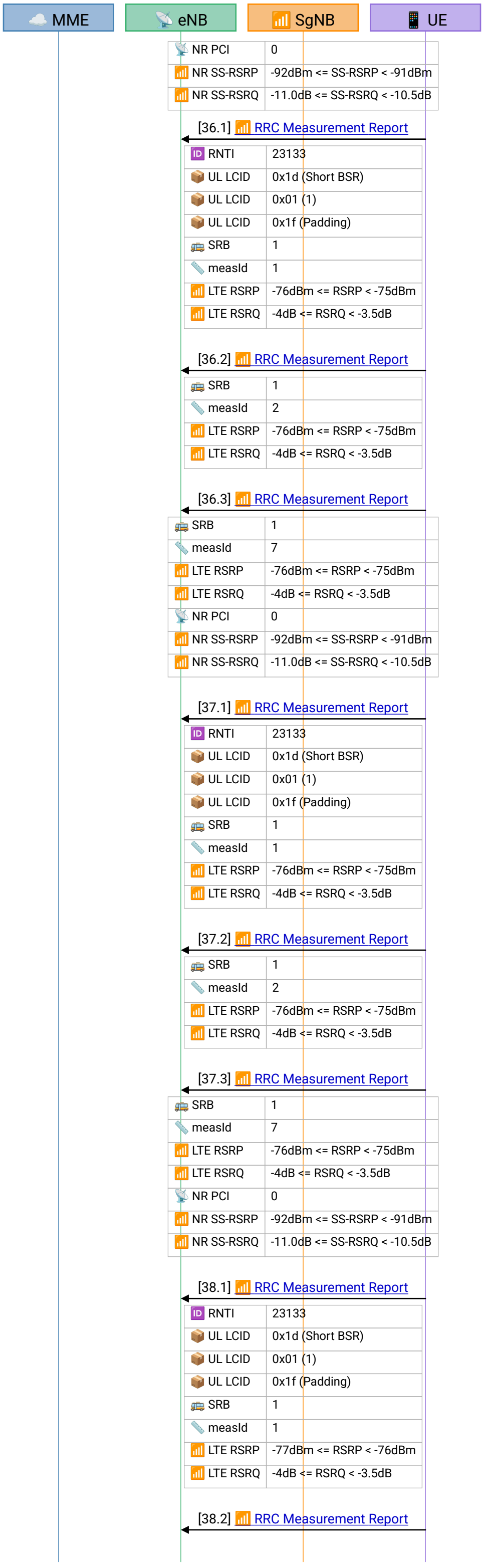
[Frame 34.2] measId 2 (event A1), LTE serving. No NR.

[Frame 34.3] measId 7 (event B1-NR) — carries the 5G neighbour (PCI 0, SS-RSRP near -92 dBm).

[Frame 35.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat. E-UTRA-only.

[Frame 35.2] measId 2 (event A1), LTE serving. No NR.

[Frame 35.3] measId 7 (event B1-NR) — the 5G-carrying sub-report (NR PCI 0).



[Frame 36.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat. E-UTRA-only.

[Frame 36.2] measId 2 (event A1), LTE serving. No NR.

[Frame 36.3] measId 7 (event B1-NR) — the 5G-carrying sub-report (NR PCI 0).

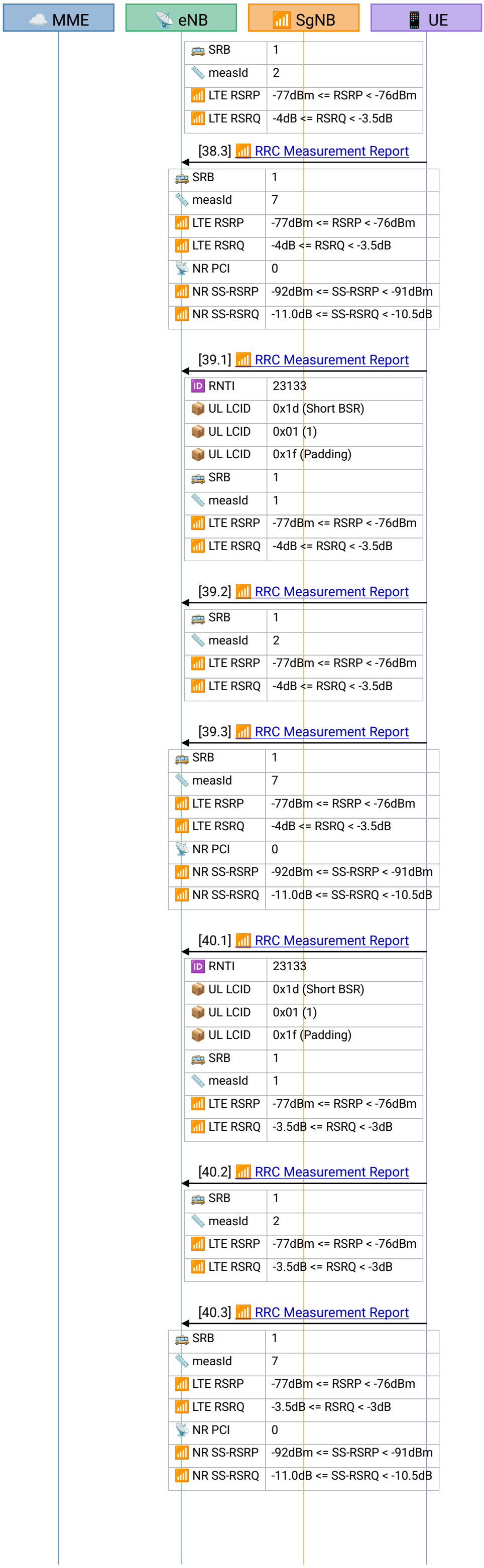
[Frame 37.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat. E-UTRA-only.

[Frame 37.2] measId 2 (event A1), LTE serving. No NR.

[Frame 37.3] measId 7 (event B1-NR) — the 5G-carrying sub-report (NR PCI 0).

[Frame 38.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat. RSRP easing back toward the -77 to -76 dBm bucket. E-UTRA-only.

[Frame 38.2] measId 2 (event A1), LTE serving. No NR.



[Frame 38.3] measId 7 (event B1-NR) — the 5G-carrying sub-report (NR PCI 0).

[Frame 39.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat. E-UTRA-only.

[Frame 39.2] measId 2 (event A1), LTE serving. No NR.

[Frame 39.3] measId 7 (event B1-NR) — the 5G-carrying sub-report (NR PCI 0).

[Frame 40.1] Periodic bundle, sub 1 — measId 1 LTE serving heartbeat; the capture ends here with EN-DC established and both legs being monitored. E-UTRA-only.

[Frame 40.2] measId 2 (event A1), LTE serving. No NR.

[Frame 40.3] measId 7 (event B1-NR) — the final 5G-carrying sub-report of the trace (NR PCI 0), confirming the 5G neighbour is still present as the capture closes.