3GPP TR 38.874 V16.0.0 (2018-12)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
NR;
Study on Integrated Access and Backhaul;
(Release 16)

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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where:

x the first digit:

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The present document is related to the study item "Integrated Access and Backhaul" [1].

The document describes the architectures, the radio protocols, and the physical layer aspects related to relaying of access traffic by sharing radio resources between access and backhaul links.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document in the same Release as the present document.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP RP-172290, "Study on Integrated Access and Backhaul for NR"

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

[4] 3GPP TS 38.474, "NG-RAN; F1 data transport"

[5] 3GPP TS 38.470, "NG-RAN; F1 general aspects and principles"

[6] 3GPP TS 23.502, "Procedures for the 5G System; Stage 2"

[7] 3GPP TS 38.401, "NG-RAN; Architecture description"

[8] 3GPP TS 38.425, "NG-RAN; NR user plane protocol"

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

IAB-node RAN node that supports wireless access to UEs and wirelessly backhauls the access traffic.
IAB-donor RAN node which provides UE's interface to core network and wireless backhauling functionality to IAB-nodes.

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

IAB Integrated Access and Backhaul
BH Backhaul

4 Introduction

At the 3GPP TSG RAN #75 meeting, the Study Item description on "Study on Integrated Access and Backhaul for NR" was approved [2]. The objective of the study was to identify and evaluate potential solutions for efficient operation of integrated access and wireless backhaul for NR. Frequency ranges up to 100 GHz will be considered. Detailed objectives of the study item were:

- Topology management for single-hop/multi-hop and redundant connectivity [RAN2, RAN3], e.g.:
  - Protocol stack and network architecture design (including interfaces between rTRPs) considering operation of multiple relay hops between the anchor node (e.g. connection to core) and UE;
  - Control and User plane procedures, including handling of QoS, for supporting forwarding of traffic across via one or multiple wireless backhaul links.
- Route selection and optimization [RAN2, RAN1, RAN3], e.g.:
  - Mechanisms for discovery and management of backhaul links for TRPs with integrated backhaul and access functionalities;
  - RAN-based mechanisms to support dynamic route selection (potentially without core network involvement) to accommodate short-term blocking and transmission of latency-sensitive traffic across backhaul links;
  - Evaluate the benefit of resource allocation/route management coordination across multiple nodes, for end-to-end route selection and optimization.
- Dynamic resource allocation between the backhaul and access links [RAN1, RAN2], e.g.:
  - Mechanisms to efficiently multiplex access and backhaul links (for both DL and UL directions) in time, frequency, or space under a per-link half-duplex constraint across one or multiple backhaul link hops for both TDD and FDD operation;
  - Cross-link interference (CLI) measurement, coordination and mitigation between rTRPs and UEs.
- High spectral efficiency while also supporting reliable transmission [RAN1]:
  - Identification of physical layer solutions or enhancements to support wireless backhaul links with high spectral efficiency.

NOTE: support of these functionalities should consider existing mechanisms for access links as a starting point.

NOTE: rTRP may refer to IAB-node and anchor node may refer to Donor-node in the other sections.

The results and findings of the study are documented in this technical report.

5 Requirements

5.1 Use cases and deployment scenarios

5.1.1 Relay deployment scenarios

A key benefit of IAB is enabling flexible and very dense deployment of NR cells without densifying the transport network proportionately. A diverse range of deployment scenarios can be envisioned including support for outdoor small cell deployments, indoors, or even mobile relays (e.g. on buses or trains).

Requirement: The Rel. 15 study item shall focus on IAB with physically fixed relays. This requirement does not preclude optimization for mobile relays in future releases.

5.1.2 In-band vs. out-of-band backhaul

In-band- and out-of-band backhauling with respect to the access link represent important use cases for IAB. In-band backhauling includes scenarios where access- and backhaul link at least partially overlap in frequency creating half-duplexing or interference constraints, which imply that the IAB-node cannot transmit and receive simultaneously on both links. In the present context, out-of-band scenarios are understood as not posing such constraints.

It is critical to study in-band backhauling solutions that accommodate tighter interworking between access and backhaul in compliance with half-duplexing and interference constraints.

Requirement: The architectures considered in the study should support in-band and out-of-band scenarios:

- In-band IAB scenarios including (TDM/FDM/SDM) of access- and backhaul links subject to half-duplex constraint at the IAB-node should be supported (this requirement does not exclude full duplex solutions to be studied);
- Out-of-band IAB scenarios should also be supported using the same set of RAN features designed for in-band scenarios. The study should identify if additional RAN features are needed for out-of-band scenarios.

5.1.3 Access/backhaul RAT options

IAB can support access and backhaul in above-6GHz- and sub-6GHz spectrum. The focus of the study is on backhauling of NR-access traffic over NR backhaul links. Solutions for NR-backhauling of LTE-access may be included into the study.

It is further considered critical that Rel. 15 NR UEs can transparently connect to an IAB-node via NR, and that legacy LTE UEs can transparently connect to an IAB-node via LTE in case IAB supports backhauling of LTE access.

Requirement: NR access over NR backhaul should be studied with highest priority:

- Additional architecture solutions required for LTE-access over NR-backhaul should be explored;
- The IAB design shall at least support the following UEs to connect to an IAB-node:
  - Rel. 15 NR UE;
  - Legacy LTE UE if IAB supports backhauling of LTE access.

5.1.4 Standalone and non-standalone deployments

IAB can support stand-alone (SA) and non-stand-alone (NSA) deployments. For NSA, relaying of the UE's SCG path (NR) is included in the study. Relaying of the UE's MCG path (LTE) is contingent on the support for IAB-based relaying of LTE-access (see 5.1.3.).

The IAB-node itself can operate in SA or NSA mode. While SA and NSA scenarios are included in the study, backhauling over the LTE radio interface is excluded from the study. Since EN-DC and SA option 2 represent relevant deployment options for early rollout of NR, EN-DC and SA option 2 for UEs and IAB-nodes have high priority in this study. Other NSA deployment options or combinations of SA and NSA may also be explored and included in the study.

Requirements:

1: SA and NSA shall be supported for the access link. For an NSA access link, relaying is applied to the NR path. Relaying of the LTE path is contingent on the support of backhauling of LTE traffic (see 5.1.3).

2: Both NSA and SA shall be studied for the backhaul link. Backhaul traffic over the LTE radio interface is excluded from the study.

3: For NSA access- and backhaul links, the study shall consider EN-DC with priority. However, other NSA options shall not be precluded from the study.

Further, for IAB-nodes, the following options are studied:

- Case 1 - Connection in Networks without NGC: The IAB-nodes connects as a UE to EPC using EN-DC;

- Case 2 - Connection in Networks with NGC: The IAB-node connects as a UE to NGC using NR:
    - This can also be used when access UEs support option 3/3X.

5.2 Architecture Requirements

5.2.1 Multi-hop backhauling

Multi-hop backhauling provides more range extension than single hop. This is especially beneficial for above-6GHz frequencies due to their limited range. Multi-hop backhauling further enables backhauling around obstacles, e.g. buildings in urban environment for in-clutter deployments.

The maximum number of hops in a deployment is expected to depend on many factors such as frequency, cell density, propagation environment, and traffic load. These factors are further expected to change over time. From the architecture perspective, flexibility in hop count is therefore desirable.

With increasing number of hops, scalability issues may arise and limit performance or increase signaling load to unacceptable levels. Capturing scalability to hop count as a KPI is therefore an important aspect of the study.

Requirements: IAB design shall support multiple backhaul hops:

- The architecture should not impose limits on the number of backhaul hops;
- The study should consider scalability to hop-count an important KPI;
- Single hop should be considered a special case of multiple backhaul hops.

5.2.2 Topology adaptation

Wireless backhaul links are vulnerable to blockage, e.g., due to moving objects such as vehicles, due to seasonal changes (foliage), or due to infrastructure changes (new buildings). Such vulnerability also applies to physically stationary IAB-nodes. Also, traffic variations can create uneven load distribution on wireless backhaul links leading to local link or node congestion.

Topology adaptation refers to procedures that autonomously reconfigure the backhaul network under circumstances such as blockage or local congestion without discontinuing services for UEs.

Requirement: Topology adaptation for physically fixed relays shall be supported to enable robust operation, e.g., mitigate blockage and load variation on backhaul links

5.2.3 L2- and L3-relay architectures

There has been extensive work in 3GPP on Layer 2 (L2) and Layer 3 (L3) relay architectures. Leveraging this work may reduce the standardization effort for IAB. The study can further establish an understanding of the tradeoff between L2- and L3-relaying in the context of IAB.

Requirement: L2- and L3-relay architectures shall be studied.

5.2.4 Core-network impact

IAB-related features such as IAB-node integration and topology adaptation may impact core-network specifications. It is desirable to minimize the impact to core-network specifications related to IAB.

Also, dependent on design, IAB features may create additional core-network signaling load. The amount of signaling load may vary among the various designs discussed in the study. Core-network signaling load is therefore considered an important KPI for the comparison of IAB designs.

Requirements:

1: The IAB design shall strive to minimize the impact to core network specifications;

2: The study should consider the impact to the core network signalling load as an important KPI.

5.2.5 Reuse of Rel-15 NR

Leveraging existing Rel-15 NR specifications can greatly reduce the standardization effort for the backhaul link.

The backhaul link may have additional requirements, which are not addressed in Rel-15 NR. For instance, both link end points of the backhaul link are expected to have similar capabilities. It may therefore be desirable to consider enhancements to Rel-15 NR specifications for the backhaul link.

Requirement: The study should strive to maximize the reuse of Rel-15 NR specifications for the design of the backhaul link. Enhancement can also be considered.

5.2.6 Network Synchronization

Time synchronization between IAB-nodes is also very essential e.g. to support TDD system and some potential features which need network synchronization. IAB may have additional requirement on network synchronization, which includes in-band wireless backhaul and multi-hops backhauling.

6 Architectures

6.1 General

6.1.1 Functions and Interfaces for IAB

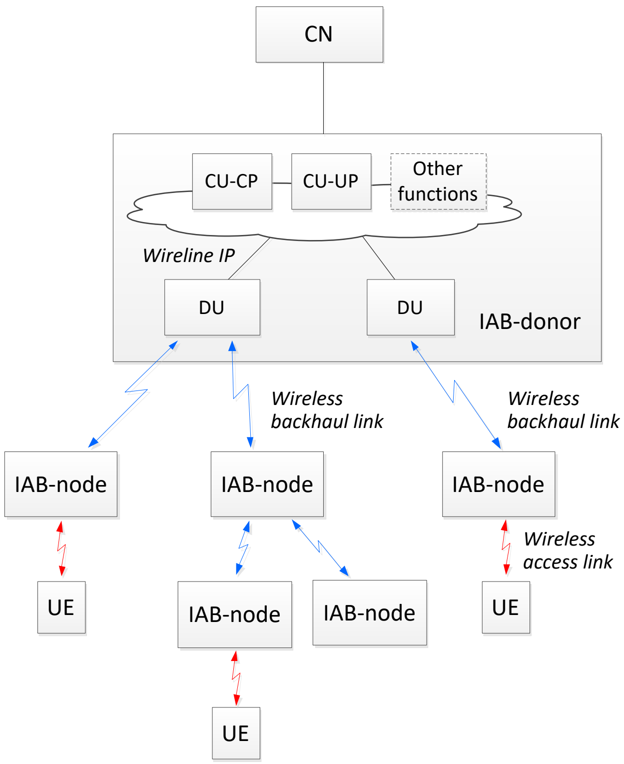

Figure 6.1.1-1: Reference diagram for IAB-architectures (SA mode)

IAB strives to reuse existing functions and interfaces defined for access. In particular, Mobile-Termination (MT), gNB-DU, gNB-CU, UPF, AMF and SMF as well as the corresponding interfaces NR Uu (between MT and gNB), F1, NG, X2 and N4 are used as baseline for the IAB architectures. Modifications or enhancements to these functions and interfaces for the support of IAB will be explained in the context of the architecture discussion. Additional functionality such as multi-hop forwarding is included in the architecture discussion as it is necessary for the understanding of IAB operation and since certain aspects may require standardization.

The Mobile-Termination (MT) function has been defined as a component of the Mobile Equipment. In the context of this study, MT is referred to as a function residing on an IAB-node that terminates the radio interface layers of the backhaul Uu interface toward the IAB-donor or other IAB-nodes.

Figure 6.1.1-1 shows a reference diagram for IAB in standalone mode, which contains one IAB-donor and multiple IAB-nodes. The IAB-donor is treated as a single *logical* node that comprises a set of functions such as gNB-DU, gNB-CU-CP, gNB-CU-UP and potentially other functions. In a deployment, the IAB-donor can be split according to these functions, which can all be either collocated or non-collocated as allowed by 3GPP NG-RAN architecture. IAB-related aspects may arise when such split is exercised. Also, some of the functions presently associated with the IAB-donor may eventually be moved outside of the donor in case it becomes evident that they do not perform IAB-specific tasks.

6.1.2 Operation in SA-mode and NSA-mode

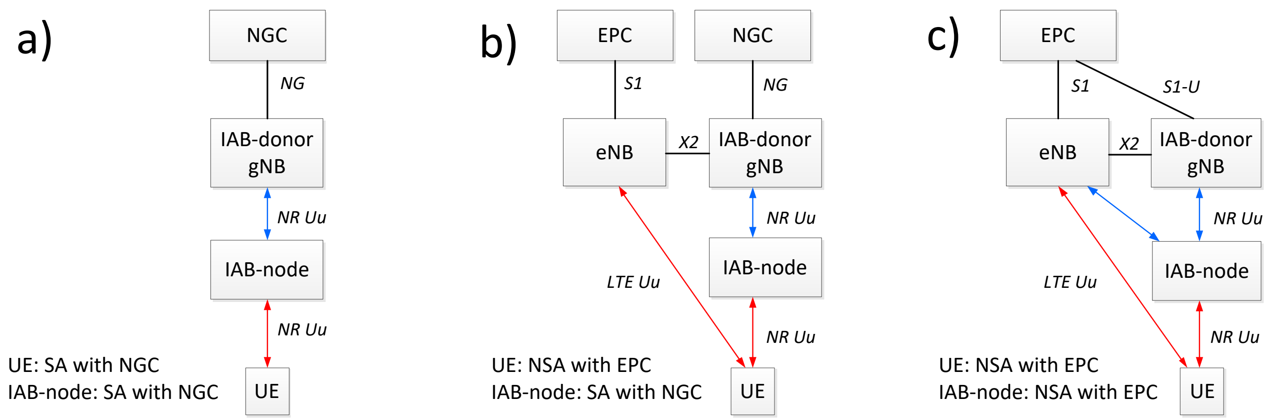

Figure 6.1.2-1: Examples for operation in SA and NSA mode. a) UE and IAB-node operate in SA with NGC, b) UE operates in NSA with EPC while IAB-node operates in SA with NGC, c) UE and IAB-node operate in NSA with EPC.

The IAB-node can operate in SA- or in NSA mode. When operating in NSA, the IAB-node only uses the NR link for backhauling.

The UE connecting to an IAB-node may choose a different operation mode than the IAB-node. The UE may further connect to a different type of core network than the IAB-node it is connected to. In this case, (e)Decor or slicing can be used for CN selection.

IAB-nodes operating in NSA-mode may be connected to the same or to different eNBs. UEs that also operate in NSA-node may connect to the same or to a different eNB than the IAB-node they are connected to.

Figure 6.1.2-1 shows examples for SA-mode with NGC and NSA-mode with EPC.

In Option c

"UE and IAB-node operate in NSA with EPC", the IAB-node may use the LTE leg for IAB-node initial access and configuration, topology management, route selection, and resource partitioning.

Option a "UE and IAB-node operate in SA with NGC" has following impacts:

- Impact to LTE RAN:
  - N/A.
- Impact to EPC:
  - N/A.
- Impact to NR RAN:
  - It may potentially require change or add NR signaling procedures for reconfiguration of IAB-MT, e.g. Configure NR IAB over NR air interface.

- Impact to NGC:
  - Support authentication/authorization of the IAB-node, and key generation in the IAB-node (SA3);
  - For some architecture options with UPF in the Donor, enhancement is needed in order to select the UPF collocated in the Donor. (This may also require some support from NG-RAN, e.g. provide the information of the local UPF to NGC).

Option b "UE operates in NSA with EPC while IAB-node operates in SA with NGC" has following impacts:

- Impact to LTE RAN:
  - N/A.
- Impact to EPC:
  - N/A.
- Impact to NR RAN:
  - It may potentially require change or add NR signaling procedures for reconfiguration of IAB-MT, e.g. Configure NR IAB over NR air interface;
  - Access control mechanism to only allow IAB-MT connects to IAB-Donor and IAB-node. An Access UE can only connect to the IAB-Donor or the IAB-node in DC or MC, and use the IAB-Donor and the IAB-node as a SN.
- Impact to NGC:
  - Support authentication/authorization of the IAB-node, and key generation in the IAB-node (SA3);
  - For some architecture options with UPF in the Donor, enhancement is needed in order to select the UPF collocated in the Donor. (This may also require some support from NG-RAN, e.g. provide the information of the local UPF to NGC).

Option c "UE and IAB-node operate in NSA with EPC" has following impacts:

- Impact to LTE RAN:
  - It may potentially require change or add LTE signaling procedures for reconfiguration of IAB-MT, e.g. Configure NR IAB over LTE air interface.
- Impact to EPC:
  - Support authentication/authorization of the IAB-node, and key generation in the IAB-node (SA3);
  - For some architecture options with UPF in the Donor, enhancement is needed in order to select the L-GW collocated in the Donor.
- Impact to NR RAN:
  - N/A.
- Impact to NGC:
  - N/A.

6.2 IAB Architectures proposed

All IAB multi-hop designs submitted to RAN-3 #99 can be represented with five architecture reference diagrams ([2]-[11]). These reference diagrams differ with respect to the modification needed on interfaces or additional functionality needed, e.g. to accomplish multi-hop forwarding. These five architectures are divided into two architecture groups. The main features of these architectures can be summarized as follows:

Architecture group 1: Consists of architectures 1a and 1b. Both architectures leverage CU/DU split architecture.

- Architecture 1a:
  - Backhauling of F1-U uses an adaptation layer or GTP-U combined with an adaptation layer;
  - Hop-by-hop forwarding across intermediate nodes uses the adaptation layer for operation with NGC or PDN-connection-layer routing for operation with EPC.
- Architecture 1b:
  - Backhauling of F1-U on access node uses GTP-U/UDP/IP;
  - Hob-by-hop forwarding across intermediate node uses the adaptation layer.

Architecture group 2: Consists of architectures 2a, 2b and 2c

- Architecture 2a:
  - Backhauling of F1-U or NG-U on access node uses GTP-U/UDP/IP;
  - Hop-by-hop forwarding across intermediate node uses PDU-session-layer routing.
- Architecture 2b:
  - Backhauling of F1-U or NG-U on access node uses GTP-U/UDP/IP;
  - Hop-by-hop forwarding across intermediate node uses GTP-U/UDP/IP nested tunneling.
- Architecture 2c:
  - Backhauling of F1-U or NG-U on access node uses GTP-U/UDP/IP;
  - Hop-by-hop forwarding across intermediate node uses GTP-U/UDP/IP/PDCP nested tunneling.

6.3 Architecture group 1

6.3.1 Architecture 1a

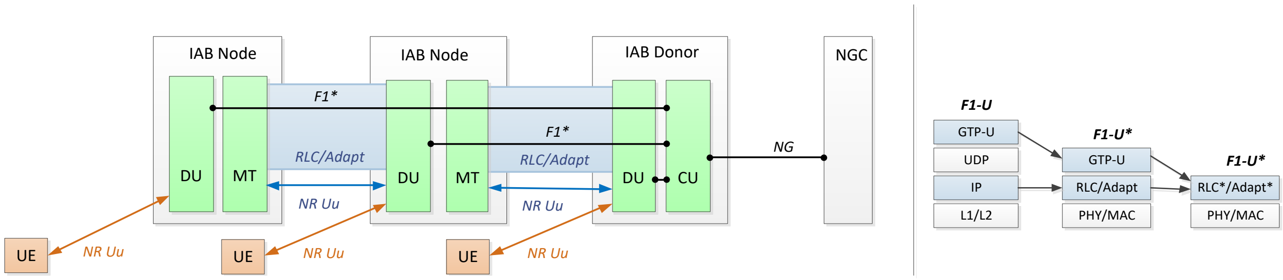

Figure 6.3.1-1: Reference diagram for architecture 1a (SA-mode with NGC)

Architecture 1a leverages CU/DU-split architecture. Figure 6.3.1-1 shows the reference diagram for a two-hop chain of IAB-nodes underneath an IAB-donor, where IAB-node and UE connect in SA-mode to an NGC.

In this architecture, each IAB-node holds a DU and an MT. Via the MT, the IAB-node connects to an upstream IAB-node or the IAB-donor. Via the DU, the IAB-node establishes RLC-channels to UEs and to MTs of downstream IAB-nodes. For MTs, this RLC-channel may refer to a modified RLC*. An IAB-node can connect to more than one upstream IAB-node or IAB-donor DU. The IAB-node may contain multiple DUs, but each DU part of the IAB-node has F1-C connection only with one IAB-donor CU-CP.

The donor also holds a DU to support UEs and MTs of downstream IAB-nodes. The IAB-donor holds a CU for the DUs of all IAB-nodes and for its own DU. It is assumed that the DUs on an IAB-node are served by only one IAB-donor. This IAB-donor may change through topology adaptation. Each DU on an IAB-node connects to the CU in the IAB-donor using a modified form of F1, which is referred to as F1*. F1*-U runs over RLC channels on the wireless backhaul between the MT on the serving IAB-node and the DU on the donor. An adaptation layer is added, which holds routing information, enabling hop-by-hop forwarding. It replaces the IP functionality of the standard F1-stack. F1*-U may carry a GTP-U header for the end-to-end association between CU and DU. In a further enhancement, information carried inside the GTP-U header may be included into the adaption layer. Further, optimizations to RLC may be considered such as applying ARQ only on the end-to-end connection opposed to hop-by-hop. The right side of Figure 6.3.1-1 shows two examples of such F1*-U protocol stacks. In this figure, enhancements of RLC are referred to as RLC*. The MT of each IAB-node further sustains NAS connectivity to the NGC, e.g., for authentication of the IAB-node. It may further sustain a PDU-session via the NGC, e.g., to provide the IAB-node with connectivity to the OAM.

For NSA operation with EPC, the MT is dual-connected with the network using EN-DC. The IAB-node's MT sustains a PDN connection with the EPC, e.g., to provide the IAB-node with connectivity to the OAM.

6.3.2 Architecture 1b

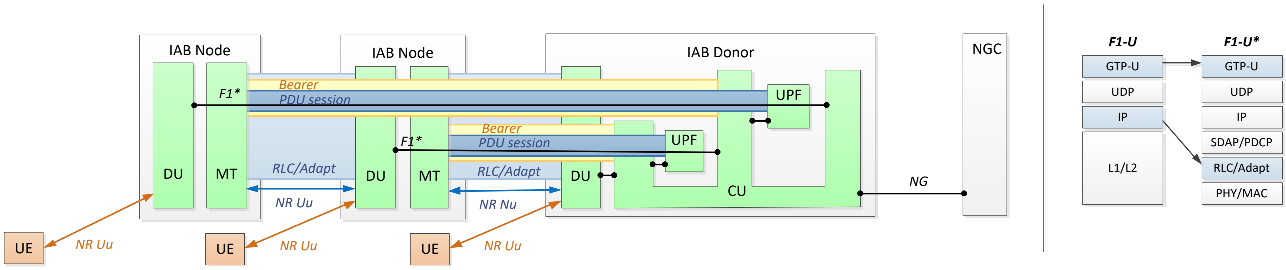

Figure 6.3.2-1: Reference diagram for architecture 1b (SA-mode with NGC)

Architecture 1b also leverages CU/DU-split architecture. Figure 6.3.2-1 shows the reference diagram for a two-hop chain of IAB-nodes underneath an IAB-donor. Note that the IAB-donor only holds one logical CU. An IAB-node can connect to more than one upstream IAB-node or IAB-donor DU. The IAB-node may contain multiple DUs, but each DU part of the IAB-node has F1-C connection only with one IAB-donor CU-CP.

In this architecture, each IAB-node and the IAB-donor hold the same functions as in architecture 1a. Also, as in architecture 1a, every backhaul link establishes an RLC-channel, and an adaptation layer is inserted to enable hop-by-hop forwarding of F1*.

Opposed to architecture 1a, the MT on each IAB-node establishes a PDU-session with a UPF residing on the donor. The MT's PDU-session carries F1* for the collocated DU. In this manner, the PDU-session provides a point-to-point link between CU and DU. On intermediate hops, the PDCP-PDUs of F1* are forwarded via adaptation layer in the same manner as described for architecture 1a. The right side of Figure 6.3.2-1 shows an example of the F1*-U protocol stack.

For NSA operation with EPC, the MT is dual-connected with the network using EN-DC. In this case, the IAB-node's MT sustains a PDN connection with a L-GW residing on the donor.

6.4 Architecture group 2

6.4.1 Architecture 2a

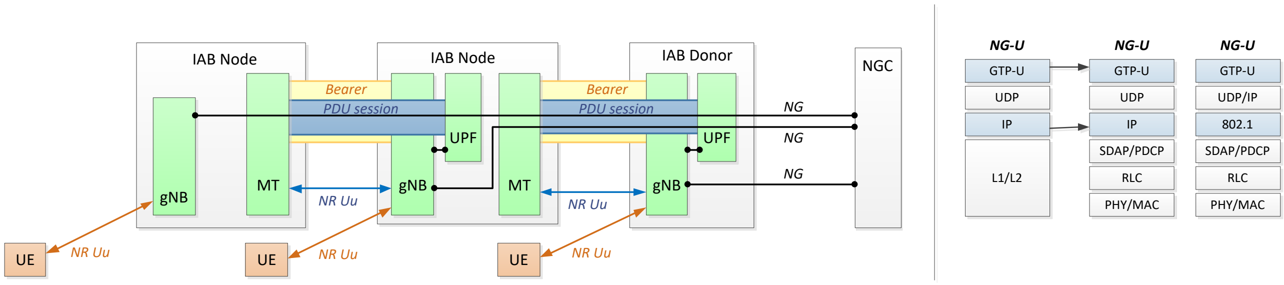

Figure 6.4.1-1: Reference diagram for architecture 2a (SA-mode with NGC)

Figure 6.4.1-1 shows the reference diagram for architecture 2a, where UE and IAB-node use SA-mode with NGC.

In this architecture, the IAB-node holds an MT to establish an NR Uu link with a gNB on the parent IAB-node or IAB-donor. Via this NR-Uu link, the MT sustains a PDU-session with a UPF that is collocated with the gNB. In this manner, an independent PDU-session is created on every backhaul link. Each IAB-node further supports a routing function to forward data between PDU-sessions of adjacent links. This creates a forwarding plane across the wireless backhaul. Based on PDU-session type, this forwarding plane supports IP or Ethernet. In case PDU-session type is Ethernet, an IP layer can be established on top. In this manner, each IAB-node obtains IP-connectivity to the wireline backhaul network. An IAB-node can connect to more than one upstream IAB-node or IAB-donor.

All IP-based interfaces such as NG, Xn, F1, N4, etc. are carried over this forwarding plane. In the case of F1, the UE-serving IAB-Node would contain a DU for access links in addition to the gNB and UPF for the backhaul links. The CU for access links would reside in or beyond the IAB-donor. The right side of Figure 6.4.1-1 shows an example of the NG-U protocol stack for IP-based and for Ethernet-based PDU-session type.

In case the IAB-node holds a DU for UE-access, it may not be required to support PDCP-based protection on each hop since the end user data will already be protected using end to end PDCP between the UE and the CU.

For NSA operation with EPC, the MT is dual-connected with the network using EN-DC. In this case, the IAB-node's MT sustains a PDN-connection with a L-GW residing on the parent IAB-node or the IAB-donor. All IP-based interfaces such as S1, S5, X2, etc. are carried over this forwarding plane.

6.4.2 Architecture 2b

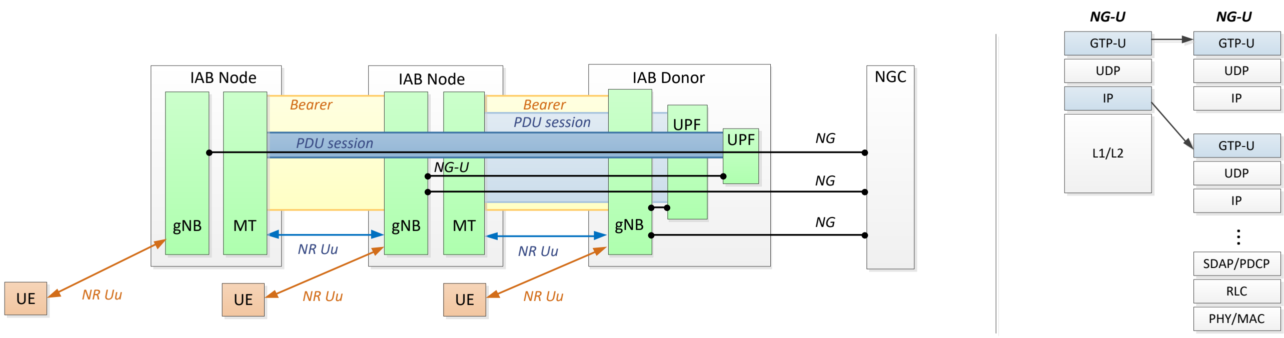

Figure 6.4.2-1: Reference diagram for architecture 2b (SA-mode with NGC)

In architecture 6.4.2-1, the IAB-node holds an MT to establish an NR Uu link with a gNB on the parent IAB-node or IAB-donor. Via this NR-Uu link, the MT sustains a PDU-session with a UPF. Opposed to architecture 2a, this UPF is located at the IAB-donor. Also, forwarding of PDUs across upstream IAB-nodes is accomplished via tunnelling. The forwarding across multiple hops therefore creates a stack of nested tunnels. As in architecture 2a, each IAB-node obtains IP-connectivity to the wireline backhaul network. All IP-based interfaces such as NG, Xn, F1, N4, etc. are carried over this forwarding IP plane. The right side of Figure 6.4.1-2 shows a protocol stack example for NG-U. An IAB-node can connect to more than one upstream IAB-node or IAB-donor.

For NSA operation with EPC, the MT is dual-connected with the network using EN-DC. In this case, the IAB-node's MT sustains a PDN-connection with a L-GW residing on the IAB-donor.

6.4.3 Architecture 2c

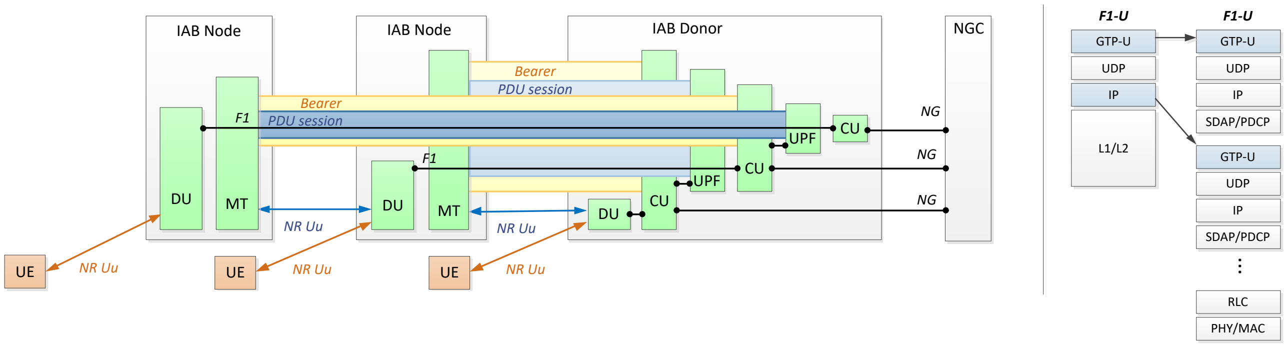

Figure 6.4.3.-1: Reference diagram for architecture 2c (SA-mode with NGC)

Architecture 6.4.3-1 leverages DU-CU split. The IAB-node holds an MT which sustains an RLC-channel with a DU on the parent IAB-node or IAB-donor. The IAB-donor holds a CU and a UPF for each IAB-node's DU. The MT on each IAB-node sustains a NR-Uu link with a CU and a PDU session with a UPF on the donor. Forwarding on intermediate nodes is accomplished via tunnelling. The forwarding across multiple hops creates a stack of nested tunnels. As in architecture 2a and 2b, each IAB-node obtains IP-connectivity to the wireline backhaul network. Opposed to architecture 2b, however, each tunnel includes an SDAP/PDCP layer. All IP-based interfaces such as NG, Xn, F1, N4, etc. are carried over this forwarding plane. The right side of Figure 6.4.3-1 shows a protocol stack example for NG-U. An IAB-node can connect to more than one upstream IAB-node or IAB-donor.

For NSA operation with EPC, the MT is dual-connected with the network using EN-DC. In this case, the IAB-node's MT sustains a PDN-connection with a L-GW residing on the IAB-donor.

7 Physical layer aspects

7.1 General

Based on the requirement listed in Section 5.2.5, the IAB design should strive to maximize the reuse of Rel-15 NR specifications for the design of the backhaul link. As a result, the Rel-15 NR physical layer should be the starting point for the physical layer of the IAB backhaul link. The following sections describe various aspects of the backhaul link physical layer design.

7.2 Backhaul link discovery and measurements

7.2.1 IAB-node initial access (Stage 1)

In case of SA deployments, initial IAB-node discovery by the MT (Stage 1) follows the same Rel-15 initial access procedure as a UE, including cell search based on the same SSBs available for access UEs, SI acquisition, and random access, in order to initially set up a connection to a parent IAB-node or an IAB-donor.

In case of an NSA deployment (from an access UE perspective), when the IAB-node MT performs initial access on the NR carrier, it follows the same Stage 1 initial access as in SA deployments (from an access UE perspective). The SSB/RMSI periodicity assumed by the MTs for initial access may be longer than 20ms assumed by Rel-15 UEs, and a single value is to be selected from the following candidate values: 20ms, 40ms, 80ms, 160ms.

NOTE: This implies that the candidate parent IAB-nodes/donors must support both NSA functionality for the UE and SA functionality for the MT on the NR carrier.

When IAB-node MT performs initial access on an LTE carrier, Stage 2 solutions can be used for IAB-node parent selection by the MT on the NR carrier.

7.2.2 Inter-IAB-node discovery and measurement (Stage 2)

For the purpose of backhaul link RSRP/RSRQ RRM measurements IAB supports both SSB-based and CSI- RS based solutions.

For the purpose of inter-IAB-node and donor detection after the IAB-node DU becomes active (Stage 2), the inter IAB-node discovery procedure needs to take into account the half-duplex constraint at an IAB-node and multi-hop topologies. The following three solutions are supported:

SSB-based solutions (Solution 1-A and 1-B):

- Solution 1-A) Reusing the same set of SSBs used for access UEs:
  - In this case, the SSBs for inter-IAB cell search in stage 2 are on the currently defined sync raster for a SA frequency layer, while for a NSA frequency layer the SSBs are transmitted inside of the SMTC configured for access UEs.
- Solution 1-B) Use of SSBs which are orthogonal (TDM and/or FDM) with SSBs used for access UEs:
  - In this case, the SSBs, that may get muted, for inter-IAB cell search and measurement in stage 2 are not on the currently defined sync raster for a SA frequency layer, while for a NSA frequency layer the SSBs are transmitted outside of the SMTC configured for access UEs.

An IAB-node should not mute its own SSB transmissions targeting UE cell search and measurement when doing inter-IAB cell search in stage 2:

- For SA, this means that SSBs transmitted on the currently defined sync raster follow the currently defined periodicity for initial access;
- In case of Solution 1-B, this implies SSBs, that may get muted, for inter-IAB stage 2 cell search is at least TDM with SSBs used for UE cell search and measurements.

CSI-RS based solutions (Solution 2):

- CSI-RS can be used for inter-IAB detection in synchronous network

To support IAB-node initial access and Stage 2 inter-IAB-node discovery and measurement, enhancements to existing Rel.15 SMTC/CSI-RS/RACH configurations and RMSI may need to be supported as well as coordination across IAB-nodes.

7.2.3 IAB-node RACH

IAB supports the ability of network flexibility to configure backhaul RACH resources with different occasions, longer RACH periodicities, and additional preamble formats allowing for longer RTT, compared to access RACH resources without impacting Rel-15 UEs.

Based on Rel-15 PRACH configurations, the network is allowed to configure offset(s) for PRACH occasions for the MT of IAB-node(s), in order to TDM backhaul RACH resources across adjacent hops.

7.2.4 Backhaul link management

An IAB-node supports mechanisms for detecting/recovering from backhaul link failure based on Rel-15 mechanisms. Enhancements to Beam Failure Recovery and Radio Link Failure procedures are beneficial and should be supported for NR IAB, including:

- Enhancements to support interaction between Beam Failure Recovery success indication and RLF;
- Enhancements to existing beam management procedures for faster beam switching/coordination/recovery to avoid backhaul link outages should be considered for IAB-nodes.

In addition, the need for additional backhaul link condition notification mechanism (E.g., if the parent IAB-node's backhaul link fails) from the parent IAB-node DU to the child IAB-node as well as corresponding IAB-node behaviour were studied. Solutions to avoid RLF at a child IAB-node due to parent backhaul link failure should be supported.

7.3 Scheduling and resource allocation/coordination

7.3.1 Scheduling of backhaul and access links

As shown in Figure 7.3.1-1, the following link types are supported for IAB:

- Access link: a link between an access UE and an IAB-node or IAB-donor ($L_{A,DL}$ or $L_{A,UL}$);
- Backhaul link: a link between an IAB-node and an IAB child node ($L_{C,DL}$ or $L_{C,UL}$) or an IAB parent node ($L_{P,DL}$ or $L_{P,UL}$).

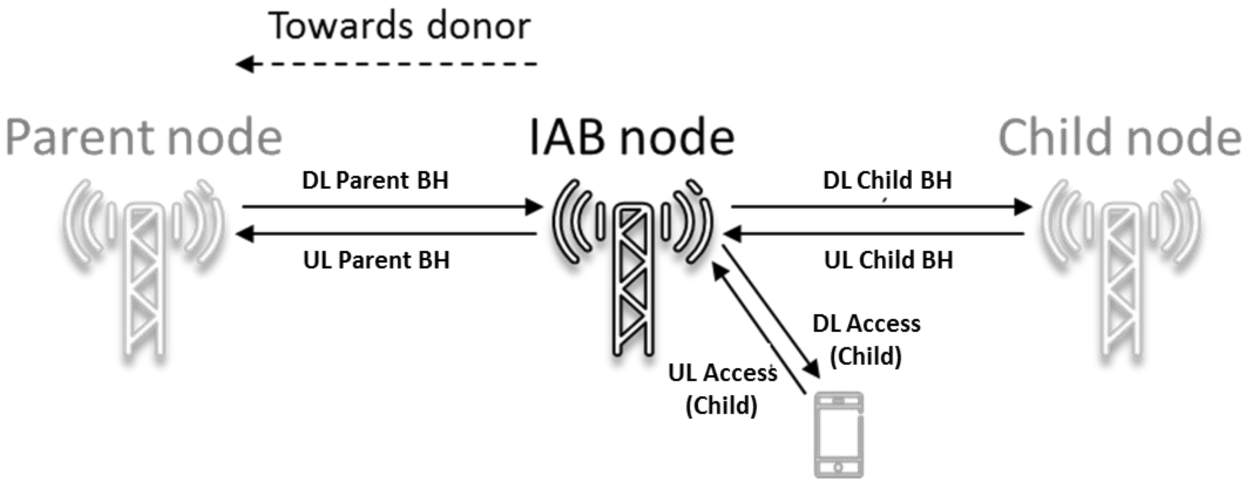

Figure 7.3.1-1: Different IAB link types

Note that depending on the topology/architectures considered in Section 6 and 9 respectively, the IAB-node may have its functions for UL access and child BH respectively in the same location or different locations, and for a given BH link for an IAB-node, it may be a parent BH or a child BH, depending on the topology/architecture.

Downlink IAB-node transmissions (i.e. transmissions on backhaul links from an IAB-node to child IAB-nodes served by the IAB-node and transmissions on access links from an IAB-node to UEs served by the IAB-node) should be scheduled by the IAB-node itself. Uplink IAB transmission (transmissions on a backhaul link from an IAB-node to its parent IAB-node or IAB-donor) should be scheduled by the parent IAB-node or IAB-donor.

7.3.2 Multiplexing of access and backhaul links

IAB supports TDM, FDM, and SDM between access and backhaul links at an IAB-node, subject to a half-duplex constraint. Mechanisms for efficient TDM/FDM/SDM multiplexing of access/backhaul traffic across multiple hops considering an IAB-node half-duplex constraint were studied.

For TDM, the supported cases are given in Table 7.3.2-1.

Table 7.3.2-1: Supported TDM cases

	TDM Between:	
Case	Link 1	Link 2
1	$L_{P,DL}$	$L_{C,DL}$
2	$L_{P,UL}$	$L_{C,UL}$
3	$L_{P,DL}$	$L_{C,UL}$
4	$L_{P,UL}$	$L_{C,DL}$
5	$L_{P,DL}$	$L_{A,DL}$
6	$L_{P,UL}$	$L_{A,UL}$
7	$L_{P,DL}$	$L_{A,UL}$
8	$L_{P,UL}$	$L_{A,DL}$
9	$L_{P,DL}$	$L_{A,DL}$ and $L_{C,DL}$
10	$L_{P,UL}$	$L_{A,UL}$ and $L_{C,UL}$
11	$L_{P,DL}$	$L_{A,UL}$ and $L_{C,UL}$
12	$L_{P,UL}$	$L_{A,DL}$ and $L_{A,DL}$
13	$L_{C,DL}$	$L_{A,DL}$
14	$L_{C,UL}$	$L_{A,UL}$
15	$L_{C,DL}$	$L_{A,UL}$
16	$L_{C,UL}$	$L_{A,DL}$

In case of transmitter-side SDM/FDM, an IAB-node simultaneously transmits in the DL (to an access UE and/or child IAB-node) and transmits in the UL (to a parent IAB-node). In case of receiver-side SDM/FDM, an IAB-node simultaneous receives in the DL (from a parent node) and receives in the UL (from an access UE and/or child IAB-node).

Additionally, an IAB-node can support multiplexing of DL transmissions to access UEs and child IAB-nodes and multiplexing of UL transmissions from access UEs and child IAB-nodes, using existing MU-MIMO or sectorization mechanisms.

The following solutions for the different multiplexing options were considered as part of the study:

- Mechanisms for orthogonal partitioning of time slots or frequency resources between access and backhaul links across one or multiple hops;
- Utilization of different DL/UL slot configurations for access and backhaul links;
- Interference management including cross-link interference;
- For support of SDM/FDM:
    - DL and UL power control enhancements and timing requirements to allow for intra-panel FDM and SDM of backhaul and access links, as well as transmit power coordination between parent and child links;
    - Considerations of single panel vs. multi-panel operation (single or multiple baseband);
    - Requirements of symbol-level timing alignment within an IAB-node (e.g. Case #6/Case #7).
- Whether a parent node or the network needs to be aware of a child IAB-node's capability, including the following aspects:
    - Support for full duplex;
    - Supporting SDM/FDM TX of parent and child links;
    - Supporting SDM/FDM RX of parent and child links;
    - Supported timing alignment cases.

DL and UL transmit power coordination between IAB-nodes is supported, including mechanisms for DL power control between a parent and child IAB-node.

7.3.3 Resource coordination

From an IAB-node MT point-of-view, as in Rel. 15, the following time-domain resources can be indicated for the parent link:

- Downlink time resource;
- Uplink time resource;
- Flexible time resource.

From an IAB-node DU point-of-view, the child link has the following types of time resources:

- Downlink time resource;
- Uplink time resource;
- Flexible time resource;
- Not available time resources (resources not to be used for communication on the DU child links).

Each of the downlink, uplink and flexible time-resource types of the DU child link can belong to one of two categories:

- Hard: The corresponding time resource is always available for the DU child link;
- Soft: The availability of the corresponding time resource for the DU child link is explicitly and/or implicitly controlled by the parent node.

At least for TDM Cases 1-12 in Section 7.3.2, an IAB-node is configured with IAB-node specific resources in time available for the links.

Mechanisms for scheduling coordination, resource allocation, and route selection across IAB-nodes/IAB-donors and multiple backhaul hops were studied, including the following aspects:

- Distributed or centralized coordination mechanisms;
- Resource granularity, adaptation period, and enhancements to existing mechanisms for the required signalling (e.g. slot or symbol-level or TDD configuration pattern) provided to the IAB-node;
- Explicit or implicit indication of the resources;
- Exchange of L1 and/or L3 measurements between IAB-nodes;
- Exchange of topology related information (e.g. hop order) impacting the study of the backhaul link physical layer design;
- Resource (frequency, time in terms of slot/slot format, etc.) coordination which is faster than semi-static coordination and the indication of resources within the configuration which can be dynamically and flexibly used for different links, including:
    - The need to consider the scheduling delay, IAB-node processing delays, or information required to be available for the use of flexible resources;
    - Mechanisms to schedule flexible resources (e.g. GC-PDCCH).

In order to support mechanisms for resource allocation for IAB-nodes, semi-static configuration is supported for the configuration of IAB-node DU resources. In addition, dynamic indication (L1 signalling) to an IAB-node of the availability of soft resources for an IAB-node DU is supported. Existing Rel.15 L1 signalling methods as the baseline, while potential enhancements (e.g. new slot formats), rules for DU/MT behaviour in case of conflicts across multiple hops, and processing time constraints at the IAB-node may need to be considered.

Tables 7.3.3-1 and 7.3.3-2 capture the possible combinations of DU and MT behavior. The tables assume an IAB not capable of full-duplex operation. In the tables below the following definitions apply:

- "MT: Tx" means that the MT should transmit if scheduled;
- "DU: Tx" means that the DU may transmit;

- "MT: Rx" means that the MT should be able to receive (if there is anything to receive);
- "DU: Rx" means that the DU may schedule uplink transmissions from child nodes or UEs;
- "MT: Tx/Rx" means that the MT should transmit if scheduled and should be able to receive, but not simultaneously;
- "DU: Tx/Rx" means that the DU may transmit and may schedule uplink transmission from child nodes and UEs, but not simultaneously;
- "IA" means that the DU resource is explicitly or implicitly indicated as available;
- "INA" means that the DU resource is explicitly or implicitly indicated as not available;
- "MT: NULL" means that the MT does not transmit and does not have to be able to receive;
- "DU: NULL" means that the DU does not transmit and does not schedule uplink transmission from child nodes and UEs.

Table 7.3.3-1 applies in case of TDM operation, where there can be no simultaneous transmission in the DU and the MT, nor any simultaneous reception in the DU and the MT.

Table 7.3.3-1: DU and MT behavior in case of TDM operation

DU Configuration	MT configuration		
	DL	UL	F
DL-H	DU: Tx MT: NULL	DU: Tx MT: NULL	DU: Tx MT: NULL
DL-S	When DU resource: IA DU: Tx MT: NULL When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Tx MT: NULL When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Tx MT: NULL When DU resource: INA DU: NULL MT: Tx/Rx
UL-H	DU: Rx MT: NULL	DU: Rx MT: NULL	DU: Rx MT: NULL
UL-S	When DU resource: IA DU: Rx MT: NULL When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Rx MT: NULL When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Rx MT: NULL When DU resource: INA DU: NULL MT: Tx/Rx
F-H	DU: Tx/Rx MT: NULL	DU: Tx/Rx MT: NULL	DU: Tx/Rx MT: NULL
F-S	When DU resource: IA DU: Tx/Rx MT: NULL When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Tx/Rx MT: NULL When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Tx/Rx MT: NULL When DU resource: INA DU: NULL MT: Tx/Rx
NA	DU: NULL MT: Rx	DU: NULL MT: Tx	DU: NULL MT: Tx/Rx

Table 7.3.3-2 applies in case of SDM operation, where there can be simultaneous transmission in the DU and the MT, alternatively simultaneous reception in the DU and the MT.

Table 7.3.3-2: DU and MT behaviour in case of SDM operation

	DL	UL	F
DL-H	DU: Tx MT: NULL	DU: Tx MT: Tx	DU: Tx MT: Tx
DL-S	When DU resource: IA DU: Tx MT: NULL When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Tx MT: Tx When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Tx MT: Tx When DU resource: INA DU: NULL MT: Tx/Rx
UL-H	DU: Rx MT: Rx	DU: Rx MT: NULL	DU: Rx MT: Rx
UL-S	When DU resource: IA DU: Rx MT: Rx When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Rx MT: NULL When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Rx (only if MT is Rx and the DU knows that ahead of time) MT: Rx When DU resource: INA DU: NULL MT: Tx/Rx
F-H	DU: Tx/Rx MT: Rx (only if DU is Rx and the parent DU is aware in advance)	DU: Tx/Rx MT: Tx (only if DU is Tx and the parent is aware in advance)	DU: Tx/Rx MT: Tx (only if DU is Tx and the parent DU knows that ahead of time), Rx (only if DU is Rx and the parent DU is aware in advance)
F-S	When DU resource: IA DU: Tx/Rx MT: Rx (only if DU is Rx and the parent DU is aware in advance) When DU resource: INA DU: NULL MT: Rx	When DU resource: IA DU: Tx/Rx MT: Tx (only if DU is Tx and the parent DU is aware in advance) When DU resource: INA DU: NULL MT: Tx	When DU resource: IA DU: Tx/Rx MT: Tx (only if DU is Tx and the parent DU knows that ahead of time), Rx (only if DU is Rx and the parent DU is aware in advance) When DU resource: INA DU: NULL MT: Tx/Rx
NA	DU: NULL MT: Rx	DU: NULL MT: Tx	DU: NULL MT: Tx/Rx

7.4 IAB-node synchronization and timing alignment

The feasibility of over-the-air (OTA) synchronization and the impact of timing misalignment on IAB performance (e.g. the number of supportable hops) was studied. With the assumption of a <=3us timing requirement across IAB-nodes within overlapping coverage, TA-based OTA synchronization can support a multi-hop IAB network (up to 5 hops) for FR2. TA-based OTA synchronization may not be sufficient to support multiple hops in FR1.

The following levels of alignment between IAB-nodes/IAB-donors or within an IAB-node were studied:

- Slot-level alignment;
- Symbol-level alignment;
- No alignment.

Mechanisms for timing alignment across multi-hop IAB networks were studied. IAB supports TA-based synchronization between IAB-nodes, including across multiple backhaul hops. Enhancements to existing timing alignment mechanisms were studied, including the TA required for IAB-nodes to support different transmission timing alignment cases.

The following cases of transmission timing alignment across IAB-nodes and IAB-donors have been considered as part of the study:

- Case #1: DL transmission timing alignment across IAB-nodes and IAB-donors:
  - If DL TX and UL RX are not well aligned at the parent node, additional information about the alignment is needed for the child node to properly set its DL TX timing for OTA based timing & synchronization.
- Case #2: DL and UL transmission timing is aligned within an IAB-node;
- Case #3: DL and UL reception timing is aligned within an IAB-node;
- Case #4: within an IAB-node, when transmitting using case 2 while when receiving using case 3;
- Case #5: Case #1 for access link timing and Case 4 for backhaul link timing within an IAB-node in different time slots;
- Case #6 (Case#1 DL transmission timing + Case #2 UL transmission timing):
  - The DL transmission timing for all IAB-nodes is aligned with the parent IAB-node or donor DL timing;
  - The UL transmission timing of an IAB-node can be aligned with the IAB-node's DL transmission timing.
- Case #7 (Case#1 DL transmission timing + Case #3 UL reception timing):
  - The DL transmission timing for all IAB-nodes is aligned with the parent IAB-node or donor DL timing;
  - The UL reception timing of an IAB-node can be aligned with the IAB-node's DL reception timing;
  - If DL TX and UL RX are not well aligned at the parent node, additional information about the alignment is needed for the child node to properly set its DL TX timing for OTA based timing & synchronization.

The impact of different cases on TDM/FDM/SDM multiplexing of access and backhaul links, potential impact of imperfect timing adjustment, overhead of required DL/UL switching gaps, cross-link interference, feasibility of the case when the IAB-node is connected to one or multiple parent nodes, and impact on access UEs (especially compatibility with Rel-15 UEs) were considered as part of the study.

Case #1 is supported for both access and backhaul link transmission timing alignment.

Cases #2-#5 are not supported for IAB.

The use of Case 6, if supported, at the IAB-node should be under control of the parent or network.

To enable alignment of DL transmissions among IAB-nodes, the following examples of solutions have been identified:

- Alt. 1: The IAB-node may need to carry out parallel (always time multiplexed) case #1 and case #6 uplink transmissions;
- Alt 2: Signalling between the parent and IAB-node of the time difference of the DL Tx and UL Rx timing at the parent node in order to correct potential misalignment of the DL Tx timing at the child node:
  - The child IAB-node compares the corresponding difference of its own DL Tx timing and BH Rx timing; if the signalled difference of the parent node is larger than measured at the child node, the child node advances its TX timing, if smaller the TX timing is delayed.
- Note: Alt 1 & Alt 2 may require maintenance of separate Rx timings at the parent node for Case 6 UL transmissions from different child nodes.

Case #7 is compatible with Rel-15 UEs by introducing an "effective" negative TA, and TDM between child IAB-nodes/Rel-16 UEs which support the new TA values and child IAB-nodes/UEs which do not support the new TA values. To enable alignment between DL and UL reception within the IAB-node the following examples of solutions have been identified:

- Alt 1: Introduce negative initial time alignment (TA) for IAB-nodes, to be applied to child nodes of the IAB-node applying case #7 timing;
- Alt 2: Apply a positive TA that enables symbol alignment, but not slot alignment, between the DL reception and the UL reception at the IAB-node;

- Alt. 3: Signalling of a relative offset w.r.t the most recent TA value, to be applied to child nodes of the IAB-node applying case #7 timing to achieve an effective negative TA.

In addition to OTA synchronization, other techniques such as GNSS and PTP, can be used to achieve synchronization across IAB-nodes.

7.5 Cross-link interference measurement and management

The impact of cross-link interference (CLI) on access and backhaul links (including across multiple hops) and interference measurement and management solutions were studied.

CLI mitigation techniques including advanced receivers and transmitter coordination were studied and prioritized in terms of complexity and performance. CLI mitigation techniques should be able to manage the following inter IAB-node interference scenarios:

- Case 1: Victim IAB-node is receiving in DL via its MT, interfering IAB-node is transmitting in UL via its MT;
- Case 2: Victim IAB-node is receiving in DL via its MT, interfering IAB-node is transmitting in DL via its DU;
- Case 3: Victim IAB-node is receiving in UL via its DU, interfering IAB-node is transmitting in UL via its MT;
- Case 4: Victim IAB-node is receiving in UL via its DU, interfering IAB-node is transmitting in DL via its DU.

Interference experienced at the IAB-node in case of FDM/SDM reception between access and backhaul links at a given IAB-node were considered as part of the study.

Mechanisms for inter IAB-node CLI measurement need to be able to capture Cases 1-4. Furthermore, CLI measurements such as short-term and long-term measurements, and multiple-antenna and beamforming based measurements were studied to enable CLI mitigation in IAB.

MT-to-DU, MT-to-MT and DU-to-DU, and DU-to-MT CLI measurements and required measurement coordination/configuration should be supported including the following aspects:

- CLI measurements can be made based on existing RS (e.g. CSI-RS/SRS/DMRS):
  - Enhancements to RS configuration for CLI measurements and transmission timing can be considered in the WI phase.
- Rely on solutions developed in the CLI WI as a baseline and enhance if needed for IAB-specific aspects:
  - Time/frequency resource configuration for measurements across multiple hops;
  - Inter IAB-node Tx/Rx beam sweeping and selection;
  - Taking DU/MT power control into account in the CLI measurements.

7.6 Spectral efficiency enhancements

One of the SI objectives in Section 4 is the identification of physical layer solutions or enhancements to support wireless backhaul links with high spectral efficiency.

Support for higher order modulation for backhaul links was considered as part of the study. Although support of up to 1024QAM is beneficial for backhaul links based on evaluation results using the simulation assumptions in Section A.1, it is not deemed essential for Rel-16 IAB operation from RAN1 perspective.

7.7 Summary of Physical Layer Enhancements for IAB

RAN1 has studied various physical layer aspects for Integrated Access and Backhaul, and from a RAN1 perspective, support for the following features and solutions has been determined to be beneficial and feasible:

- Mechanisms for discovery of IAB-nodes and management of backhaul links in both SA and NSA deployments, taking into account the half-duplex constraint at an IAB-node and multi-hop topologies, including:

- Solutions reusing the same set of SSBs used for access UEs and solutions which use of SSBs which are orthogonal (TDM and/or FDM) with SSBs used for access UEs;
- CSI-RS-based IAB-node discovery in synchronized deployments;
- Backhaul link RSRP/RSRQ RRM measurements which are SSB-based and CSI-RS based;
- Enhancements to support configuration of backhaul RACH resources with different occasions, longer RACH periodicities, and additional preamble formats allowing for longer RTT, compared to access RACH resources without impacting Rel-15 UEs.

- Enhancements to Beam Failure Recovery and Radio Link Failure procedures, including solutions to avoid RLF at a child IAB-node due to parent backhaul link failure;
- Mechanisms for supporting both in-band and out-of-band relaying by multiplexing access and backhaul links in time (TDM), frequency (FDM), or space (SDM) under a per-link half-duplex constraint at the IAB-node and across multiple backhaul hops, including:
    - Semi-static configuration for IAB-node DU resources;
    - Dynamic indication to an IAB-node of the availability of soft resources for an IAB-node DU;
    - Power control/coordination for FDM/SDM of access and backhaul links.
- Over-the-air (OTA) timing alignment across multiple backhaul hops, including:
    - Mechanisms for DL timing alignment across IAB-nodes;
    - Alignment of an IAB-node's UL transmission timing and DL transmission timing;
    - Alignment of an IAB-node's UL reception timing and DL reception timing.
- Inter-IAB-node cross-link interference (CLI) measurements and measurement coordination/configuration.
- Support of up to 1024QAM for backhaul links.

8 Radio protocol aspects

8.1 Packet Processing

Packet processing is discussed in the context of UP and CP designs below.

8.2 User-plane considerations for architecture group 1

8.2.1 General

The following subsections describe various user plane aspects for architecture group 1 including placement of an adaptation layer, functions supported by the adaptation layer, support of multi-hop RLC, and impacts on scheduler and QoS. The study analyses described architecture options to identify trade-offs between these various aspects with the goal to recommend a single architecture for this group.

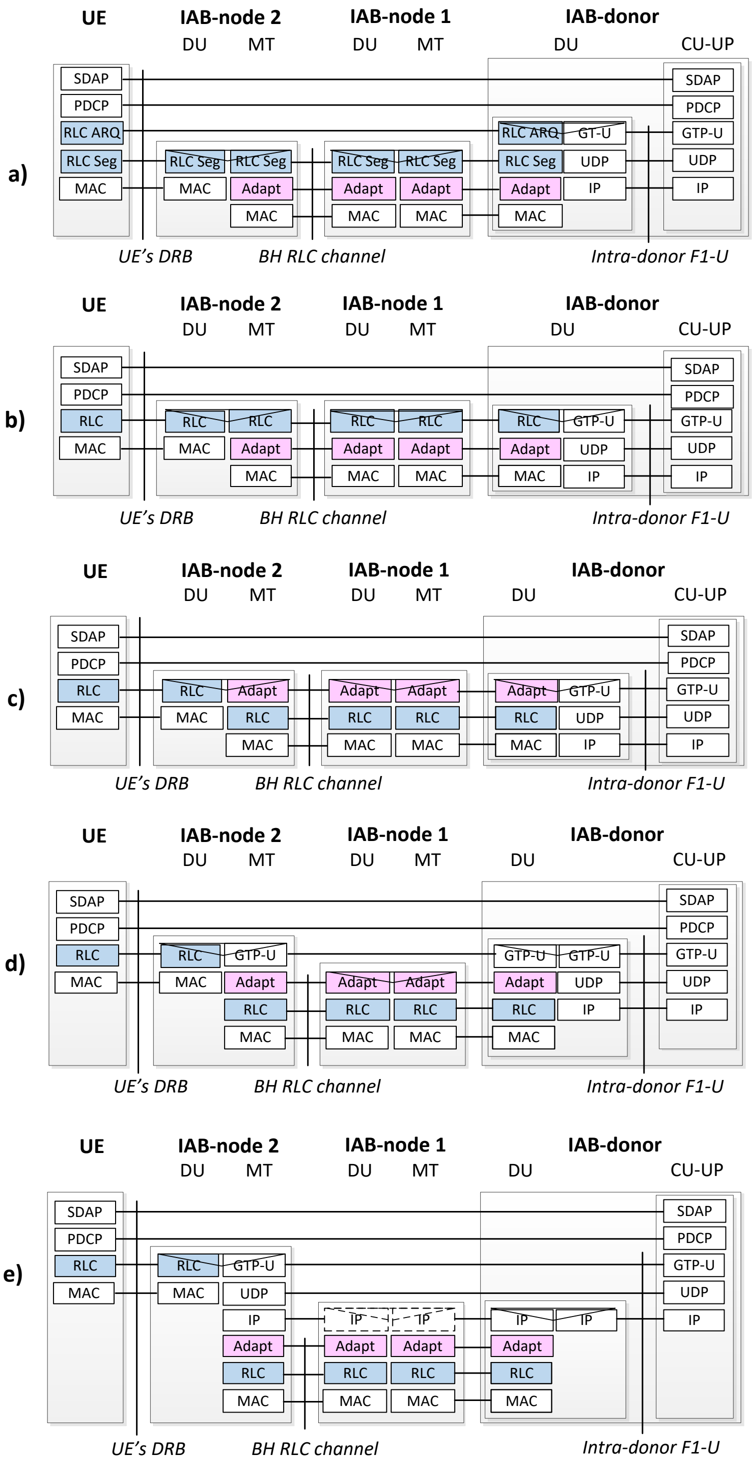

Figure 8.2.1-1: Protocol stack examples for UE-access using L2-relaying with adaptation layer for architecture 1a

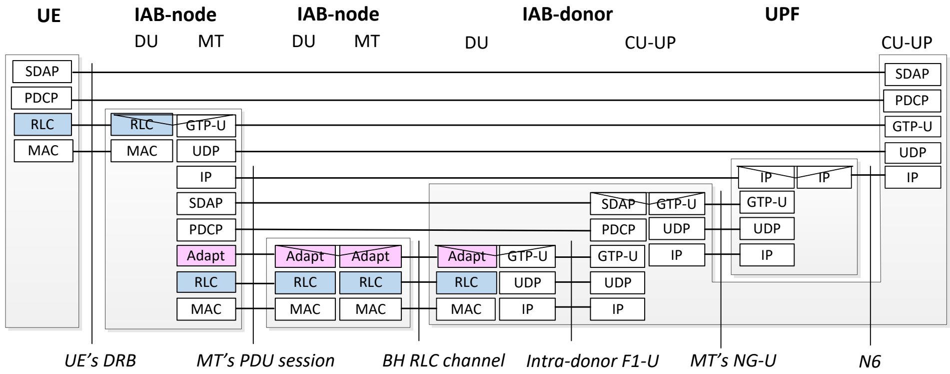

Figure 8.2.1-2: Protocol stack example for UE-access using L2-relaying with adaptation layer for architecture 1b

8.2.2 Adaptation Layer

The UE establishes RLC channels to the DU on the UE's access IAB-node in compliance with TS 38.300 [3]. Each of these RLC-channels is extended via a potentially modified form of F1-U, referred to as F1*-U, between the UE's access DU and the IAB-donor.

The information embedded in F1*-U is carried over RLC-channels across the backhaul links. Transport of F1*-U over the wireless backhaul is enabled by an adaptation layer, which is integrated with the RLC channel.

Within the IAB-donor (referred to as fronthaul), the baseline is to use native F1-U stack (see section 9). The IAB-donor DU relays between F1-U on the fronthaul and F1*-U on the wireless backhaul.

Functions supported by the adaptation layer

In architecture 1a, information carried on the adaptation layer supports the following functions:

- Identification of the UE-bearer for the PDU;
- Routing across the wireless backhaul topology;
- QoS-enforcement by the scheduler on DL and UL on the wireless backhaul link;
- Mapping of UE user-plane PDUs to backhaul RLC channels;
- Potentially other functions.

In architecture 1b, information carried on the adaptation layer supports the following functions:

- Routing across the wireless backhaul topology;
- QoS-enforcement by the scheduler on DL and UL on the wireless backhaul link;
- Mapping of UE user-plane PDUs to backhaul RLC channels;
- Potentially other functions.

In case the IAB-node is connected via multiple paths, different identifiers (e.g. route ID, IAB-node address) in the adaptation layer will be associated with the different paths, enabling adaptation layer routing on the different paths. The different paths can be associated with different backhaul RLC-channels.

Content carried on the adaptation layer header

The study identifies information to be carried on the adaptation layer header. This may include:

- UE-bearer-specific Id;
- UE-specific Id;
- Route Id, IAB-node or IAB-donor address;

- QoS information;
- Potentially other information.

IAB-nodes will use the identifiers carried via Adapt to ensure required QoS treatment and to decide which hop a packet should be sent to. A brief overview is provided below on how the above information may be used to this end, if included in the final design of Adapt.

The UE-bearer-specific Id may be used by the IAB-node and the IAB-donor to identify the PDU's UE-bearer. UE's access IAB-node would then map Adapt information (e.g. UE-specific ID, UE-bearer specific ID) into the corresponding C-RNTI and LCID. The IAB-donor DU may also need to map Adapt information into the F1-U GTP-U TEID used between Donor DU and Donor CU.

UE-bearer-specific Id, UE-specific Id, Route Id, or IAB-node/IAB-donor address may be used (in combination or individually) to route the PDU across the wireless backhaul topology.

UE-bearer-specific Id, UE-specific Id, UE's access node IAB ID, or QoS information may be used (in combination or individually) on each hop to identify the PDU's QoS treatment. The PDU's QoS treatment may also be based on the LCID.

Processing of adaptation layer information

- The study identifies, which of the information on the adaptation layer is processed to support the above functions on each on-path IAB-node (hop-by-hop);
- and/or on the UE's access-IAB-node and the IAB-donor (end-to-end).

Integration of adaptation layer into L2 Stack

The study considers the following adaptation layer placements:

- integrated with MAC layer or placed above MAC layer (examples shown in Figure 8.2.1-1a, b);
- above RLC layer (examples shown in Figure 8.2.1-1c, d, e and Figure 8.2.1-2).

For 1:1 mapping of UE-bearers to backhaul RLC-channels (see section 8.2.4), Adapt can be integrated with the MAC layer or placed above the MAC layer. A separate RLC-entity in each IAB-node is provided for each of these backhaul RLC-channels. Arriving PDUs are mapped to the corresponding RLC-entity based on the UE-bearer information carried by Adapt.

When UE-bearers are aggregated to backhaul RLC-channels (e.g. based on QoS-profile (see section 8.2.4)), Adapt can be placed above the RLC layer.

For both Adapt above RLC and Adapt above MAC, when UE bearers are aggregated to logical channels, the logical channel can be associated to a QoS profile. The number of QoS-profiles supported is limited by the LCID-space.

The figures show example protocol stacks and do not preclude other possibilities. While RLC channels serving for backhauling include the adaptation layer, the adaptation layer may or may not be included in IAB-node access links.

Adaptation header structure

The adaptation layer may consist of sublayers. It is perceivable, for example, that the GTP-U header becomes a part of the adaptation layer. It is also possible that the GTP-U header is carried on top of the adaptation layer to carry end-to-end association between the IAB-node DU and the CU (example is shown in Figure 8.2.1-1d).

Alternatively, an IP header may be part of the adaptation layer or carried on top of the adaptation layer. One example is shown in Figure 8.2.1-1e. In this example, the IAB-donor DU holds an IP routing function to extend the IP-routing plane of the fronthaul to the IP-layer carried by adapt on the wireless backhaul. This allows native F1-U to be established end-to-end, i.e. between IAB-node DUs and IAB-donor CU-UP. The scenario implies that each IAB-node holds an IP-address, which is routable from the fronthaul via the IAB-donor DU. The IAB-nodes' IP addresses may further be used for routing on the wireless backhaul.

Note that the IP-layer on top of Adapt does not represent a PDU session. The MT's first hop router on this IP-layer therefore does not have to hold a UPF.

Observations on adaptation layer placement

1. The above-RLC adaptation layer can only support hop-by-hop ARQ. The above-MAC adaptation layer can support both hop-by-hop and end-to-end ARQ.

2. Both adaptation layer placements can support aggregated routing, e.g. by inserting an IAB-node address into the adaptation header.

3. UE-specific ID may be a completely new identifier or one of the existing identifiers can be reused. The identifier(s) included in Adapt may vary depending on the adaptation layer placement.

4. Both adaptation layer placements can support per-UE-bearer QoS treatment. In order for each UE bearer to receive individual QoS support when their number exceeds the size of the LCID space, one possible solution is the extension of the LCID-space which can be achieved through changes to the MAC sub-header, or by dedicated information placed in the Adapt header. Enhancements to BSR reporting may be required.

5. Both adaptation layer placements can support aggregated QoS handling as in the following example network configurations:

   a. For above-RLC adaptation layer, UE-bearers with same QoS profile could be aggregated to one backhaul RLC-channel for this purpose;

   b. For above-MAC or integrated-with-MAC adaptation layer, UE-bearers with same QoS profile could be treated with same priority by the scheduler.

6. For both adaptation layer placements, aggregation of routing and QoS handling allows proactive configuration of intermediate on-path IAB-nodes, i.e. configuration is independent of UE-bearer establishment/release.

7. For both adaptation layer placements, RLC ARQ can be pre-processed on TX side.

8.2.3 Multi-hop RLC ARQ

For RLC AM, ARQ can be conducted hop-by-hop along access and backhaul links (Figure 8.2.1-1b, c, d, e and 8.2.1-2). It is also possible to support ARQ end-to-end between UE and IAB-donor (Figure 8.2.1-1a). Since RLC segmentation is a just-in-time process it is always conducted in a hop-by-hop manner. The figures show example protocol stacks and do not preclude other possibilities.

The study includes hop-by-hop and end-to-end RLC ARQ.

The type of multi-hop RLC ARQ and adaptation-layer placement have the following interdependence:

- End-to-end ARQ: Adaptation layer is integrated with MAC layer or placed above MAC layer;

- Hop-by-hop ARQ: No interdependence.

Table 8.2.3-1 summarizes observations for end-to-end and hop-by-hop ARQ.

Table 8.2.3-1: Observations for end-to-end and hop-by-hop ARQ

Metric	Hop-by-hop RLC ARQ	End-to-end RLC ARQ
Forwarding latency	Potentially higher as packets have to pass through RLC-state machine on each hop.	Potentially lower as packets do not go through the RLC state machine on intermediate IAB-nodes.
Latency due to retransmission	Independent of number of hops	Increases with number of hops
Capacity	Packet loss requires retransmission only on one link. Avoids redundant retransmission of packets over links where the packet has already been successfully transmitted.	Packet loss may imply retransmission on multiple links, including those where the packet was already successfully transmitted.
Hop count limitation due to RLC parameters	Hop count is not affected by max window size.	Hop count may be limited by the end-to-end RLC latency due to max window size.
Hop count limitation due to PCDP parameters	Hop count may be limited by increasing disorder of PDCP PDUs over sequential RLC ARQ hops. This may increase probability to exceed max PDCP window size.	Hop count does not impact disorder of PDCP PDUs due to RLC ARQ.
Processing and memory impact on intermediate IAB-nodes	Larger since processing and memory is required on intermediate IAB-nodes.	Smaller since intermediate path-nodes do not need ARQ state machine and flow window.
RLC specification impact	No stage-3 impact expected	Potential stage-3 impact
Operational impact for IAB-node to IAB-donor upgrades	IAB-nodes and IAB-donors use the same hop-by-hop RLC ARQ. As a result, this functionality is completely unaffected by the upgrade of IAB-node to IAB-donor at availability of fiber, potentially reducing the effort required to confirm proper operation.	End-to-end RLC ARQ results in a greater architectural difference between IAB-nodes vs. IAB-donor nodes. As a result, additional effort may be required to complete an upgrade of an IAB-node to an IAB-donor upon availability of fiber.
Configuration complexity	RLC timers are not dependent on hop-count.	RLC timers become hop-count dependent.
Lossless delivery of UL data	Current specification cannot ensure data lossless delivery at certain scenarios (e.g., when IAB topology changes are performed after backhaul-link failure or when inter-CU handover happens) without additional enhancements (examples listed below).	Lossless delivery ensured due to end to end RLC feedback.

The issue of end to end reliability in hop-by-hop RLC ARQ case could be addressed by specifying, e.g., the following mechanisms:

- Modification of PDCP protocol/procedures. This mechanism would not be applicable to Rel-15 UEs which means that Rel-15 UE performance may be impaired;
  - When either PDCP data recovery / PDCP re-establishment is triggered by RRC or PDCP status report is received, UE retransmits UL data irrespective of whether successful delivery has been confirmed by RLC;
  - New field may be included in the RRC message or PDCP status report in order to indicate, whether the UE performs UL data retransmission regardless of confirmation of successful delivery by RLC.

- Rerouting of PDCP PDUs buffered on intermediate IAB-nodes in response to a route update:
  - UL data is buffered on IAB-node(s) until the IAB-node receives from its parent node either information about UL data, which has been successfully delivered to IAB-donor, or RLC positive ACK;
  - When forwarding path is (re)configured, the buffered data is retransmitted by the IAB-node that is either the last unchanged node in the new path or where backhaul-link failure occurs.
- Introducing UL status delivery (from the Donor gNB to the IAB-node):
  - One way is that UE's access IAB-node delays the sending of RLC positive ACKs to UE until receiving a confirmation of data reception from IAB-donor. Another way is that an IAB-node delays the sending of RLC positive ACKs to its child node or UE until receiving RLC positive ACKs from its parent node;
  - When PDCP data recovery / PDCP re-establishment is triggered by RRC, UE retransmits UL data as in the current specifications.

Table 8.2.3-2: Comparison of mechanisms for lossless delivery of UL data in hop-by-hop RLC ARQ case

	Modification of PDCP protocol/procedures	**Rerouting of PDCP PDUs buffered on intermediate IAB-nodes**	**Introducing UL status delivery**
Applicable to Rel-15 UEs	**No**	**Yes**	**Yes**
Signaling overhead	**Yes** New signaling for triggering data retransmission	**Yes** New signaling for either deciding whether to discard the buffered data or configuring the forwarding path for the buffered data on the old route.	**Yes** New signaling for confirming data reception and/or triggering data retransmission.
Support of lossless delivery of UL data	**Yes**	**No**	**Yes**

8.2.4 Scheduler and QoS impacts

8.2.4.1 UE-bearer-to-BH-RLC-Channel mapping

An IAB-node needs to multiplex the UE DRBs to the BH RLC-Channel. The following two options can be considered on bearer mapping in IAB-node.

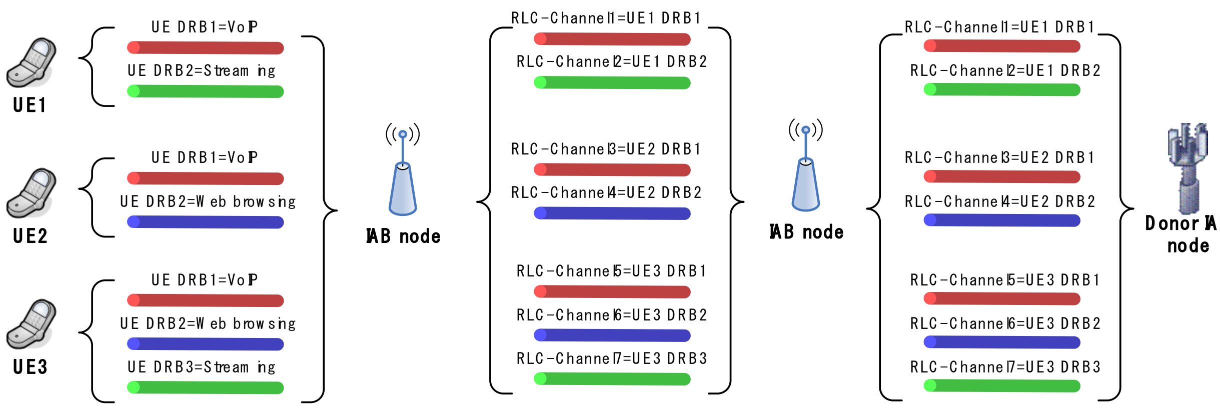

Figure 8.2.4.1-1: Example of one-to-one mapping between UE DRB and BH RLC-Channel

Option 1. One-to-one mapping between UE DRB and BH RLC-channel

In this option, each UE DRB is mapped onto a separate BH RLC-channel. Further, each BH RLC-channel is mapped onto a separate BH RLC-channel on the next hop. The number of established BH RLC-channels is equal to the number of established UE DRBs.

Identifiers (e.g. for the UE and/or DRB) may be required (e.g. if multiple BH RLC-channels are multiplexed into a single BH logical channel). Which exact identifiers are needed, and which of these identifier(s) are placed within the adaptation layer header depends on the architecture/protocol option.

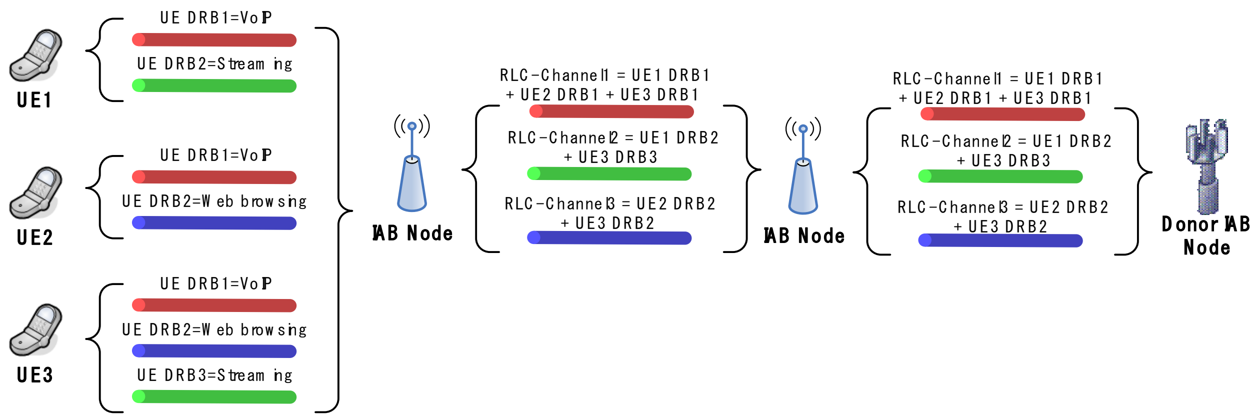

Figure 8.2.4.1-2: Example of many-to-one mapping between UE DRBs and BH RLC-channel

Option 2. Many-to-one mapping between UE DRBs and BH RLC-channel

For the many-to-one mapping, several UE DRBs are multiplexed onto a single BH RLC-channel based on specific parameters such as bearer QoS profile. Other information such as hop-count could also be configured. The IAB-node can multiplex UE DRBs into a single BH RLC-channel even if they belong to different UEs. Furthermore, a packet from one BH RLC-channel may be mapped onto a different BH RLC-channel on the next hop (details of IAB L2 structure for bearer multiplexing are given in section 8.2.5). All traffic mapped to a single BH RLC-channel receive the same QoS treatment on the air interface.

Since the BH RLC-channel multiplexes data from/to multiple bearers, and possibly even different UEs, each data block transmitted in the BH RLC-channel needs to contain an identifier of the UE, DRB, and/or IAB-node it is associated with. Which exact identifiers are needed, and which of these identifier(s) are placed within the adaptation layer header depends on the architecture/protocol option.

8.2.4.2 Enforcement of Fairness Schemes

An IAB network should attempt to schedule the wireless resources to meet each UE bearer's requirement regardless of the number of hops a given UE is away from the Donor DU.

The scheduler on the wireless backhaul link can distinguish the QoS profiles associated with different RLC channels. It may also apply information regarding the number of hops a packet needs to traverse, in addition to the QoS profile of the bearers, in order to provide hop-agnostic performance. Different scheduling techniques may differ in their normative impact.

When one-to-one mapping is used between UE bearer and RLC-channel on the backhaul, the IAB-node has explicit information on each UE bearer and can therefore apply appropriate QoS differentiation among QoS profiles, as well as fairness among UE bearers with same QoS profile.

While QoS differentiation is still possible when UE bearers are aggregated to backhaul RLC-channels, enforcement of fairness across UE bearers becomes less granular.

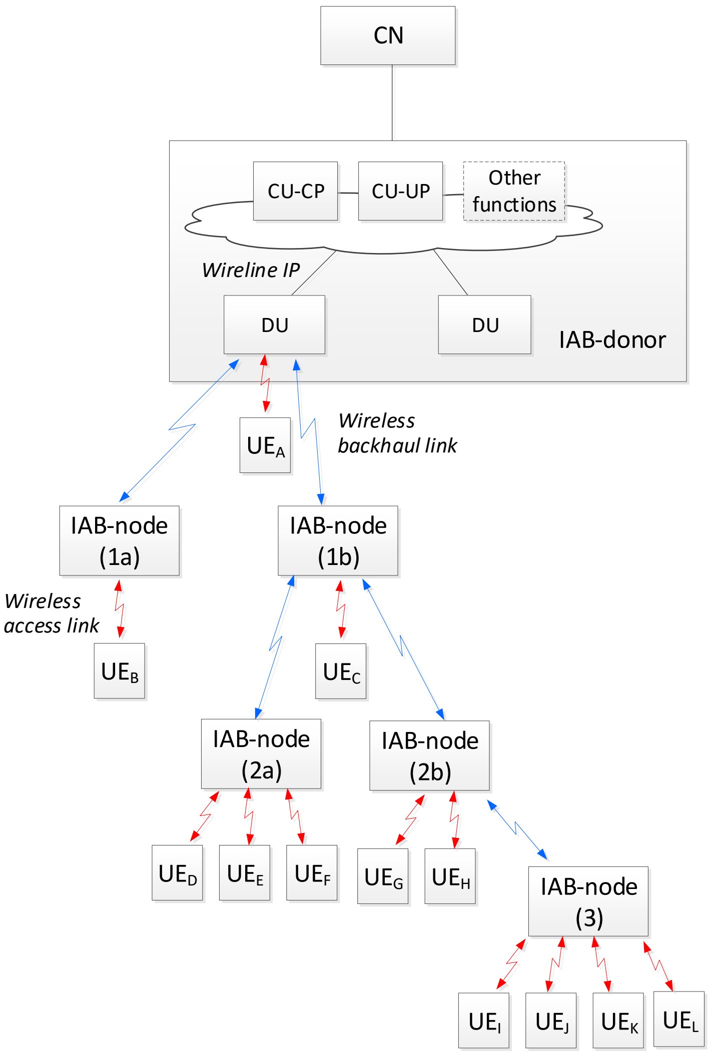

Figure 8.2.4.2-1: IAB network with 3 hops and 12 UEs

Figure 8.2.4.2-1 shows an example scenario of an IAB network with 3 hops and 12 UEs attached. The UEs are assumed to have one bearer each with same QoS profile (e.g. default bearer). The UE-bearers are assumed to share the same RLC channel on BH links. Consequently, each backhaul link carries different number of UE-bearers (Table 8.2.4.2-1).

Below are the two options for applying fairness schemes across backhaul and access links (other options are not precluded):

- Option 1: The DU scheduler obtains information about the number of UE bearers carried on each backhaul link. This enables the scheduler to apply fairness schemes. For this, the scheduler has to be updated whenever the number of UE bearers change on one of its backhaul RLC-channels. Alternatively, the scheduler derives the number of UE bearers carried on the backhaul RLC-channel from packet inspection;

- Option 2: The DU scheduler obtains information about the number of descendant IAB-nodes supported by each backhaul link. This allows enforcing fairness schemes as long as the total traffic is balanced across IAB-nodes.

Table 8.2.4.2-1: UE bearers and IAB-nodes served

DU Scheduler	UE bearers Served			Descendent IAB-nodes served	
	Access	Backhaul link 1	Backhaul link 2	Backhaul link 1	Backhaul link 2
IAB-donor	1	1	10	1	4
IAB-node (1a)	1				
IAB-node (1b)	1	3	6	1	2
IAB-node (2a)	3				
IAB-node (2b)	2	4			1
IAB-node (3)	4				

8.2.4.3 Radio aware scheduling

NR enables radio aware scheduling for the access link by providing the timely channel quality feedback and the ability to monitor the per UE bearer windowed throughput at the radio scheduling function in the DU. IAB scheduling should also be provided with timely feedback to enable efficient radio aware scheduling. Some examples of feedback may include:

- Number of UEs served by child IAB-nodes and their subtending IAB-nodes as shown in Table 8.2.4.2-1;
- UE bearer windowed throughput to identify the service rate of the access link;
- UE congestion at the next hop due to unscheduled packets (e.g. next hop queue depth);
- The relative benefit/penalty for scheduling a given UE or backhaul bearer on the adjacent hop.

The example feedback listed above, and possibly other information, may be forwarded from child to parent and parent to child to support efficient scheduling in an IAB network. Efficiency may be improved by appropriately sizing traffic on the most congested links. Efficiency may further be improved by appropriately allocating resources on the backhaul hops to match the load existing on partitions of the IAB topology (e.g. subtending tree). Efficiency may also be improved by limiting traffic on congested branches by reducing the overall interference.

Radio-aware and efficient scheduling for IAB may also be further enabled by mechanisms for resource coordination (see 7.3.3).

8.2.5 L2 structure

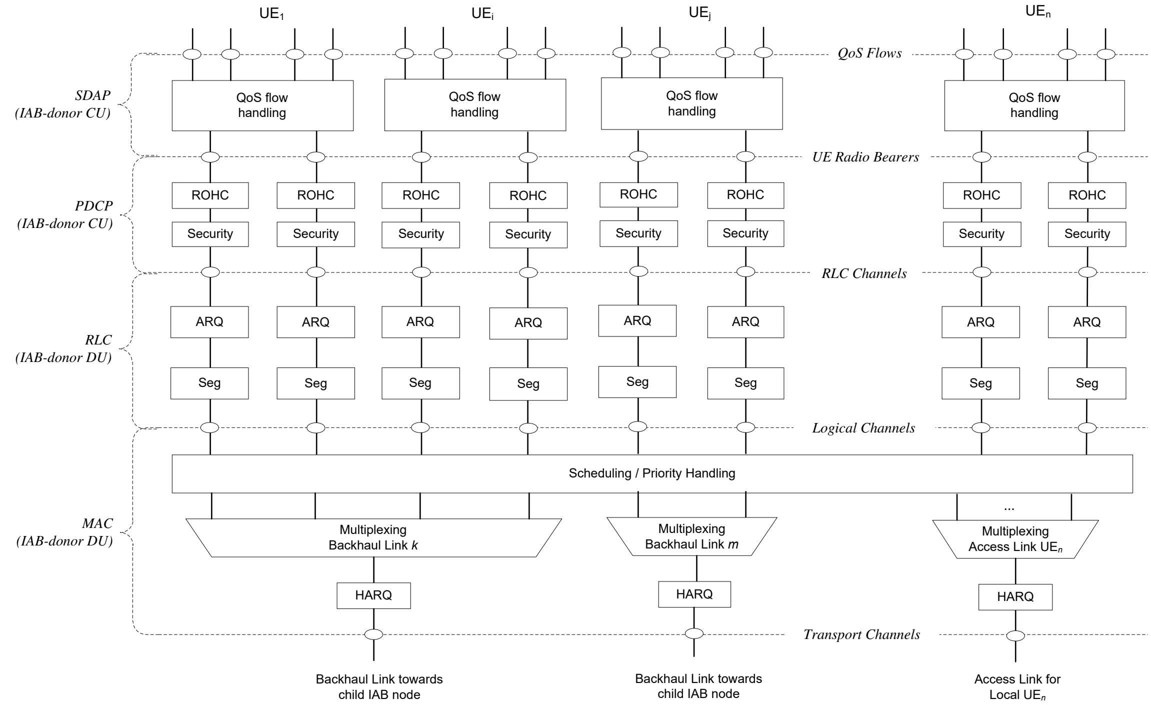

Figure 8.2.5-1a: DL L2-structure of IAB-donor for 1:1 mapping of UE-bearers to BH RLC-channels

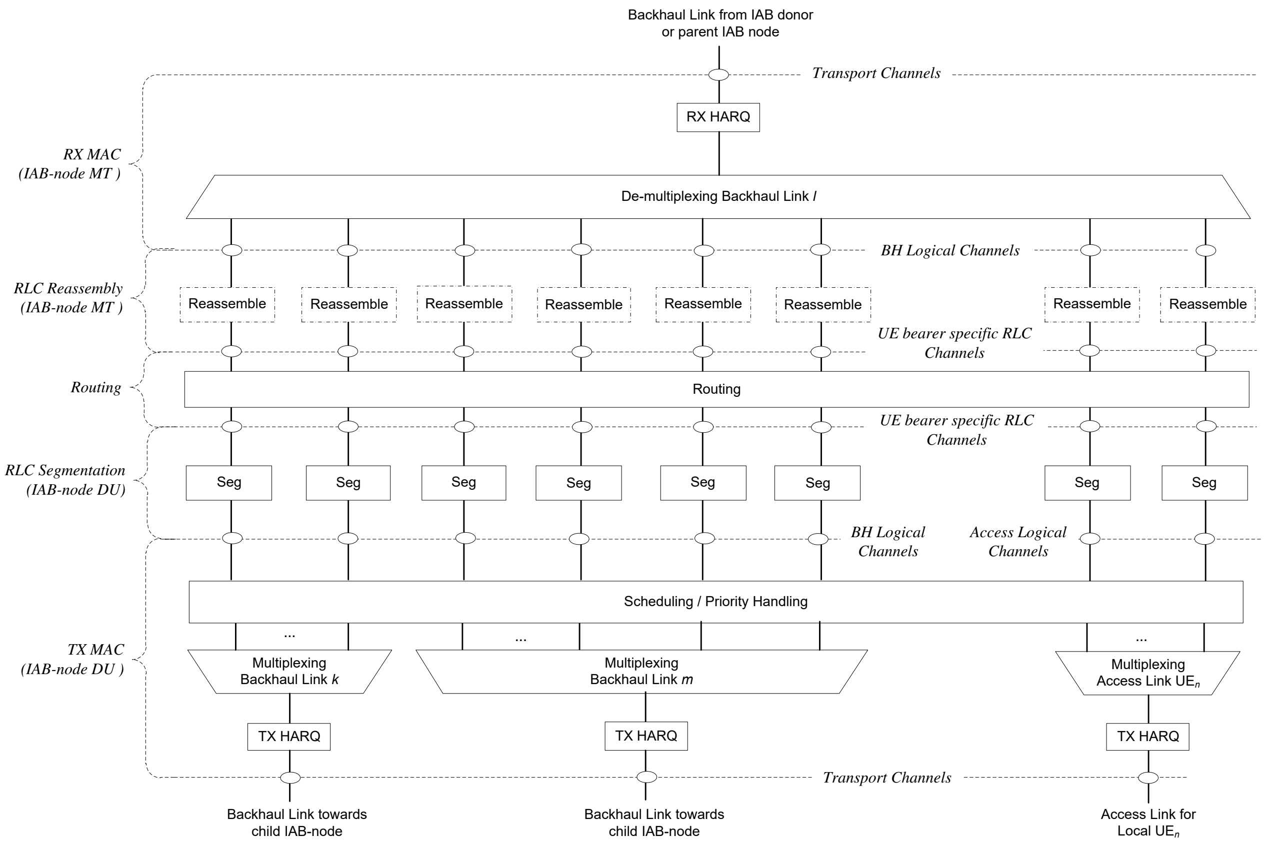

Figure 8.2.5-1b: DL L2-structure of IAB-node for 1:1 mapping of UE-bearers to BH RLC-channels for end-to-end RLC ARQ

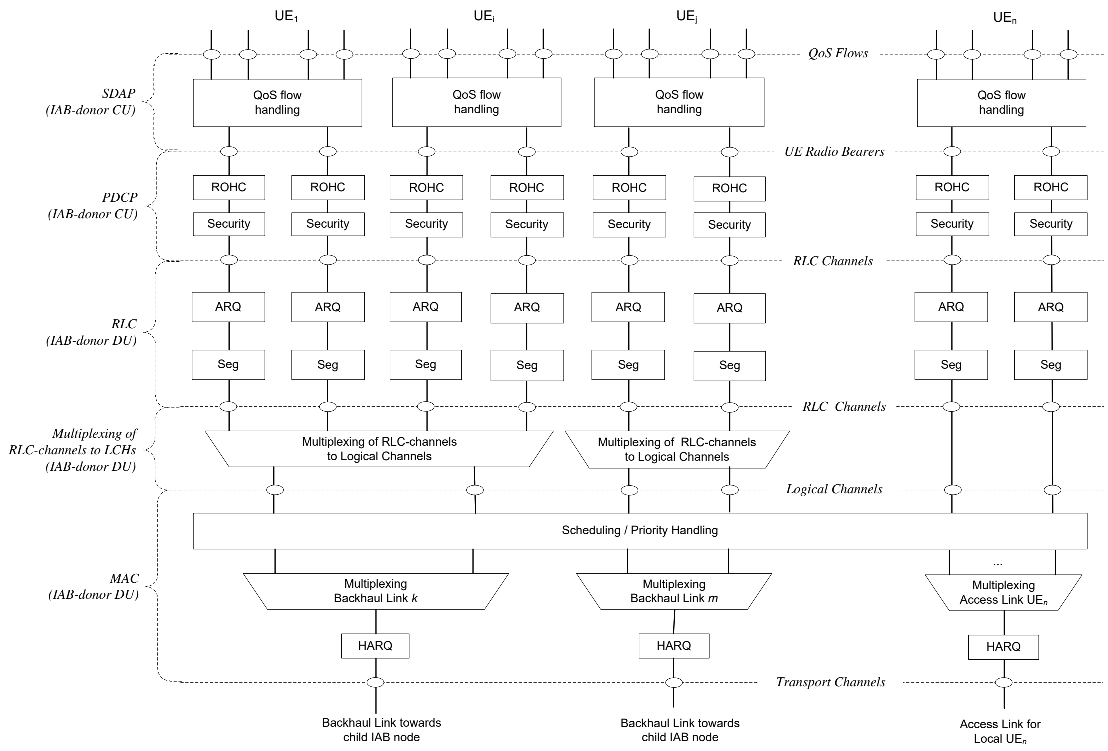

Figure 8.2.5-2a: DL L2-structure of IAB-donor for 1:1 mapping of UE-bearers to BH RLC-channels and multiplexing of RLC-channels to logical channels

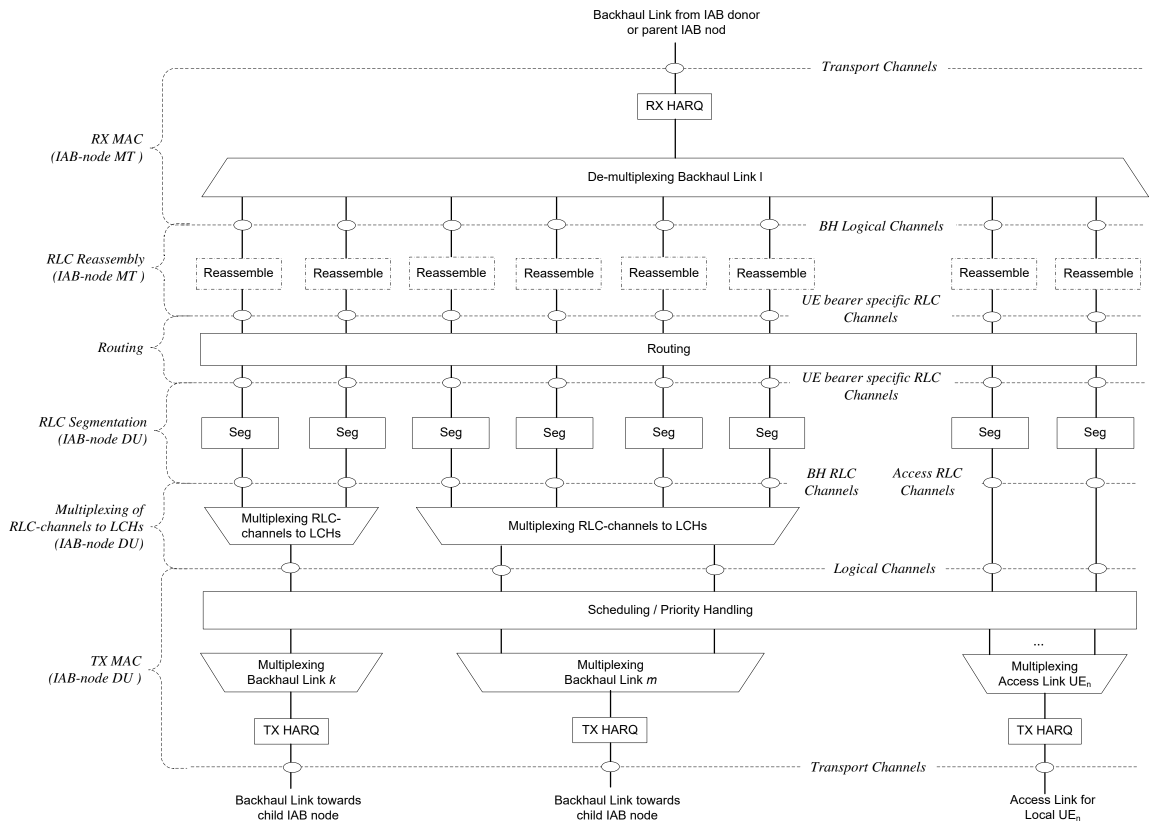

Figure 8.2.5-2b: DL L2-structure of IAB-node for 1:1 mapping of UE-bearers to BH RLC-channels, multiplexing of RLC-channels to logical channels, and end-to-end RLC ARQ

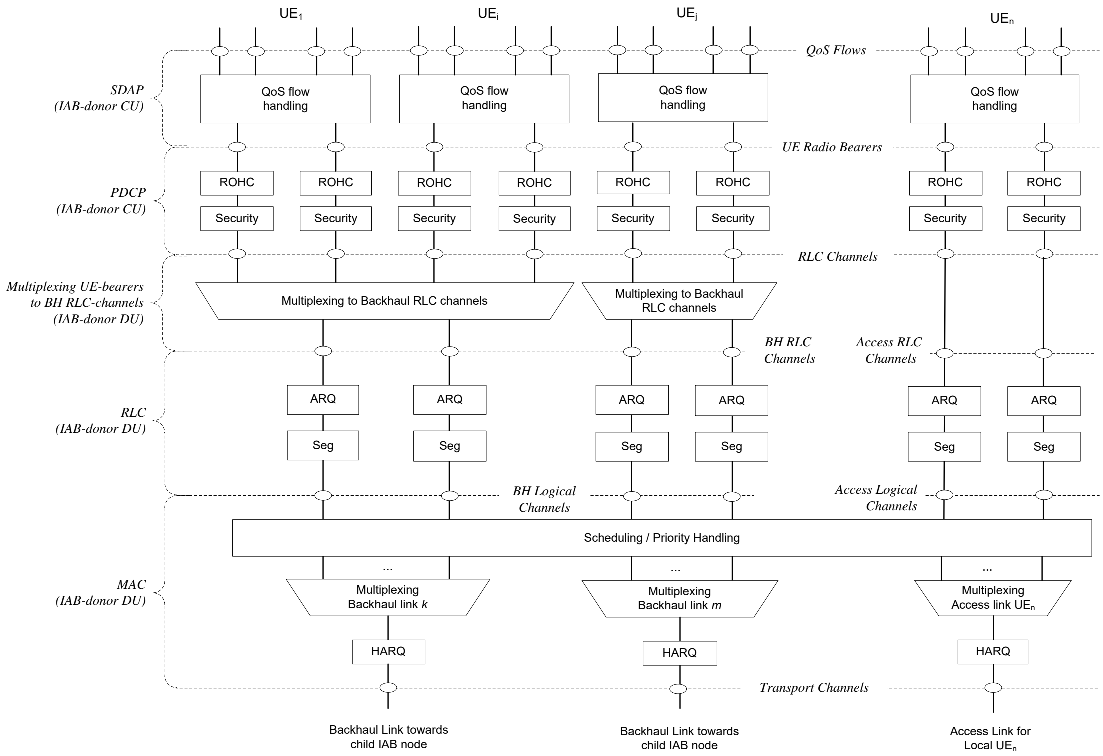

Figure 8.2.5-3a: DL L2-structure of IAB-donor for many-to-one mapping of UE-bearers to BH RLC-channels

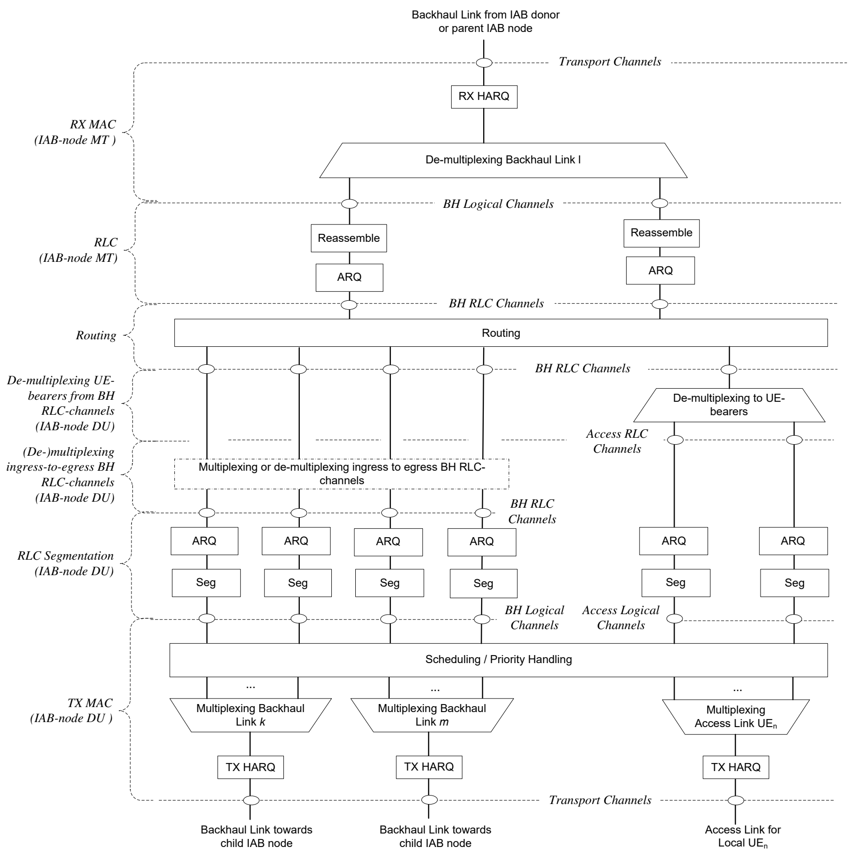

Figure 8.2.5-3b: DL L2-structure of IAB-node for many-to-one mapping of UE-bearers to BH RLC-channels

The Figures 8.2.5-1, 8.2.5-2, and 8.2.5-3 provide examples for L2-structures for multi-hop IAB in the downlink direction (IAB-donor towards UE).

Figure 8.2.5-1a shows an example of the DL L2 structure of the IAB-donor for 1:1 mapping of UE access bearers to BH RLC-channels. This L2-structure is the same as defined for Rel-15 NR access. Since a separate RLC-entity is supported on each backhaul link for each UE access bearer, the number of logical channels required on backhaul links may exceed the LCID space, which demands for an LCID-space extension or introduction of an additional identifier.

In this L2-structure, the MAC scheduler can support UE-bearer-specific QoS on the backhaul link. The L2-structure may support aggregation of UE bearers based on QoS profiles by applying the same QoS treatment to multiple UE-bearers.

Figure 8.2.5-1b shows an example of the DL L2 structure of the IAB-node for 1:1 mapping of UE access bearers to BH RLC-channels and end-to-end RLC ARQ. The reassembly step is optional, i.e., RLC SDU segments can be forwarded without waiting for the reassembly. In this L2-structure, the IAB-node performs routing decisions by selecting an RLC-outbound channel for a data unit based on this data-unit's incoming RLC-channel. The pairwise-mapping between inbound and outbound RLC-channels is configured when the RLC-channels are established.

Figure 8.2.5-2a shows an example of the DL L2 of the IAB-donor structure for 1:1 mapping of UE-access bearers to RLC-channels. In contrast to Figure 8.2.5-1a, RLC channels are multiplexed to logical channels. For the RLC-channels, a new identifier is introduced such as a UE-bearer-specific identifier. This identifier is carried on the adaptation layer.

As in the L2-structure of Figure 8.2.5-1a, the MAC scheduler can support UE-bearer-specific QoS on the backhaul link. For that purpose, the MAC scheduler has to consider the multitude of RLC-channels. It may also support mapping based on QoS profiles, e.g., by applying the same QoS treatment to multiple RLC-channels multiplexed into the same logical channel.

Figure 8.2.5-2b shows an example of the DL L2 structure of the IAB-node for 1:1 mapping of UE access bearers to BH RLC-channels, multiplexing of RLC-channels to logical channels, and end-to-end RLC ARQ. The IAB-node performs routing decisions by selecting an RLC-outbound channel for a data unit based on this data-unit's incoming RLC-channel. The RLC-channel of a data unit on an inbound link may be indicated by the UE-bearer-specific identifier carried in the Adapt header. The mapping between an RLC-channel and an outbound logical channel could be configured when the RLC-channel is established.

Figure 8.2.5-3a shows an example of the DL L2 structure of the IAB-donor for many-to-one mapping of UE access bearers to BH RLC-channels and hop-by-hop RLC ARQ. This mapping introduces an additional multiplexing step above RLC ARQ.

Figure 8.2.5-3b shows an example of the DL L2 structure of the IAB-node for many-to-one mapping of UE access bearers to BH RLC-channels.

In this L2-structure, the IAB-node performs routing decisions by selecting an outbound link for a data unit based on a route identifier or destination-node identifier carried in the Adapt header. The mapping between this route- or destination-node identifier and the outbound RLC-channel could be configured when the route is established.

8.2.6 Flow control and congestion handling

In the multi-hop backhaul, congestion may occur on intermediate IAB-nodes.

On the uplink, an intermediate IAB-node acts as a gNB-DU to child IAB-nodes and can control the amount of uplink data from child IAB-nodes and UEs by adjusting the UL grants, i.e. the current transmission/scheduling mechanisms control uplink data rate to an IAB-node. This mechanism allows mitigating congestion at the intermediate IAB-node. Additional control mechanism may be needed to handle uplink data congestion.

On the downlink, the IAB-node's link capacity to a child IAB-node or a UE may be smaller than the link capacity of a backhaul link from the parent IAB-node. The DU side of the parent IAB-node may not know the downlink buffer status of the IAB-node. As a result, the ingress data rate scheduled by the parent IAB-node's DU may be larger than the egress data rate the IAB-node's DU can schedule to its child IAB-nodes and UEs, which may result in downlink data congestion and packet discard at the intermediate IAB-node. Discarding of packets at intermediate IAB-nodes may have negative consequences (e.g. may lead to TCP slow start for impacted UE flows).

End-to-end flow control (e.g. flow control via F1-U or F1*-U) could help to address packet discard at the intermediate IAB-nodes due to the downlink data congestion problem to some extent by providing a downlink delivery status from the UE's access IAB-node DU in hop-by-hop ARQ to the IAB-donor CU. End-to-end ARQ similarly can address packet discard by intermediate IAB-nodes due to downlink data congestion. However, these mechanisms may be slow to react to local congestion problems in intermediate IAB-nodes as they do not provide information to pin point at which link/node the congestion is occurring. Thus, hop-by-hop flow control may also be required together with end-to-end congestion handling.

The congested IAB-node may provide feedback information to the parent IAB-node or the IAB-donor. Based on this feedback, the parent IAB-node or IAB-donor may perform flow control and alleviate downlink data congestion.

The flow control feedback may include the following information:

- IAB-node buffer load;
- IAB-node ID, where the congestion has occurred;
- Potentially other information.

The granularity of the feedback information can be e.g. per UE radio bearer, per RLC-channel, per backhaul link.

8.2.7 UP support of IAB-node

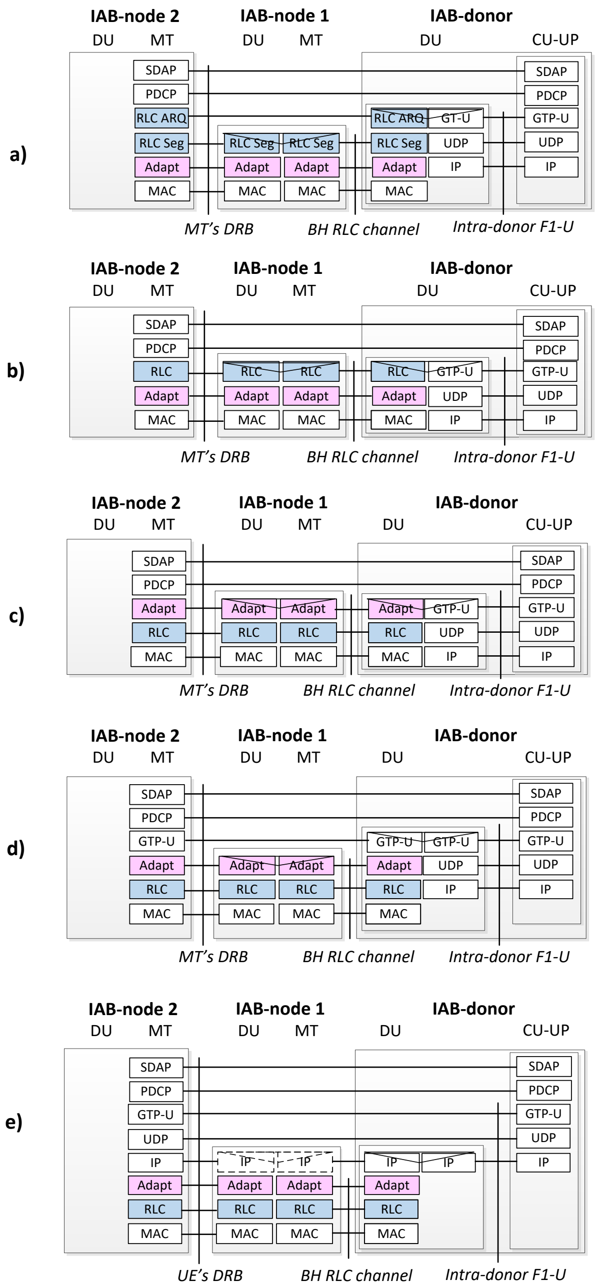

Figure 8.2.7-1: Protocol stack examples for MT-access using L2-relaying with adaptation layer for architecture 1a

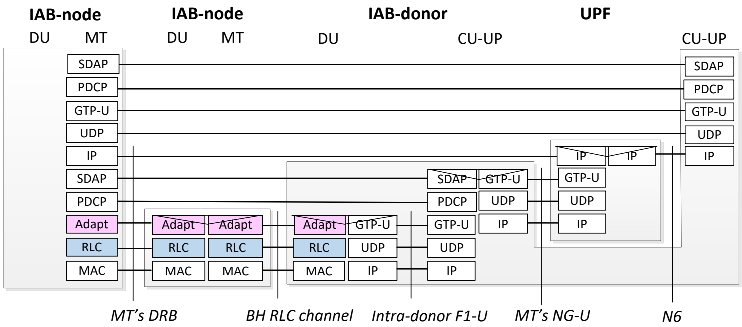

Figure 8.2.7-2: Protocol stack examples for MT-access using L2-relaying with adaptation layer for architecture 1b

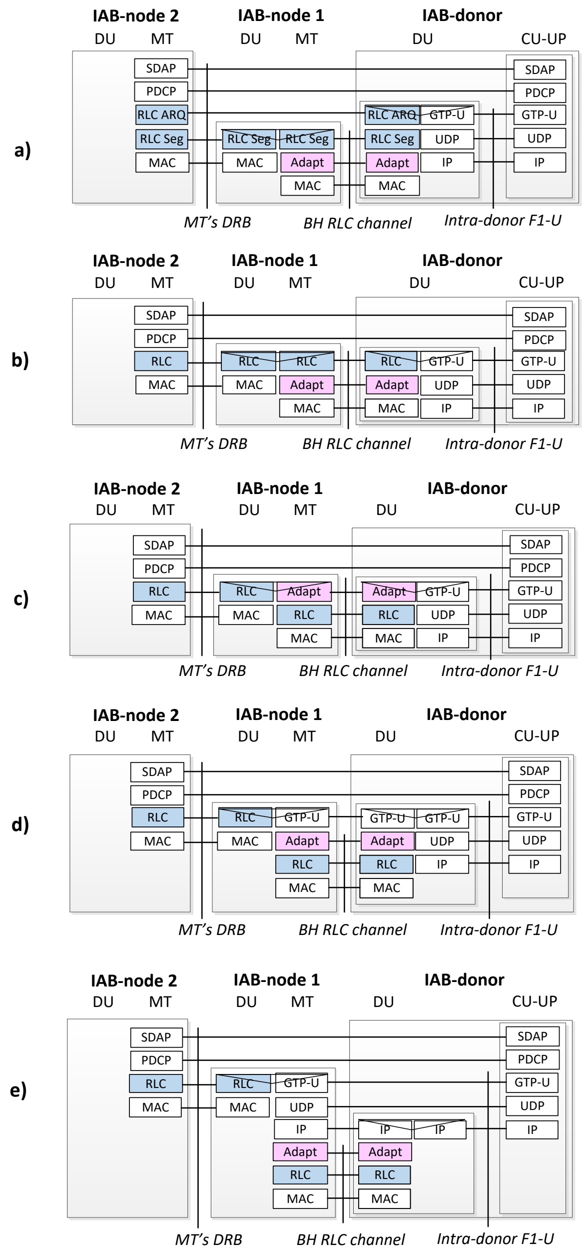

Figure 8.2.7-3: Protocol stack examples for MT-access using L2-relaying without adaptation layer for architecture 1a

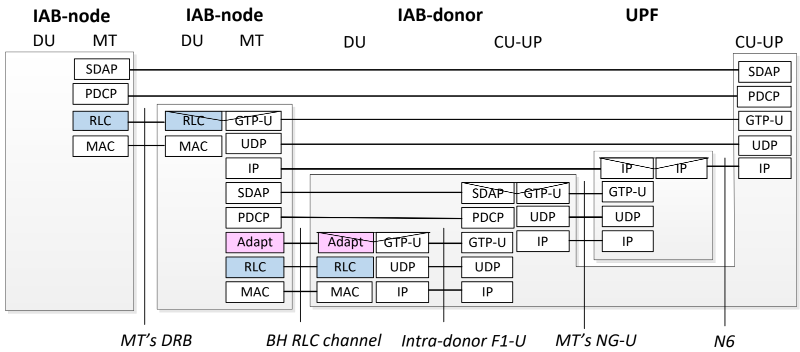

Figure 8.2.7-4: Protocol stack examples for MT-access using L2-relaying without adaptation layer for architecture 1b

The MT on the IAB-node may also have its own access traffic, e.g., for OAM support. Figures 8.2.7-1, -2, -3 and -4 show examples of protocol stacks to support MT-access traffic.

In Figures 8.2.7-1 and -2, the MT uses backhaul RLC channels to carry its own traffic. In this case, the MT's access traffic is encapsulated in F1*-U on the MT's backhaul link.

In Figures 8.2.7-3 and -4, the MT uses access RLC channels for its own traffic like a UE.

Table 8.2.7-1 shows comparisons between both options.

Table 8.2.7-1: Comparison between transport of MT's own traffic on MT's backhaul RLC channel or on access RLC channel

MT's own traffic transported on backhaul RLC channel	MT's own traffic transported on access RLC channel
1. The logical channel space is not decreased through MT access traffic.	1. Separate logical channel needs to be assigned for MT access traffic, which reduces the number of logical channels available for BH traffic.
2. Same processing rules are used for MT's access traffic and BH traffic on last hop.	2. Different processing rules are used for MT's access traffic than for BH traffic on last hop.
3. Different processing rules are used for MT-access traffic than for UE access traffic.	3. Same processing rules are used for MT access traffic and UE access traffic.
4. Additional overhead on last hop for MT's access traffic due to F1*-U.	4. No additional overhead on last hop for MT's access traffic.

8.2.8 Security protection of F1*-U

F1*-U can be security-protected via PDCP or IPsec. One example is given for each of these two options. Other options are not precluded.

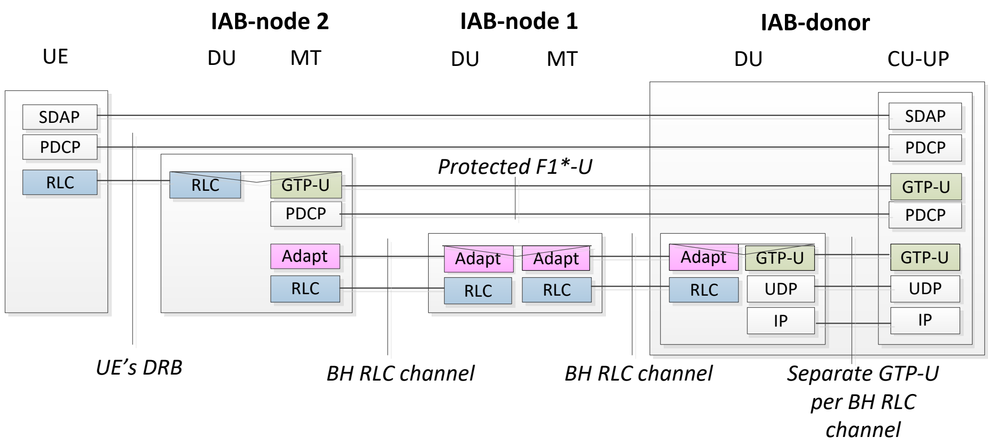

Figure 8.2.8-1: Protocol stack example for PDCP-based security protection of F1*-U

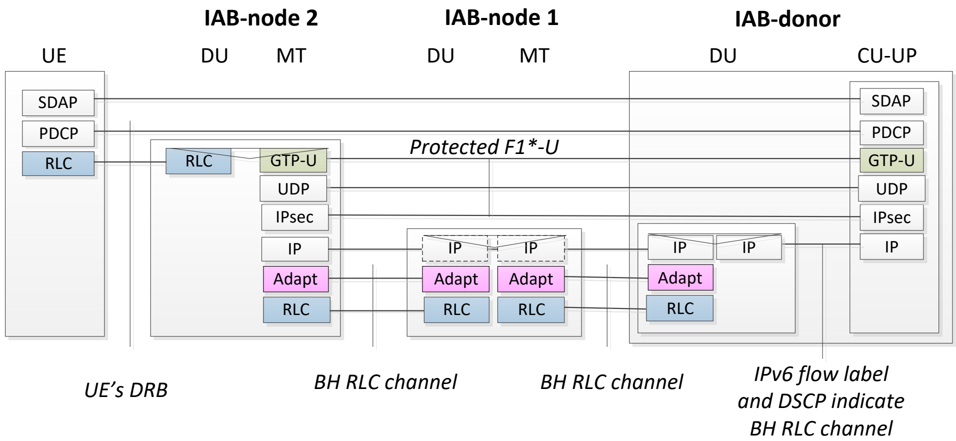

Figure 8.2.8-2: Protocol stack example for IPsec-based security protection of F1*-U

Figure 8.2.8-1 shows a protocol stack example where F1*-U is protected via PDCP. In this example, the adaptation layer is carried on top of RLC. Other options for adaptation layer placement are not precluded. The IP-termination point resides at the IAB-donor DU. This example supports the requirements of the unified design in the following manner:

- The outer GTP-U layer between CU and IAB-donor DU maps to the RLC-channel used on the wireless backhaul link;
- The inner GTP-U layer represents the UE-bearer's F1-U.

Both, 1:1 and N:1 bearer mapping can be supported by either allocating for each inner GTP-U one outer GTP-U, or by aggregating multiple inner GTP-U into one outer GTP-U.

Figure 8.2.8-2 shows a protocol stack example where F1*-U is protected via IPsec. In this example, the IP-termination point resides at the IAB-node. This example supports the requirements of the unified design in the following manner:

- The DSCP or Flow-Label value on the IPv6 header maps to the RLC-channel used on the wireless backhaul link. The IPv6 Flow Label has been designed for this purpose (IETF RFC 6294);
- The inner GTP-U layer represents the UE-bearer's F1-U.

Both, 1:1 and N:1 bearer mapping can be supported by either allocating for each GTP-U one specific Flow-Label value, or by aggregating multiple GTP-U to one DSCP or Flow-Label value.

8.2.9 Unified design for architecture group 1

The IAB architecture should support many-to-one and one-to-one bearer mappings in a common design since both mapping options provide benefits in different deployment and traffic scenarios.

This design should allow many-to-one and one-to-one bearer mappings to be used at the same time.

The design supports hop-by-hop ARQ. End-to-end ARQ is not excluded for one-to-one mapping.

The design addresses LCID-space and LCG-space limitations to support fine-granular QoS for a sufficiently large number of bearers.

8.2.10 Examples of unified design for architecture group 1

Below, two examples are provided for the unified design. Both examples use the same identifiers on the wireless backhaul, but they differ in the L2 processing of N:1 and 1:1 bearer mapping. Support for the IAB-node-MT's access traffic is not included in these examples.

8.2.10.1 Design Example 1

<u>Characteristics:</u>

- UE-bearers are N:1-mapped to RLC-channels, where N=1 is permitted;
- RLC-channels are 1:1-mapped to LCHs;
- Identification of ingress RLC-channel based on LCID;
- LCID-space extension is required to support N=1 for many bearers.

<u>Identifiers and their placement in L2 header stack:</u>

- **UE-bearer-ID** above RLC:
  - Used at IAB-donor DU for mapping to F1-U on wireless fronthaul and at UE's access IAB-node for mapping to UE's access RLC-channel.
- **IAB-node-address/IAB-node DU-address** above RLC:
  - Used on L2 for routing.
- **LCID** on MAC sub-header:
  - Used at receiver to determine ingress RLC-channel.

<u>Variants, options, optimizations:</u>

- IAB-node/IAB-donor DU may have multiple addresses, or the address may contain a route-Id for the support of multiple independent routes.

<u>Downstream processing by IAB-donor DU and IAB-node</u>

Table 8.2.10.1-1: Downstream packet processing - consolidated example 1 (red: ingress parameters; blue: egress parameters)

	IAB-donor DU	IAB-node
Ingress packet	On wireline network, packet received from CU holds: - GTP-U TEID	On BH-link, packet received from parent holds: - UE-bearer-ID - IAB-node-address - LCID

Packet processing	Node derives from packet header and lookup tables:
	- Egress link type based on GTP-U TEID:
	  - "UE-access" if UE of UE-bearer-ID is local
	  - "BH" if UE of UE-bearer-ID is remote
	- If egress link type = "UE-access", derive:
	  - Egress link based on GTP-U TEID
	  - Egress RLC channel from GTP-U TEID
	- If egress link type = "BH", derive:
	  - UE-bearer-ID and IAB-node-address based on GTP-U TEID
	  - Egress link based on IAB-node-address (routing)
	  - Egress RLC-channel based on UE-bearer-ID (N:1 bearer mapping).
	- Egress LCID based on 1:1 mapping between RLC channel and LCH.
		- Node derives from packet header and lookup tables:
		- Ingress RLC channel through 1:1 mapping from LCID
		- Egress link type based on IAB-node-address:
		  - "UE-access" if address is local
		  - "BH" if address is remote
		- If egress link type = "UE-access", derive:
		  - Egress link from UE-bearer-ID
		  - Egress RLC channel from UE-bearer-ID
		- If egress link type = "BH", derive:
		  - Egress IAB-node-address = Ingress IAB-node-address
		  - Egress link based on IAB-node-address (routing)
		  - Egress RLC channel based on ingress RLC channel and IAB-node-address (mapping between BH RLC channels)
		- Egress LCID via 1:1 mapping between RLC channel and LCH.

Egress packet	On BH link, packet transmitted to child holds: - UE-bearer-ID - IAB-node-address - LCID On UE-access link, RLC packet transmitted to UE holds: - LCID	On BH link, packet transmitted to child holds: - UE-bearer-ID - IAB-node-address - LCID On UE-access link, RLC packet transmitted to UE holds: - LCID

Upstream processing by IAB-donor DU and IAB-node

Table 8.2.10.1-2: Upstream packet processing – consolidated example 1 (red: ingress parameters; blue: egress parameters)

	IAB-donor DU	IAB-node
Ingress packet	On BH link, packet received from child holds: - UE-bearer-ID - IAB-donor DU-address - LCID On UE-access link, RLC packet received from UE holds: - LCID	On BH link, packet received from child holds: - UE-bearer-ID - IAB-donor DU-address - LCID On UE-access link, RLC packet received from UE holds: - LCID

Packet processing	Node derives from packet header content and lookup tables:
	- Ingress RLC-channel based on LCID using 1:1 mapping between RLC channel and LCH.
	- If ingress link type is "UE-access", derive:
	  - GTP-U TEID from ingress link and LCID
	- If ingress link type is "BH", derive:
	  - GTP-U TEID from UE-bearer-ID
		Node derives from packet header content and lookup tables:
		- Ingress RLC-channel based on LCID using 1:1 mapping between RLC channel and LCH.
		- If ingress link type is "UE-access", derive:
		  - UE-bearer-ID from ingress link and LCID
		  - IAB-donor DU-address based on UE-bearer-ID
		  - Egress link based on IAB-donor DU-address (routing)
		  - Egress RLC-channel based on UE-bearer-ID (N:1 bearer mapping)
		- If ingress link type is "BH", derive:
		  - Egress IAB-donor DU-address = Ingress IAB-donor DU-address
		  - Egress link based on IAB-donor DU-address
		  - Egress RLC channel based on ingress RLC channel and IAB-donor DU-address (mapping between BH RLC channels)
		- LCID via 1:1 mapping between RLC channel and LCH.

Egress packet	On wireline network, packet transmitted to CU holds: - GTP-U TEID	On BH link, packet transmitted to parent holds: - UE-bearer-ID - IAB-donor DU-address - LCID

8.2.10.2 Design Example 2

Characteristics:

- UE-bearers are either N:1 or 1:1 mapped to RLC-channels;
- Mapping of RLC-channels to LCHs:
  - For N:1 bearer mapping, RLC-channels are 1:1 mapped to LCHs;
  - For 1:1 bearer mapping, RLC-channels are K:1 mapped to LCHs ($K \geq 1$).
- Identification of ingress RLC-channel:
  - For N:1 bearer mapping, RLC-channels are identified by LCH;
  - For 1:1 bearer mapping, RLC-channels are identified by UE-bearer-ID.
- Bearer mapping type is indicated explicitly or implicitly (e.g. a set of LCIDs may be configured for N:1 mapping, the complement set for 1:1 mapping);
- LCID-space extension may not be needed.

Identifiers and their placement in L2 header stack:

- **UE-bearer-ID**
  - Used at receiver to determine ingress RLC-channel for 1:1 mapping;

  - Used at IAB-donor DU for mapping to F1-U on wireless fronthaul and at UE's access IAB-node for mapping to UE's access RLC-channel.

- **IAB-node-address/IAB-donor DU-address**

  - Used for L2 for routing.

- **LCID** on MAC sub-header:

  - Used at the MAC to multiplex/demultiplex N:1 and 1:1 bearer mapping (in case of implicit indication as shown in processing table below).

  - Used at receiver to determine ingress RLC-channel for N:1 mapping

<u>Variants, options, optimizations:</u>

- IAB-node/IAB-donor DU may have multiple addresses, or the address may contain a route-Id for the support of multiple independent routes;

- For 1:1 mapping, the UE-bearer-Id may be replaced by UE-Id + LCID.

<u>Downstream processing by IAB-donor DU and IAB-node</u>

Table 8.2.10.2-1: Downstream packet processing - consolidated example 2 (red: ingress parameters; blue: egress parameters)

	IAB-donor DU	IAB-node
Ingress packet	On wireline network, packet received from CU holds: - GTP-U TEID	On BH-link, packet received from parent holds: - UE-bearer-ID - IAB-node-address - LCID

Packet processing	Node derives from packet header and lookup tables:
	- Egress link type based on GTP-U TEID
	  - "UE-access" if UE of UE-bearer-ID is local
	  - "BH" if UE of UE-bearer-ID is remote
	- If egress link type = "UE-access", derive:
	  - Egress link and UE-bearer from GTP-U TEID
	  - Egress RLC channel from GTP-U TEID
	  - Egress LCID via 1:1 mapping between RLC channel and LCH.
	- If egress link type = "BH", derive:
	  - UE-bearer-ID and IAB-node-address based on GTP-U TEID
	  - Egress link based on IAB-node-address (routing)
	  - Egress RLC-channel based on UE-bearer-ID
	  - If bearer mapping = N:1
	    - Egress LCID based on 1:1 mapping between RLC channel and LCH.
	  - If bearer mapping = 1:1:
	    - Egress LCID based on K:1 mapping between RLC channels and LCH.
		Node derives from packet header and lookup tables:
		- Determination of N:1 vs. 1:1 bearer mapping based on LCID.
		- If "N:1 bearer mapping":
		  - Ingress RLC channel through 1:1 mapping from LCID
		- If "1:1 bearer mapping":
		  - Ingress RLC channel based on combination of UE-bearer-ID + LCID
		- Egress link type based on IAB-node-address:
		  - "UE-access" if address is local
		  - "BH" if address is remote
		- If egress link type = "UE-access", derive:
		  - Egress link and UE-bearer from UE-bearer-ID
		  - Egress RLC channel from UE-bearer-ID
		  - Egress LCID via 1:1 mapping between RLC channel and LCH.
		- If egress = "BH", derive:
		  - Egress IAB-node-address = Ingress IAB-node-address
		  - Egress link based on IAB-node-address (routing)
		  - If bearer mapping = N:1:
		    - Egress RLC channel based on ingress RLC channel and IAB-node-address (mapping between BH RLC channels)
		    - Egress LCID via 1:1 mapping between RLC channel and LCH.
		  - If bearer mapping = 1:1:
		    - Egress RLC-channel based on ingress RLC-channel (mapping is implicit, since for 1:1 mapped bearers we can consider ingress and egress RLC channels to be the same RLC-channel)
		    - Egress LCID via K:1 mapping between RLC channel and LCH.

Egress packet	On BH link, packet transmitted to child holds: - UE-bearer-ID - IAB-node-address - LCID On UE-access link, RLC packet transmitted to UE holds: - LCID	On BH link, packet transmitted to child holds: - UE-bearer-ID - IAB-node-address - LCID On UE-access link, RLC packet transmitted to UE holds: - LCID

<u>Upstream processing by IAB-donor DU and IAB-node</u>

Table 8.2.10.2-2: Upstream packet processing - consolidated example 2 (red: ingress parameters; blue: egress parameters)

<table>
<tr><th></th><th>IAB-donor DU</th><th>IAB-node</th></tr>
<tr><td>Ingress packet</td><td>On BH link, packet received from child:
- UE-bearer-ID
- Donor-DU-address
- LCID
On UE-access link, RLC packet received from UE holds:
- LCID</td><td>On BH link, packet received from child holds:
- UE-bearer-ID
- IAB-node-address
- LCID
On UE-access link, RLC packet received from UE holds:
- LCID</td></tr>
<tr><td>Packet processing</td><td>Node derives from packet header content and lookup tables:
- If ingress link type is "UE-access", derive:
  - GTP-U TEID from ingress link and LCID
- If ingress link type is "BH", derive:
  - N:1 vs. 1:1 bearer mapping based on LCID.
  - If "N:1 bearer mapping":
    - Ingress RLC channel based on LCID using 1:1 mapping between RLC channel and LCH.
  - If "1:1 bearer mapping":
    - Ingress RLC channel based on combination of UE-bearer-ID + LCID
    - GTP-U TEID from UE-bearer-ID</td><td>Node derives from packet header content and lookup tables:
- If ingress link type = "UE-access", derive:
  - UE-bearer-ID from ingress link and LCID.
  - IAB-donor DU-address based on UE-bearer-ID
  - Egress link based on IAB-donor DU-address (routing)
  - Egress RLC-channel based on UE-bearer-ID (N:1 bearer mapping)
  - Egress LCID via 1:1 mapping between RLC channel and LCH.
- Determination of N:1 vs. 1:1 bearer mapping based on LCID.
  - If "N:1 bearer mapping":
    - Ingress RLC channel through 1:1 mapping from LCID
  - If "1:1 bearer mapping":
    - Ingress RLC channel based on combination of UE-bearer-ID + LCID
- If ingress = "BH", derive:
  - Egress IAB-donor DU-address = Ingress IAB-donor DU-address
  - Egress link based on IAB-donor DU-address
  - If bearer mapping = N:1:
    - Egress RLC channel based on ingress RLC channel and IAB-donor DU-address (mapping between BH RLC channels).
    - Egress LCID via 1:1 mapping between RLC channel and LCH.
  - If bearer mapping = 1:1:
    - Egress RLC-channel based on ingress RLC-channel (mapping is implicit, since for 1:1 mapped bearers we can consider ingress and egress RLC channels to be the same RLC-channel).
    - Egress LCID via K:1 mapping between RLC channel and LCH.</td></tr>
<tr><td>Egress packet</td><td>On wireline network, packet transmitted to CU holds:
- UE-bearer-ID = GTP-U TEID</td><td>On BH link, packet transmitted to parent holds:
- UE-bearer-ID
- IAB-donor DU-address
- LCID</td></tr>
</table>

8.3 Control-plane considerations for architecture group 1

8.3.1 Routing and QoS enforcement for CP signaling

CP signaling across wireless backhaul-link uses the same routing and QoS enforcement mechanisms as defined for UP traffic.

NOTE The priority and QoS requirements of the CP signaling can be different from the UP traffic.

8.3.2 CP signaling protocols

Signaling between the MT on an IAB-node and the CU-CP on the IAB-donor uses RRC protocol.

Signaling between DU on an IAB-node and the CU-CP on the IAB-donor uses F1-AP protocol.

IAB specific enhancements to RRC and F1-AP are not precluded

8.3.3 Control plane transport requirements

The following essential functionalities are required for transporting of control plane messages between the donor CU and IAB DUs over the IAB backhaul network:

- Reliable transport;
- In-order delivery;
- Security.

Other aspects that can be studied further include (this list is not exhaustive):

- how to achieve low bounded latency (e.g. by avoiding head of line blocking);
- route redundancy;
- minimizing impact to existing F1-AP procedures;
- overhead of transport solution, both in terms of headers and control aspects to setup/maintain transport.

8.3.4 CP signaling security protection

RRC and F1-AP connections are secured over the wireless backhaul links.

The RRC connection has at least the same level of protection on the wireless backhaul link as on the access link.

The baseline assumption is that the F1-AP connection has at least the same level of protection on the wireless backhaul link as the RRC connection.

NOTE: SA3 has to confirm whether the same level of protection for F1-AP as for RRC is acceptable or whether new requirements are needed.

The following protocols are used for CP signaling protection:

- PDCP is used to protect RRC.
- PDCP is baseline to protect F1-AP over the wireless backhaul.
    - Other solutions (e.g. based on using NDS) are not precluded for F1-AP protection.

8.3.5 CP alternatives for architecture 1a

In architecture 1a, the UE's and the MT's UP and RRC traffic can be protected via PDCP over the wireless backhaul. A mechanism has to be defined to also protect F1-AP traffic over the wireless backhaul.

The following five alternatives can be considered. Other alternatives are not precluded.

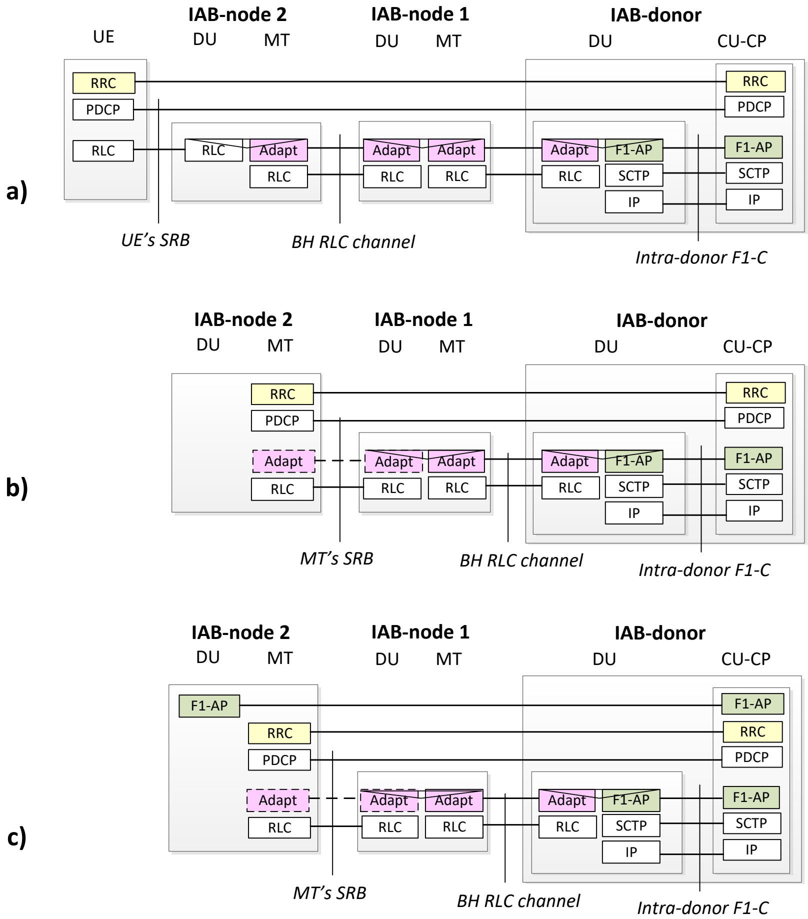

Figure 8.3.5-1: Example for alternative 1 of architecture 1a. 1a: UE's RRC, 1b: MT's RRC, 1c: DU's F1-AP

Alternative 1:

Figure 8.3.5-1 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for alternative 1. In these examples, the adaptation layer is placed on top of RLC. On the IAB-node's access link, the adaptation layer may or may not be included. The example does not preclude other options. This alternative has the following main features:

- The UE's and the MT's RRC are carried over SRB;
- On the UE's or MT's access link, the SRB uses an RLC-channel;
- On the wireless backhaul links, the SRB's PDCP layer is carried over RLC-channels with adaptation layer. The adaptation layer placement in the RLC channel is the same for C-plane as for U-plane. The information carried on the adaptation layer may be different for SRB than for DRB;
- The DU's F1-AP is encapsulated in RRC of the collocated MT. F1-AP is therefore protected by the PDCP of the underlying SRB;
- Within the IAB-donor, the baseline is to use native F1-C stack (see section 9);
- The following essential control plane functionalities are supported:
    - Reliable transport: via RLC over the wireless backhaul;
    - In-order delivery: via PDCP;
    - Security: via PDCP.

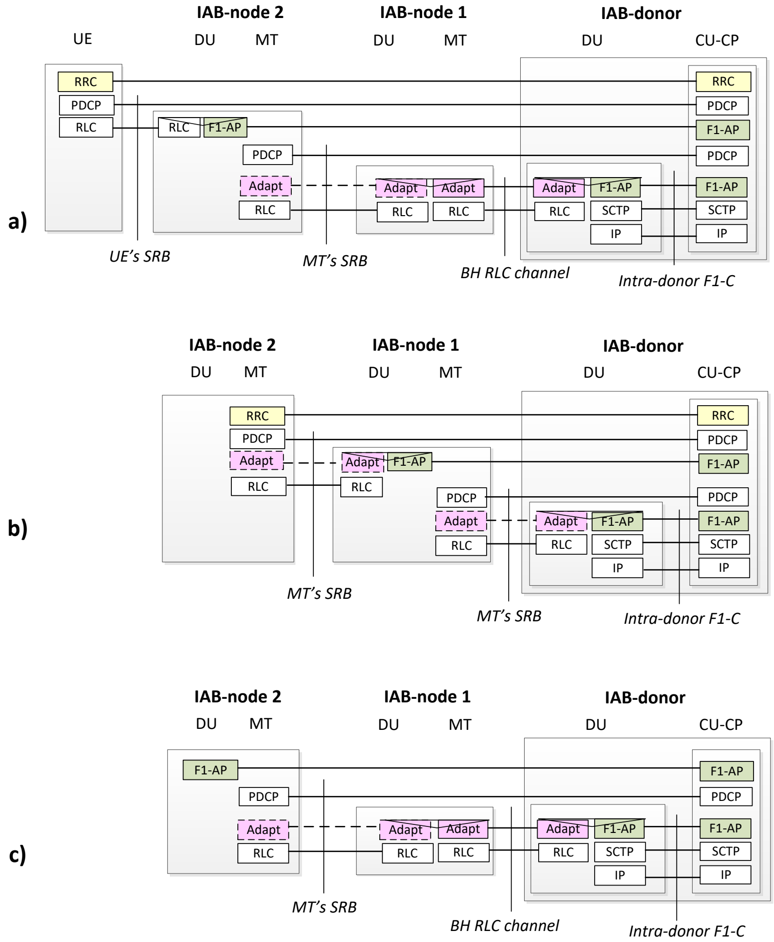

Figure 8.3.5-2: Example for alternative 2 of architecture 1a. 2a: UE's RRC, 2b: MT's RRC, 2c: DU's F1-AP

Alternative 2:

Figure 8.3.5 - 2 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for alternative 2. In these examples, the adaptation layer resides on top of RLC. On the IAB-node's access link, the adaptation layer may or may not be included. The example does not preclude other options. This alternative has the following main features:

- The UE's and the MT's RRC are carried over SRB;
- On the UE's or MT's access link, the SRB uses an RLC-channel;
- On the wireless backhaul link, the PDCP of the RRC's SRB is encapsulated into F1-AP;
- The DU's F1-AP is carried over an SRB of the collocated MT. F1-AP is protected by this SRB's PDCP;
- On the wireless backhaul links, the PDCP of the F1-AP's SRB is carried over RLC-channels with adaptation layer. The adaptation layer placement in the RLC channel is the same for C-plane as for U-plane. The information carried on the adaptation layer may be different for SRB than for DRB;
- Within the IAB-donor, the baseline is to use native F1-C stack (see section 9);
- The following essential control plane functionalities are supported:
  - Reliable transport: via RLC over the wireless backhaul;
  - In-order delivery: via PDCP;
  - Security: via PDCP.

NOTE: For CP Alternative 2, in order to carry F1-AP over an SRB, due to conventional RRC operation RRC encapsulation of F1-AP may be required.

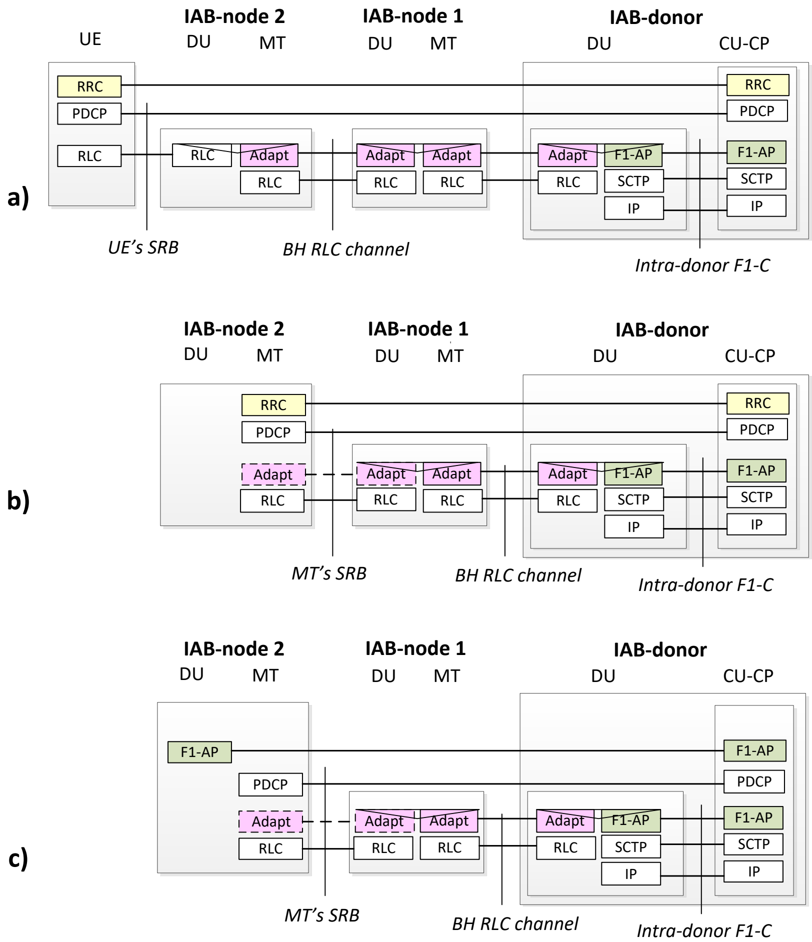

Figure 8.3.5-3: Example for alternative 3 of architecture 1a. 3a: UE's RRC, 3b: MT's RRC, 3c: DU's F1-AP

Alternative 3:

Figure 8.3.5 - 3 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for alternative 3. In these examples, the adaptation layer resides on top of RLC. On the IAB-node's access link, the adaptation layer may or may not be included. The example does not preclude other options. This alternative has the following main features:

- The UE's and the MT's RRC are carried over SRB;
- On the UE's or MT's access link, the RRC's SRB uses an RLC-channel. On the wireless backhaul links, the SRB's PDCP layer is carried over RLC-channels with adaptation layer. The adaptation layer placement in the RLC channel is the same for C-plane as for U-plane. The information carried on the adaptation layer may be different for SRB than for DRB;
- The DU's F1-AP is also carried over an SRB of the collocated MT. F1-AP is protected by this SRB's PDCP;
- On the wireless backhaul links, the PDCP of the SRB is also carried over RLC-channels with adaptation layer;
- Within the IAB-donor, the baseline is to use native F1-C stack (see section 9);
- The following essential control plane functionalities are supported:
  - Reliable transport: via RLC over the wireless backhaul;
  - In-order delivery: via PDCP;
  - Security: via PDCP.

a)

b)

c)

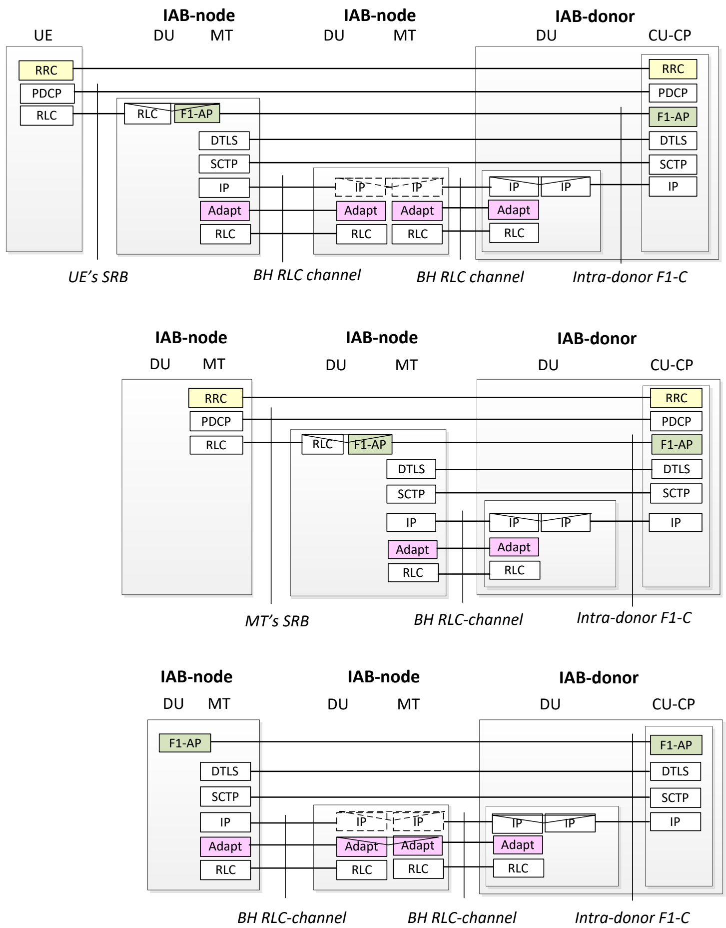

Figure 8.3.5-4: Example for alternative 4 of architecture 1a. 4a: UE's RRC, 4b: MT's RRC, 4c: DU's F1-AP

Alternative 4:

Figure 8.3.5 - 4 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for alternative 4. In these examples, the adaptation layer resides on top of RLC and carries an IP-layer as discussed in section 8.2.2. This alternative has the following main features:

- The IP-layer carried by adapt is connected to the fronthaul's IP-plane through a routing function at the IAB-donor DU. On this IP-layer, all IAB-nodes hold IP-addresses, which are routable from the IAB-donor CU-CP;
- For deployments with IPv6, IP address assignment to the IAB-node could be based on IPv6 Neighbour Discovery Protocol where the DU act as an IPv6 router sending out ICMPv6 Router Advertisement over one or more backhaul bearer towards the IAB-node. The IP address may also be assigned by the CU-CP via RRC. Other methods are not excluded;
- The extended IP-plane allows native F1-C to be used between IAB-node DU and IAB-donor CU-CP. Signalling traffic can be prioritized on this IP routing plane using DSCP markings in compliance with TS 38.474 [4];
- F1-C is protected via NDS, e.g. via D-TLS, as established by S3-181838;
- The UE's and the MT's RRC use SRB, which is carried over F1-C in compliance with TS 38.470 [5];
- The following essential control plane functionalities are supported:
    - Reliable transport: via SCTP;
    - In-order delivery: via SCTP;
    - Security: via NDS.

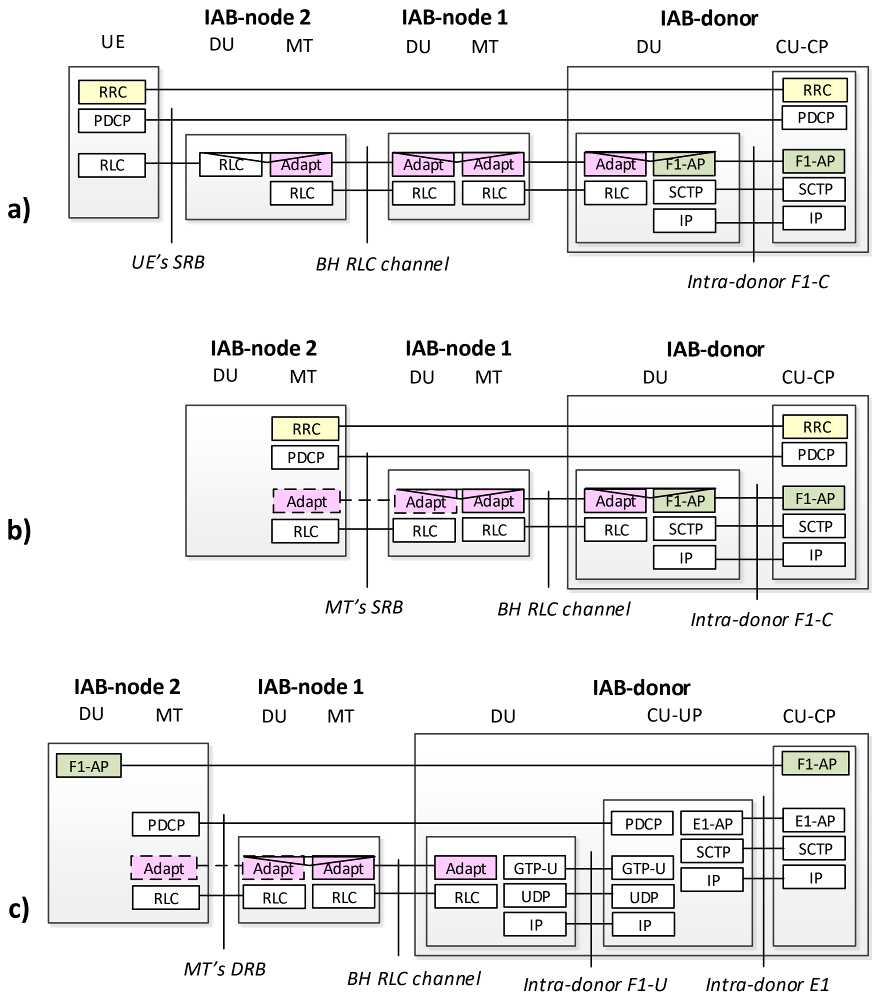

Figure 8.3.5-5: Example for alternative 5 of architecture 1a. 5a: UE's RRC, 5b: MT's RRC, 5c: DU's F1-AP

Alternative 5:

Figure 8.3.5-5 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for alternative 5. In these examples, the adaptation layer is placed on top of RLC. On the IAB-node's access link, the adaptation layer may or may not be included. The example does not preclude other options. This alternative has the following main features:

- The UE's and the MT's RRC are carried over SRB.
- On the UE's or MT's access link, the SRB uses an RLC-channel.
- On the wireless backhaul links, the SRB's PDCP layer is carried over RLC-channels with adaptation layer. The adaptation layer placement in the RLC channel is the same for C-plane as for U-plane. The information carried on the adaptation layer may be different for SRB than for DRB.
- The DU's F1-AP is carried over a DRB. F1-AP is therefore protected by this DRB's PDCP.
- Within the IAB-donor, the baseline is to use native F1-U stack. The DU's F1-AP is carried over E1 interface.
- The following essential control plane functionalities are supported:
  - Reliable transport: via RLC over the wireless backhaul;
  - In-order delivery: via PDCP;
  - Security: via PDCP.

Summary:

For Encapsulation (for relaying RRC messages):

- Without F1-AP Encapsulation: The IAB-node doesn't use F1-AP to carry UE's RRC/MT's RRC. The IAB-node maps UE's RRC/MT's RRC directly on RLC-channels;
- Using F1-AP Encapsulation: The IAB-node uses F1-AP to carry UE's RRC/MT's RRC. The IAB-node encapsulates UE's RRC/MT's RRC with F1-AP RRC message containers;
- Using F1-AP Encapsulation with SCTP/IP: The IAB-node uses F1-AP to carry UE's RRC/MT's RRC. In addition, the IAB-node uses SCTP/IP for adaptation layer.

For Using DRB or SRB for transmission of CP signaling (F1-AP mapping on PDCP entity):

- Encapsulated in RRC of the collocated MT: The IAB-node encapsulates DU's F1-AP. F1-AP is protected by the PDCP of the underlying SRB;
- Carried via SRB: The IAB-node uses another SRB to carry DU's F1-AP without encapsulation in RRC;
- Carried over native F1-C: The IAB-node uses native F1-C format to carry DU's F1-AP;
- Carried over DRB: The IAB-node uses a DRB to carry DU's F1-AP.

For Security of F1-AP:

- Via PDCP: F1-AP is protected by the PDCP;
- Via DTLS: F1-AP is protected by the DTLS.

The comparison analysis of the five CP alternatives are provided in the Table 10.2-1. More comparison aspects are not excluded.

Only CP alternatives 2 and 4 are considered further in this study.

NSA operation:

In CP alternatives where the IAB-node potentially uses an SRB to carry F1-AP to the IAB-donor, when the IAB-node operates in SA with NGC (described as "Option a" and "Option b" in Section 6.1.2), the SRB uses the NR air interface. In case the IAB-node operates in NSA with EPC (described as "Option c" in Section 6.1.2), for those CP alternatives the SRB may be carried over the LTE air interface.

For downlink, the IAB-donor CU could send the RRC message for the IAB-node MT to MeNB first via X2AP RRC transfer message. And then, the MeNB could send the RRC message received in the X2AP RRC transfer message to the corresponding IAB-node MT. However, X2AP RRC transfer message is not used for DL RRC message transfer in the current specification.

8.3.6 Control Signalling to BH-RLC-Channel mapping for architecture 1a

In this section, only CP alternatives 2 and 4 are considered for the control signaling mapping. In both alternatives,-the control signaling to BH RLC channel mapping can be considered as mapping of MT terminated SRBs to BH RLC Channels. The following two options can be considered:

Option 1: One-to-one mapping

In this option, the BH RLC channel is specific to MT's SRB. Thus, the number of BH RLC channels used for transport of UE/MT's SRBs is the same as the number of UE/MT's SRBs. There is no need to multiplex UE/MT's SRB. Furthermore, each BH RLC channel is mapped onto a separate BH RLC channel on the next hop.

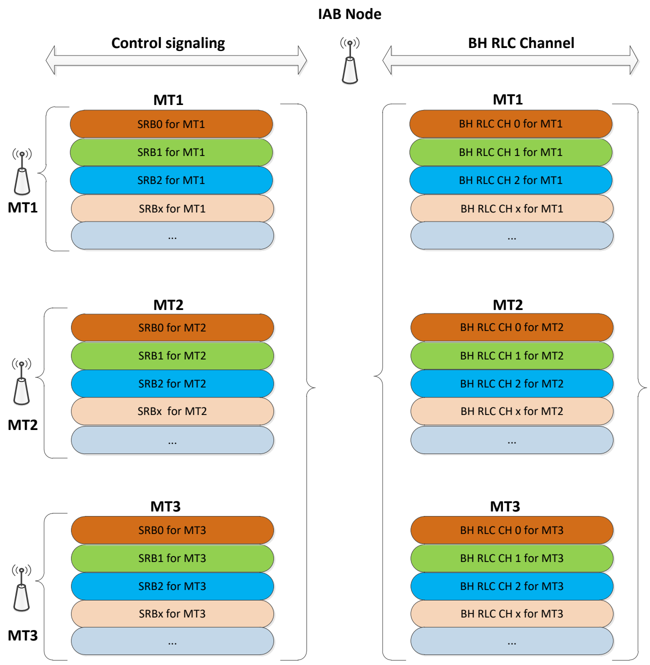

Figure 8.3.6-1: Example of one-to-one mapping between MT's SRBs and BH RLC-Channel(s)

Option 2: many-to-one mapping

In this option, several MT's SRBs (e.g., MT's SRBs with same priority, or MT's SRBs with different priorities) are multiplexed onto a single BH RLC channel. Specifically, MT's SRBs with same priority level are multiplexed onto a single BH RLC channel over all the hops. Thus, the number of BH RLC channels required depends on the set of MT' SRBs. For example, if we have a set of three SRBs, i.e. SBR0, SRB1, and SRB2, then many-to-one mapping needs only three BH RLC channels on all the hops. Furthermore, the MT SRBs mapped to different BH RLC channels on one hop may be mapped onto the same BH RLC channel on the next hop.

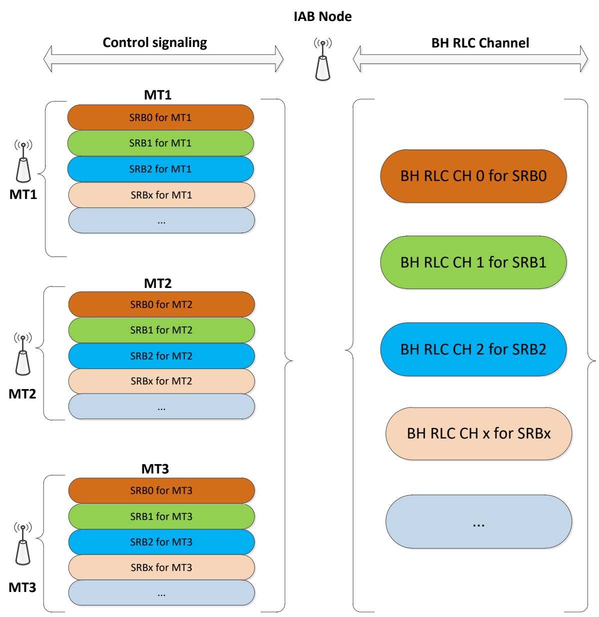

Figure 8.3.6-2: Example of many-to-one mapping between MT's SRB and BH RLC-Channel(s)

8.3.7 CP alternatives for architecture 1b

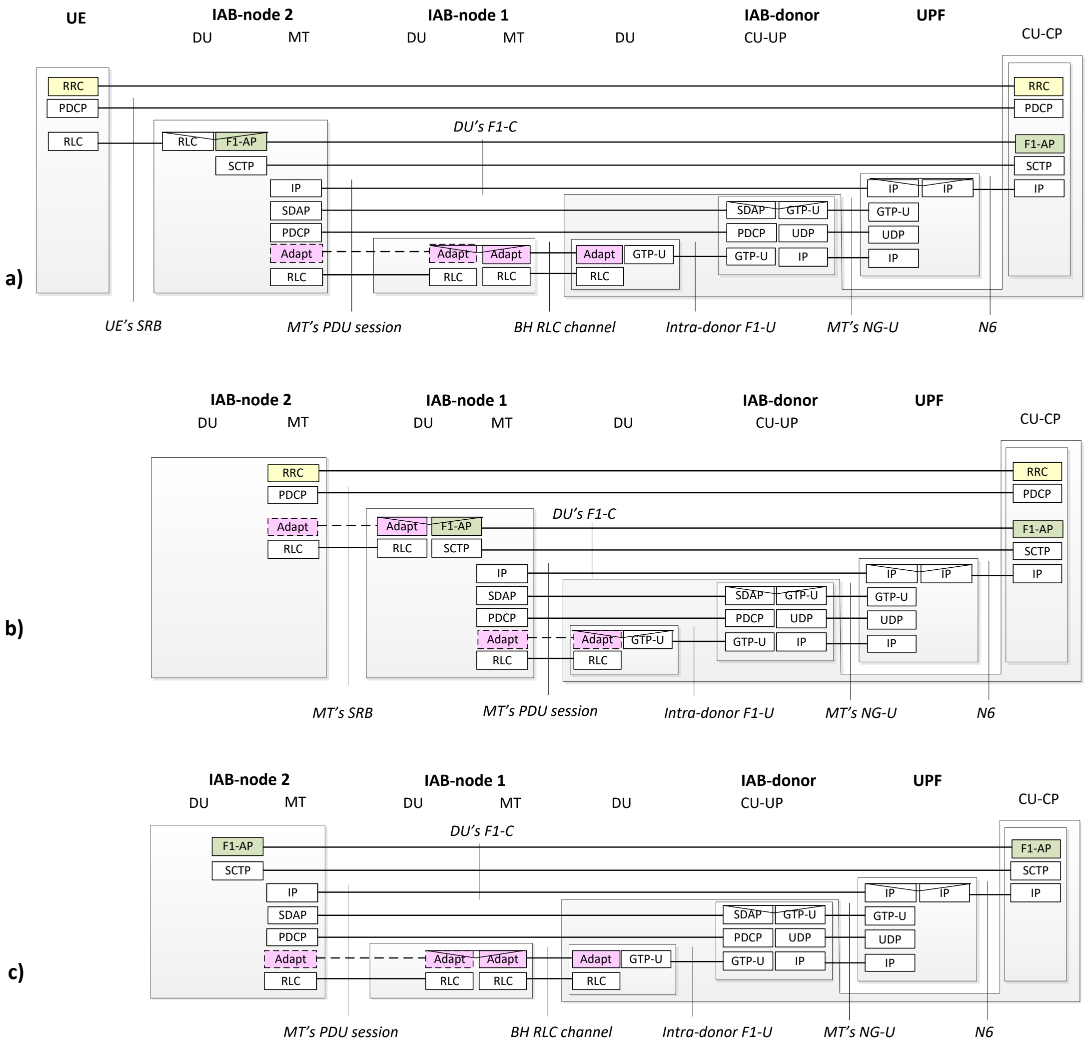

Figure 8.3.7-1: RRC and F1-AP for architecture 1b. 4a: UE's RRC, 4b: MT's RRC, 4c: DU's F1-AP

Figure 8.3.7-1 shows protocol stacks for UE's RRC, MT's RRC and DU's F1-AP for architecture 1b. In these examples, the adaptation layer carrying the DRB's PDCP resides on top of RLC. On the IAB-node's access link, the adaptation layer may or may not be included. The example does not preclude other options.

For architecture 1b, the UE's or MT's RRC is carried over SRB. On the wireless backhaul, this SRB's PDCP is carried over native F1-C.

The DUs on IAB-node and IAB-donor use native F1-C stack.

- Over the wireless backlinks, the IP-layer of this native F1-C stack is provided by a PDU-session. This PDU-session is established between the MT collocated with the DU and a UPF.

- The PDU-session is carried by a DRB between the MT and the CU-UP. Between CU-UP and UPF, the PDU-session is carried via NG-U.

- IP transport between UPF and CU-CP is provided by the PDU-session's DN. The baseline assumption is that this transport is protected.

NOTE: SA3 may evaluate requirements on the protection of F1-C transport across the DN between UPF and CU-CP.

8.4 User-plane considerations for architecture group 2

8.4.1 General

An MT component in each IAB-node establishes a Connectivity Service to transport a payload over an IAB hop. Each PDU session is terminated at the next upstream hop in a simplified UPF that supports packet forwarding/routing and minimal other functions. Connectivity services over IAB hops may be concatenated to support multi-hop scenarios. Donors may have a DU/CU split, so IAB PDU Sessions setup from IAB-nodes directly connected to the Donor may use a centrally located CU and UPF, as would be typical for a UE without IAB. Similarly, an IAB-node may use a DU to serve UEs. For IAB-nodes connected to upstream IAB-nodes, a CU and UPF in the upstream node are used. The chained connectivity services are capable of transporting packets containing any payload, including N1, N2, N3, N4, Xn, F1, N3, OA&M, Wi-Fi Ethernet, LTE S1 or other packets, as the IAB PDU Sessions are independent of the "Application" transported by the IAB-node MT.

8.4.2 User-plane protocol stack

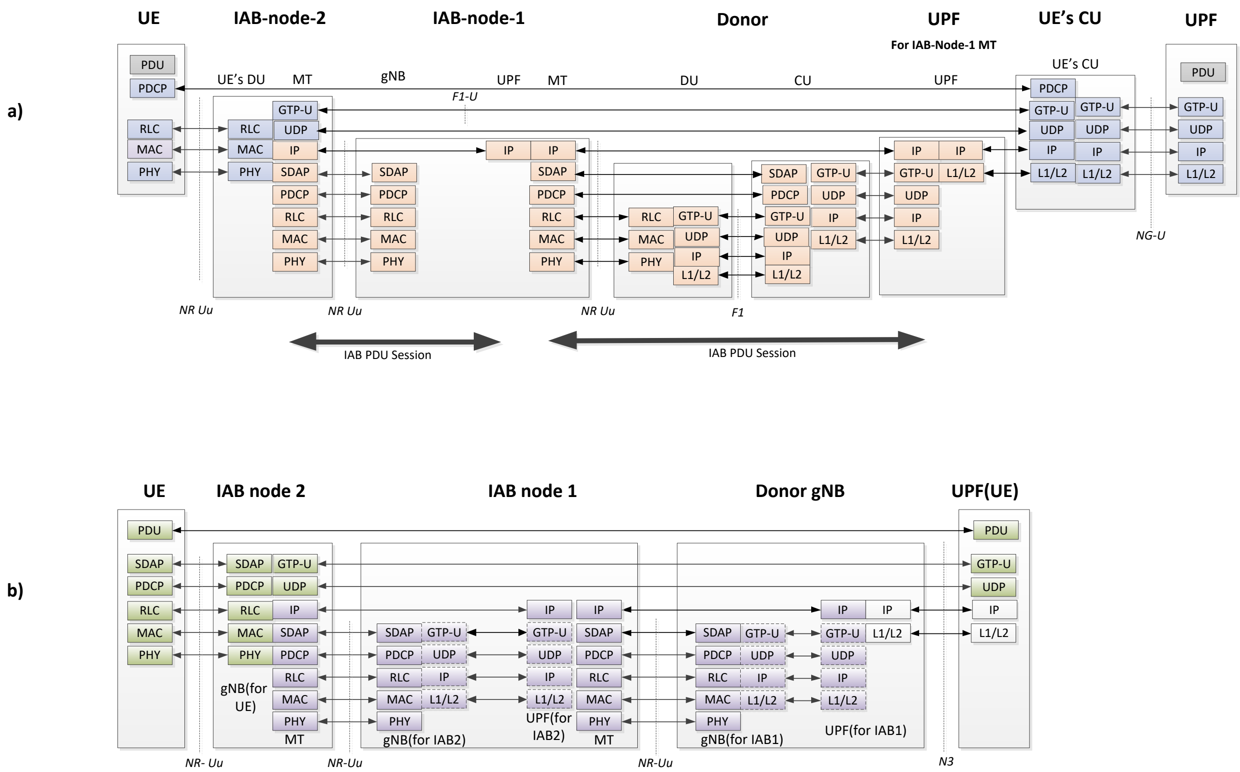

Figure 8.4.2-1: Protocol stack example showing transport of NR UE U-plane for Architecture 2a

In Figure 8.4.2-1, some examples of the architecture 2a user plane protocol stacks are shown for the transport of NR access.

For Option a), the following are key attributes of the protocol

1. The example shows a DU/CU split in the IAB-node serving the UE. F1-U is transported from IAB-Node-2, and both directly connected UEs and IAB-node MTs may use a common gNB in an upstream IAB-node.

2. IAB-nodes at intermediate hops (e.g.: IAB-node 1) may also contain a DU to serve directly connected UEs, similar to the DU in IAB-node 2, In this case a single IAB-node MT may relay both F1-U and NG-U between their respective tunnel endpoints. Methods to ensure that IAB-node MTs access only the gNB and UEs only the DU require further investigation. Network/RAN slicing, use of private networks and mechanisms similar to 4G Closed Subscriber Groups are options to investigate.

3. If the MT PDU session F1-U header does not require protection, hop-by-hop PDCP layer encryption may be deactivated for the example protocol stack as user plane data are protected by PDCP between the UE and the UE's CU.

For Option b), the UE's serving IAB-node (IAB-node 2) behaves as a full stack gNB towards the UE in access link, and the UE related NG interface terminates (e.g., N3 connection of user plane) at IAB-node 2. The N3 interface for the UE is carried over hop-by-hop PDU sessions for the MT part of each intermediate IAB-node. If we take the assumption that the PDU session type for IAB is IP, the routing of UE's N3 packets across intermediate IAB-nodes and DgNB is IP layer based. Thus, the intermediate IAB-node needs to fulfil 3 different roles; gNB for child node, UPF for child node, and MT for parent node. The 3 parts should be conceptually interconnected by some internal interfaces, e.g. internal N3 interface, etc. Protocol stacks designed for NR Uu interface can be reused in the backhaul interface (i.e., interface between IAB-nodes, interface between IAB-node and DgNB, etc.

For both option a) and b):

1. Packets are forwarded through the IAB topology based on the IP packet header (eg: GTP tunnel destination IP address). This means reusing usual routing tables one would normally have with wired backhaul. The Donor CU may configure routes via C-plane or U-plane signaling.

2. Multiple UEs may be aggregated by the IAB-node MT onto a PDU Session and transported transparently. IAB-node MTs may setup separate PDU Sessions to transport traffic of different types (e.g.: U-plane, C-plane, OA&M). IAB PDU sessions may be setup for UE traffic with specific QoS requirements, or UE traffic with different QoS requirements may be differentiated via QFI markings within a PDU session.

8.5 Control-plane considerations for architecture group 2

8.5.1 General

This section describes the C-plane for architecture 2a. All C-plane signaling is carried over IAB hops by the IAB PDU session user plane. Hence the IAB transport layers are unchanged from the U-plane and are identical for all C-plane stacks. Variation among C-plane protocol stacks is due solely to the content transported.

As with the U-plane, a connectivity service is setup by a MT component in each IAB-node to transport the control plane payload over each hop. Also, like the UE U-plane, the IAB PDU sessions are terminated in simplified UPFs that support packet forwarding/routing and minimal other functions. Connectivity services over IAB hops may be concatenated to support multi-hop scenarios. In the first example shown in the next section, IAB PDU Session setup from IAB-nodes directly connected to the IAB-donor may use a CU and a centrally located UPF. The UE serving IAB-node uses a DU to serve directly connected UEs. In the second example, at each hop a full gNB is used to serve both users and downstream IAB-node MTs.

8.5.2 Control Plane Protocol Stacks

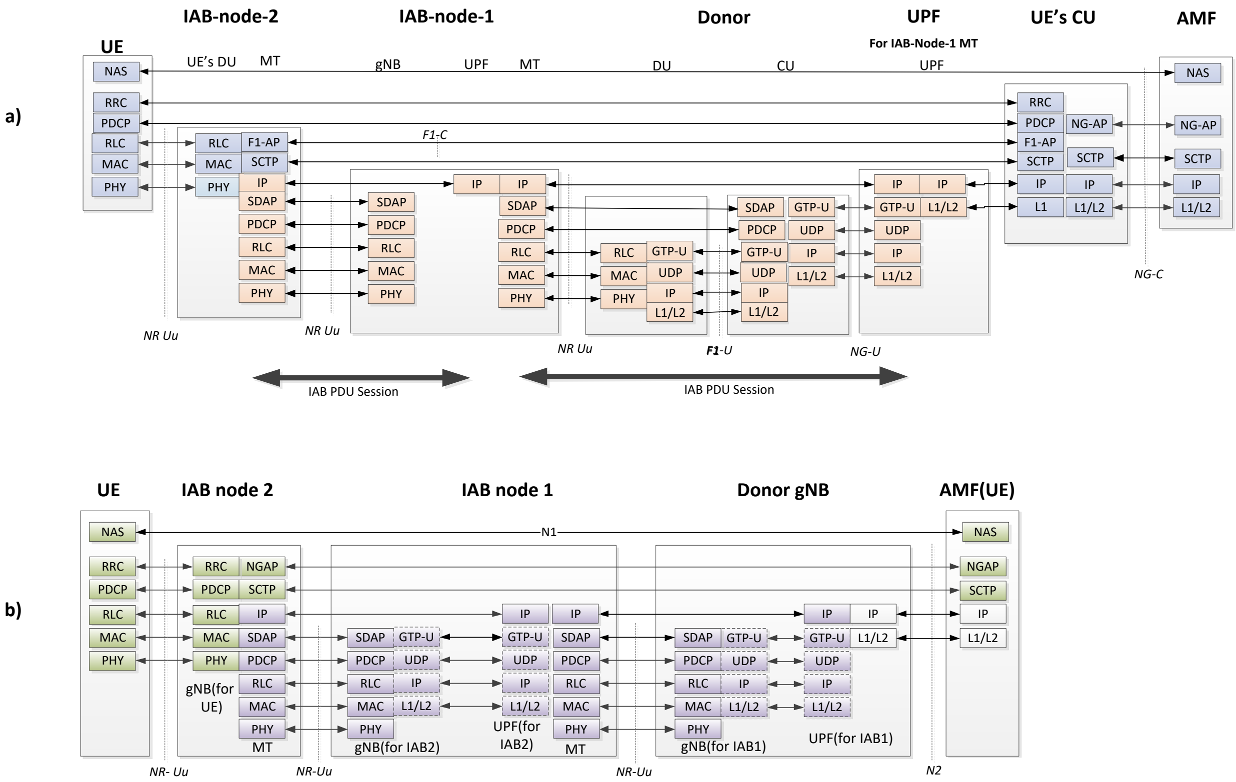

Figure 8.5.2-1: Protocol Stack examples showing transport of NR UE C-plane for Architecture 2a

In Figure 8.5.2-1, examples for the architecture-2a UE C-plane protocol stacks are shown. In Option a), the UE C-plane-related layers are colored in gray while U-plane layers specific to IAB transport are shown in orange. NAS and RRC are transported over the UE-serving IAB-node's F1 interface as would be the case without IAB. F1-C from the DU is carried over the IAB transport layers, which are identical to those used for U-plane transport.

For Option b), IAB-node 2 behaves as fully functional gNB and provides all the CP-related layers (including RRC, PDCP, RLC, MAC, PHY) of the Uu interface towards a UE. The N2 interface corresponding to the UE is terminated at IAB-node 2, and such N2 interface is carried over hop-by-hop PDU sessions for the MT part of each intermediate IAB-node, just like the UE related N3 interface. Thus, the N2 messages between IAB-node 1 and the AMF serving the UE will also be forwarded by the Donor gNB and IAB-node 1 according to IP-layer-based routing. The UP protocol stack designed for Uu interface will be reused for backhaul links, which means that CP messages need to be carried via DRBs on backhaul links.

Some variants of L3 relaying solutions are also possible for architecture 2a. For example, a kind of proxy node may be introduced inside the intermediate IAB-nodes and the Donor gNB to provide a hop-by-hop NG proxy function between the UE's serving IAB-node and NGC nodes. Such a solution enables UE-related NG contexts to be known by all intermediate nodes, and it could facilitate QoS guarantees across intermediate hops.

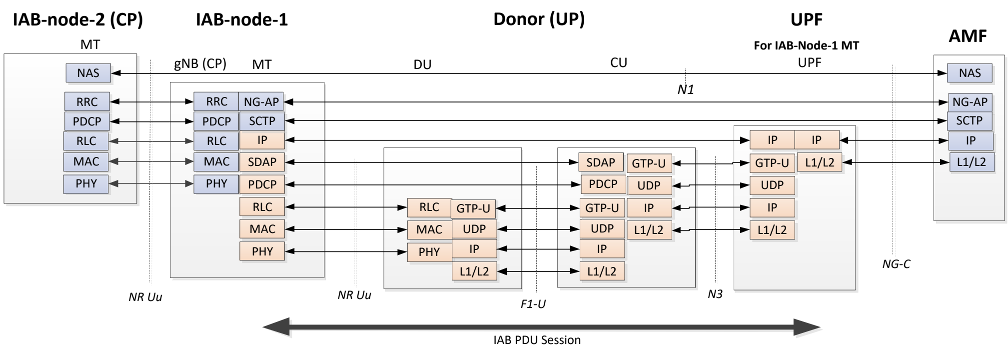

Figure 8.5.2-2: Protocol Stack example showing transport of IAB-node MT C-plane for Architecture 2a

Figure 8.5.2-2 shows an example of the architecture-2a IAB-mode MT C-plane. IAB-node MT C-plane-related layers are colored gray while U-plane layers specific to IAB transport are shown in orange. IAB-node-2's NAS and RRC are transported over the user plane of IAB-node 1.

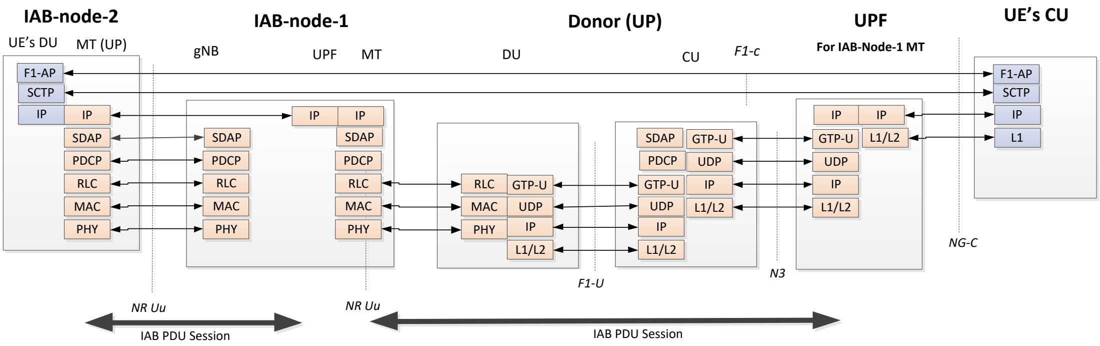

Figure 8.5.2-3: Protocol Stack example showing transport of IAB-node DU C-plane (F1-C) for Architecture 2a

Figure 8.5.2-3 shows an example of the architecture-2a IAB-node-DU's C-plane (F1-C). IAB DU and CU control plane layers are colored gray while U-plane layers specific to IAB transport are shown in orange. IAB-node-2's F1-C is transported over the U-plane by the chained PDU sessions between IAB-node-2 and IAB-node-1, and between IAB-node-1 and the UPF upstream of the IAB-donor.

8.5.3 Other aspects

Following are some further control plane aspects which need to be considered for architecture group 2.

- Routing in architecture 2a

The required processing in IAB/Donor needs to be investigated, i.e. adding/replacing/removing the routing related information, and how to configure the IAB/Donor.

- QoS enforcement

Need to clarify the required QoS information in the PDU-session-layer for the QoS enforcement of all types of user traffic over the air interface. For example, if the PDU session type is IP, DSCP may be used, but need to determine the mapping of DSCP to the QoS, and whether the granularity of DSCP is enough.

- Procedures of IAB-node integration

The IAB integration procedure in Section 9.3 may be affected, for example, setup the IAB-node's gNB and UPF, etc.

- Support of multi-connectivity

Need to clarify how the multiple-connectivity is supported.

- Topology adaptation

During topology adaptation, the IAB-node MT may connect to a different IAB-node, which causes the change of UPF. The detail about the procedures of topology adaptation, such as context and data forwarding, CN-involved signalling, etc., needs to be investigated.

8.6 Latency in UL scheduling

Increased latency due to multiple hops in an IAB network can adversely impact the performance of both control plane procedures (such as handover and radio link recovery) and also user plane data transmission. In order to achieve hop agnostic performance in IAB scheduling, it is important to reduce the E2E delay from the UE to the IAB-donor, and meet the latency requirement, regardless of how many hops the UE is away from the IAB-donor.

In multi-hop networks, upstream data arriving from a child node may suffer scheduling delays at the parent node and intermediate nodes. To some extent, this is no different from a single-hop UE where new data arrives into UE buffers after a BSR is sent. However, in a multi-hop network, the delays are likely to accumulate due to number of hops and aggregated volume of data at IAB-nodes and may require mitigation mechanisms. Request of uplink resources at each hop and UL data transmission are shown in Figure 8.6-1.

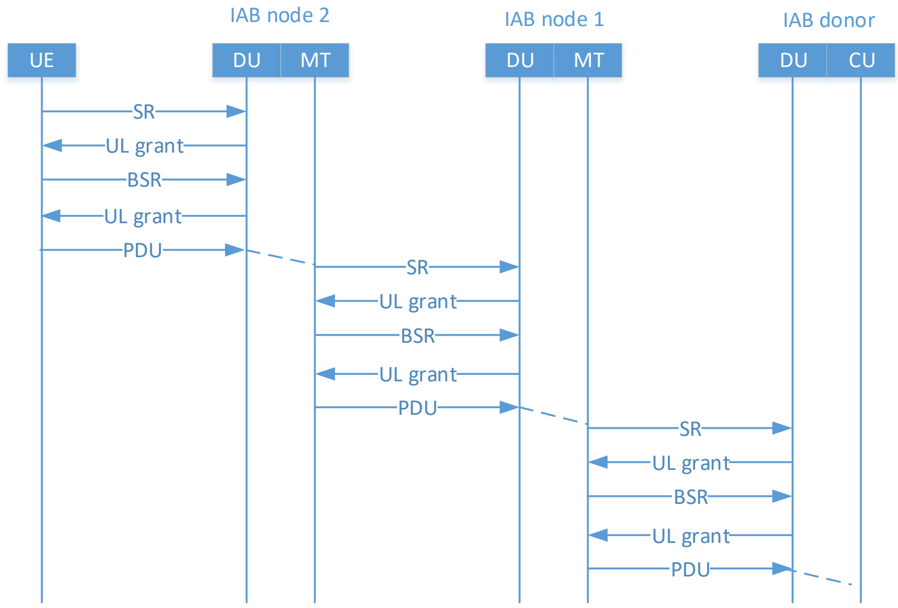

Figure 8.6-1: Uplink Delays in IAB Network: worst case scenario, where none of the intermediate nodes have any UL resources allocated to them

It is clear that this process can be significantly longer than the corresponding process in one-hop networks, due to the multiple consecutive uplink resource request and allocation steps. The underlying reason for these delays is that the MT part of an IAB-node can only request uplink resources for the UL data transmission after it actually receives the data to be transmitted.

One approach to mitigate such delays consists of initiating an uplink resource request at an IAB-node based on data that is expected to arrive. This would enable the IAB-node to obtain the uplink resource prior to actual data reception from its child IAB-node or a UE that it serves.

The details of the content and triggers of the SR/BSR and UL scheduling are left for the WI phase.

9 Backhaul aspects

9.1 Additional Interfaces

No additional interfaces were considered in this study.

9.2 IAB Topologies

The following IAB topologies were considered in the study:

1. Spanning tree (ST)
2. Directed acyclic graph (DAG)

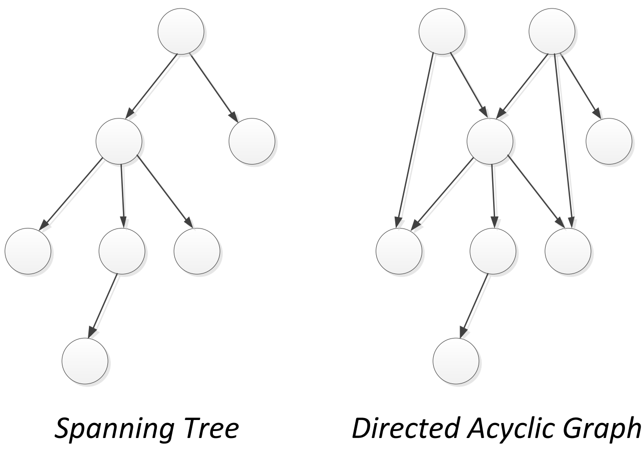

Figure 9.2-1: Examples for spanning tree and directed acyclic graph. The arrow indicates the directionality of the graph edge.

The directionality of the Uu-backhaul link, defined by uplink and downlink, is aligned with the hierarchy of the ST or DAG.

For ST, each IAB-node has only one parent node, which can be another IAB-node or the IAB-donor. Each IAB-node is therefore connected to only one IAB-donor at a time, and only one route exists between IAB-node and this IAB-donor.

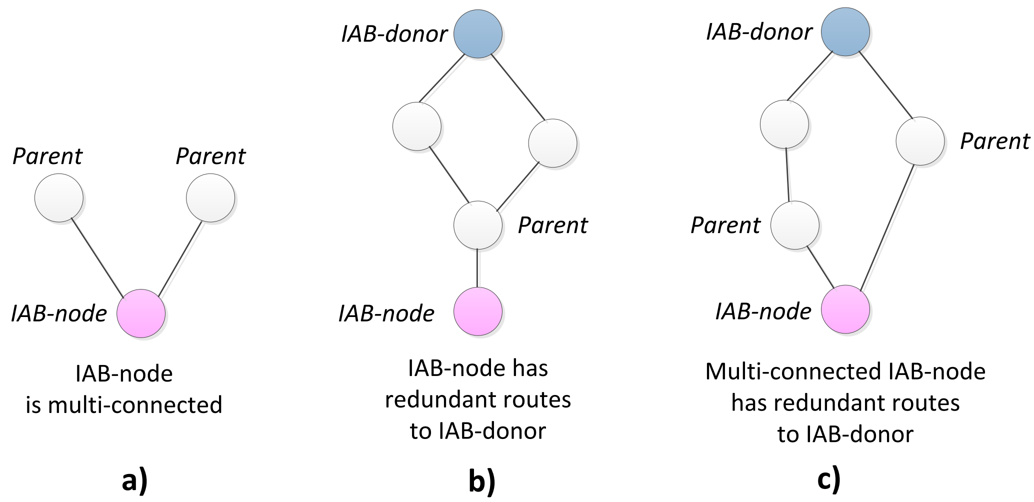

Figure 9.2-2: Examples for link- and route redundancy in DAG

For DAG, the following options can be considered:

- The IAB-node is multi-connected, i.e., it has links to multiple parent nodes (Fig 9.2-2a).
- The IAB-node has multiple routes to another node, e.g. the IAB-donor (Fig 9.2-2b).
- Both options can be combined, i.e., the IAB-node may have redundant routes to another node via multiple parents (Fig 9.2-2c).

Multi-connectivity or route redundancy may be used for back-up purposes. It is also possible that redundant routes are used concurrently, e.g., to achieve load balancing, reliability, etc.

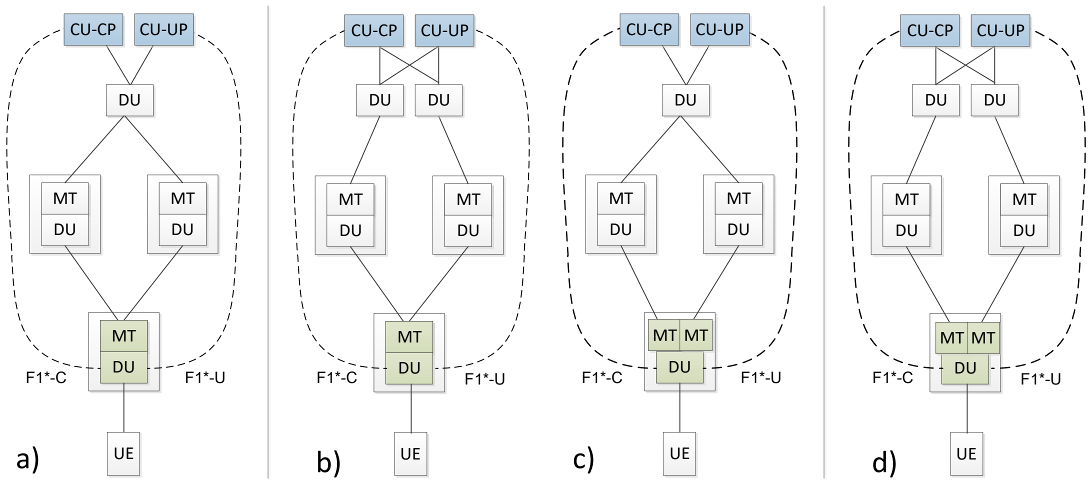

Figure 9.2-3: Route redundancy in arch group 1 either using single MT function or multiple MT functions

For architecture group 1, the CP/UP split architecture of IAB-donor CU needs to be considered for an IAB-node with redundant routes.

For the CP, the following applies:

- Each IAB-node DU connects to only one IAB-donor-CU-CP.
- Each IAB-node DU may be connected to this IAB-donor-CU-CP via redundant routes. These routes may pass through the same IAB-donor DU or through different IAB-donor DUs (Figure 9.2.3).
- The IAB-node MT may be connected to one or more IAB-donor-CU-CPs.

For the UP, the following applies:

- Each IAB-node DU may connect to one or more IAB-donor-CU-UPs, for access UE's traffic. Each F1-U connection may be supported via redundant routes. These routes may pass through the same IAB-donor DU or through different IAB-donor DUs of same or different Donor.
- The IAB-node MT may be connected to one or more IAB-donors for its own traffic, e.g. OAM support.

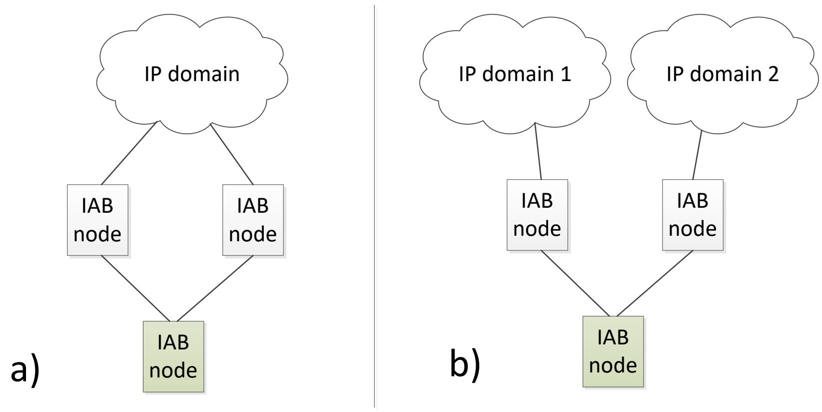

Figure 9.2-4: Examples for link- and route redundancy in arch group 2

For architecture group 2, the following scenarios need to be considered for an IAB-node with redundant routes. These routes may pertain to:

- The same IP domain;
- Different IP domains.

For at least some of these topologies, aspects of IP address management as well as procedures for topology adaptation will be studied. Further prioritization of these topologies may be necessary.

9.3 Integration of IAB-node

IAB-node integration has the following phases:

1. The IAB-node authenticates with the operator's network and establishes IP connectivity to reach OAM functionality for OAM configuration:
   - This phase includes discovery and selection of a serving node, which can be an IAB-donor or another IAB-node. The IAB-node may retrieve this information, e.g. from OAM or via RAN signaling such as OSI or RRC.
   - This phase further includes setting up connectivity to other RAN nodes and CN.
   - This phase involves the MT function on the IAB-node.
2. The IAB-node's DU, gNB, or UPF are set up together with all interfaces to other RAN-nodes and CN. This phase must be performed before the IAB-node can start serving UEs or before further IAB-nodes can connect:
   - For architectures 1a and 1b, this phase involves setup of the IAB-node's DU and the F1-establishment to the IAB-donor's CU-CP and CU-UP.
   - For architecture 2a, this phase involves setup of the IAB-node's gNB and UPF as well as integration into the PDU-session forwarding layer across the wireless backhaul.
   - This phase includes the IAB-node's integration into topology and route management.
3. The IAB-node provides service to UEs or to other integrated IAB-nodes:
   - UEs will not be able to distinguish access to the IAB-node from access to gNBs.

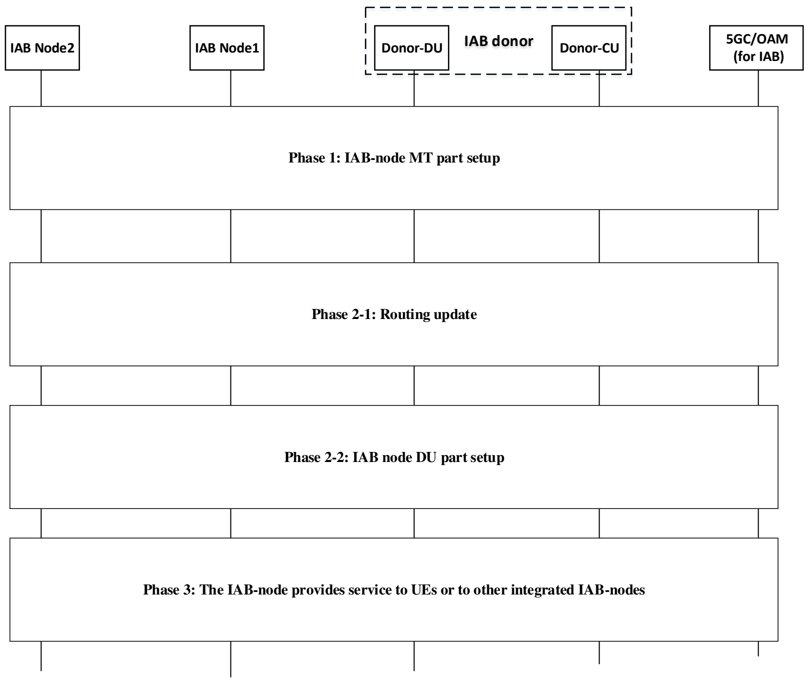

Figure 9.3-1: IAB-node's Integration Procedure

A high-level flow chart for SA-based IAB integration is shown in the Figure 9.3-1:

1. IAB-node's integration procedure phase 1: IAB-node MT part setup. In this phase, IAB-node MT part connects the network as a normal UE, such as IAB-node MT part performs RRC connection setup procedure between donor-CU, authentication and PDU session establishment between OAM, IAB-node MT part related context and

bearer configuration in RAN side, and etc. For CP alternative 2 and alternative 4 for 1a and 1b, the intermediate IAB-node DU part encapsulates the related RRC messages of the IAB-node MT part in F1-AP messages.

2. IAB-node's integration procedure phase 2-1: Routing update. In this phase, the routing information are updated for all related IAB-nodes due to the setup of IAB-node.

3. IAB-node's integration procedure phase 2-2: IAB-node DU part setup. For CP alternative 2 and alternative 4 for 1a and 1b, the IAB-node's DU part performs F1-AP setup procedure.

4. IAB-node's integration procedure phase 3: The IAB-node provides service to UEs or to other integrated IAB-nodes.

NSA-based IAB-node integration has the following phases:

Phase 1: IAB-node MT part setup. In this phase, IAB-node MT part performs the connection setup procedure and authentication via LTE RRC signaling to the LTE network. The eNB then configures the IAB-node MT part with an NR measurement configuration in order to perform discovery, measurement, and measurement reporting of candidate parent IAB-nodes to the eNB. The IAB-node MT part then connects to the parent IAB-node's DU and CU via the EN-DC SN addition procedure.

Phase 2-1: Routing update. In this phase, routing information is updated on the IAB-node's parent and its ancestor nodes to establish an NR backhaul path between IAB-node and IAB-donor.

Phase 2-2: IAB-node DU part setup. The IAB-node's DU performs F1-AP setup procedure. It can use the same transport over the NR backhaul as in SA mode. Alternatively, it may leverage SRBs over LTE and the X2 connection between eNB and CU for the transport of F1-AP as outlined in section 8.3.4. Both alternatives can be further studied, considering robustness and overhead of transmissions on the LTE or NR carrier(s).

Phase 3: The IAB-node DU provides service to UEs or to other integrated IAB-nodes via NR and the IAB-node MT maintains connectivity with the LTE eNB and parent IAB-node.

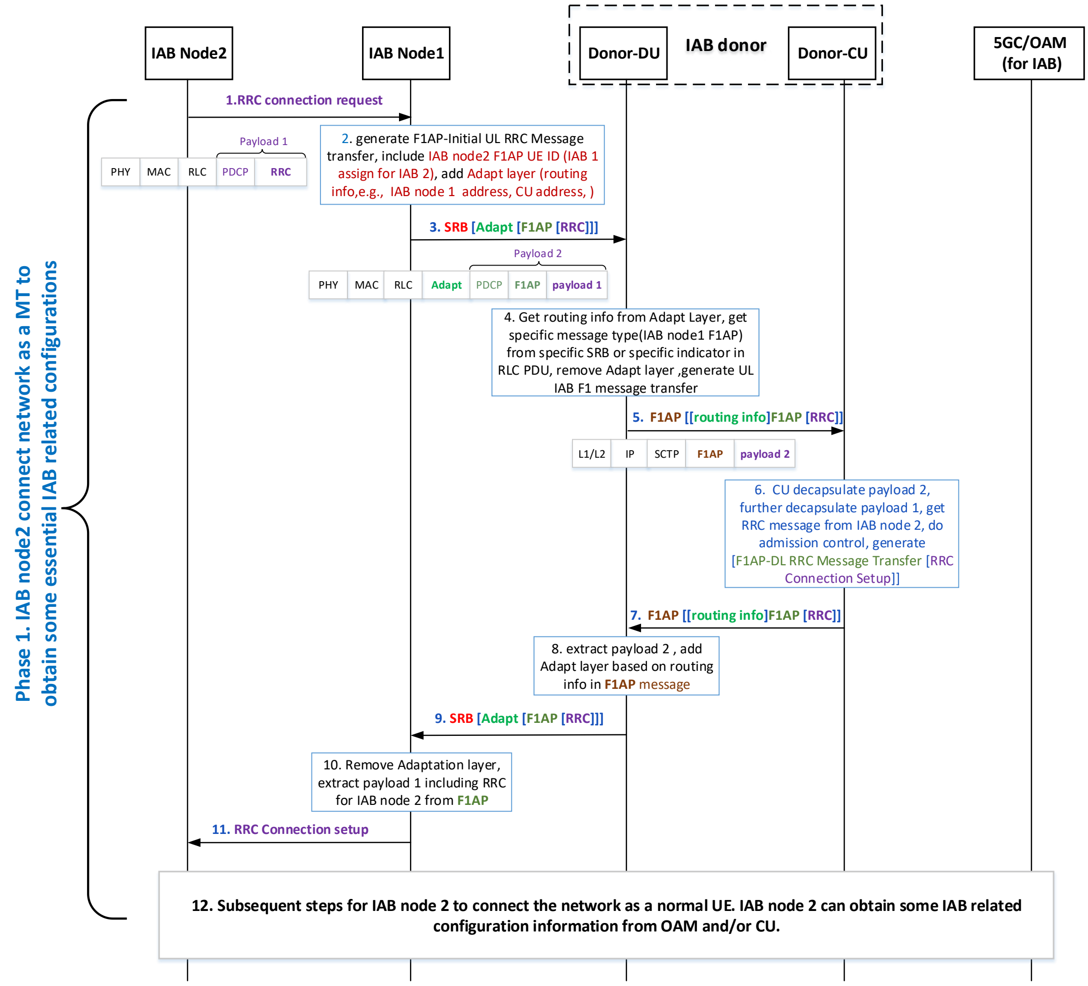

Figure 9.3-2(a): IAB-node's Integration Procedure Phase 1

As an example, one of possible IAB-node integration procedure for architecture-1a CP alternative 2 is given as in the Figure 9.3-2.

IAB-node's integration procedure phase 1: IAB-node MT part setup

1. IAB-node2 MT part performs normal cell discovery and cell selection and sends "RRC connection request" to IAB-node1 DU part.

2. IAB-node1 DU part generates F1AP message (i.e. the initial UL RRC Message) to carry the RRC message sent from IAB-node2 MT part.

3. IAB-node1 MT part transmits the encapsulated uplink F1AP message to Donor-DU via SRB.

4. Donor-DU learns the specific message type (F1AP message of IAB-node). Then it removes the header of adaptation layer, and encapsulates the payload2 (including the F1AP message of IAB-node) in its own F1AP message.

5. Donor-DU sends its F1AP message which contains the IAB-node1's F1AP message towards the donor-CU.

6. After decapsulation of the F1AP message received from Donor-DU, Donor-CU get payload2, and obtains the "RRC connection request" message inside payload2 through further decapsulation.

7. Donor-CU sends the F1AP message (e.g. DL IAB F1AP message transfer) which contains payload2 towards the Donor-DU and routing information (e.g., IAB-node 1 address, Donor-CU address, etc.) for the payload2.

8. Donor-DU extract payload2 from the received F1AP message (e.g. DL IAB F1AP message transfer), and adds the adaptation layer header which includes essential routing information for payload2.

9. Donor-DU transmits the encapsulated downlink F1AP message (DL RRC message transfer, inside payload2) towards IAB-node1 MT part via SRB.

10. IAB-node1 MT part learns the specific message type (F1AP message of IAB-node) according to the specific SRB or the message type indicator, and knows that the F1AP message is for itself from the routing information in the adaptation header. Then IAB-node 1 MT part removes the header of adaptation layer, and forwards the F1AP message which contains the RRC message for IAB-node 2 after receiver processing of the PDCP layer to IAB-node 1 DU part. The IAB-node 1 DU part extracts the RRC message from F1-AP message.

11. IAB-node1 DU parts send the RRC message (RRC connection setup) towards IAB-node 2.

12. More subsequent steps for IAB-node2 MT part to connect the network as a normal UE, such as IAB-node sending RRC connection setup complete towards donor-CU, authentication, PDU session establishment for connection to OAM, security mode configuration, IAB-node2 related context configuration in RAN side, setup of IAB-node2's radio bearer, etc.

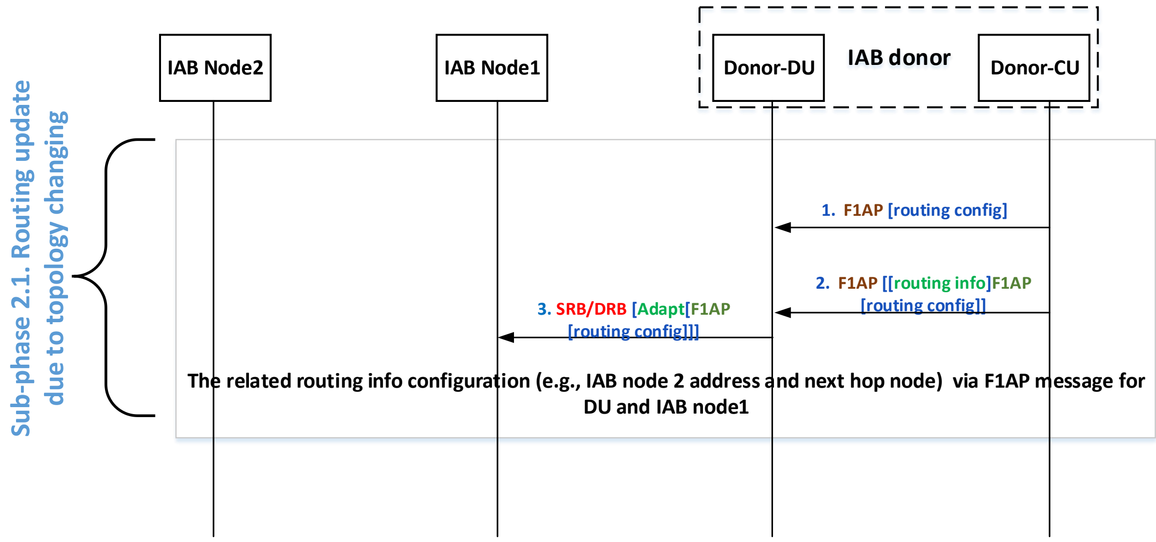

Figure 9.3-2(b): IAB-node's Integration Procedure Phase 2-1

IAB-node's integration procedure phase 2-1: Routing update

For CP alternative 2:

1. Identifiers and routing information are configured by F1-AP messages. Donor-CU sends the related F1AP message to the newly integrated IAB-node2 to assign its identifier. Donor-CU sends another F1AP message to the intermediate IAB-node1 to update its routing information.

2. The adaptation layer in donor-CU and IAB-node2 can include the configured identifier and routing information to each adaptation headers which are attached to the BH packets. The adaptation layer in IAB-node1 decide the destination of each BH packets based on updated routing information.

For CP alternative 4:

1. Identifier assignments are done by using IPv6 mechanism. The donor DU sends out ICMPv6 Router Advertisement (RA) to the IAB-node2. The IAB-node2, when it receives the ICMPv6 RA, generates 1 or more IPv6 addresses. The IAB-node2 announces the IP addresses to the donor DU using ICMPv6 Neighbor Solicitation and Neighbor Advertisement. The donor DU creates a mapping between IP addresses of the IAB-nodes and establishes the routing information for IAB-nodes, and broadcasts the information.

2. The adaptation layer in donor-CU and IAB-node1, IAB-node2 can use IP addresses and the configured IP routing information for BH packets forwarding.

For CP alternative 1, 3, and 5:

1. Identifiers and routing information are configured by adaptation layer. Donor-CU assigns a new identifier to the IAB-node2 by sending an adaptation layer command. Donor-CU sends another adaptation layer command to the intermediate IAB-node1 to update the routing information.

2. The adaptation layer in donor-CU and IAB-node2 can include the configured identifier to each adaptation headers which are attached to the BH packets. The adaptation layer in IAB-node1 decide the destination of each BH packets based on updated routing information.

Figure 9.3-2(b) depicts the procedure for CP alternative 2.

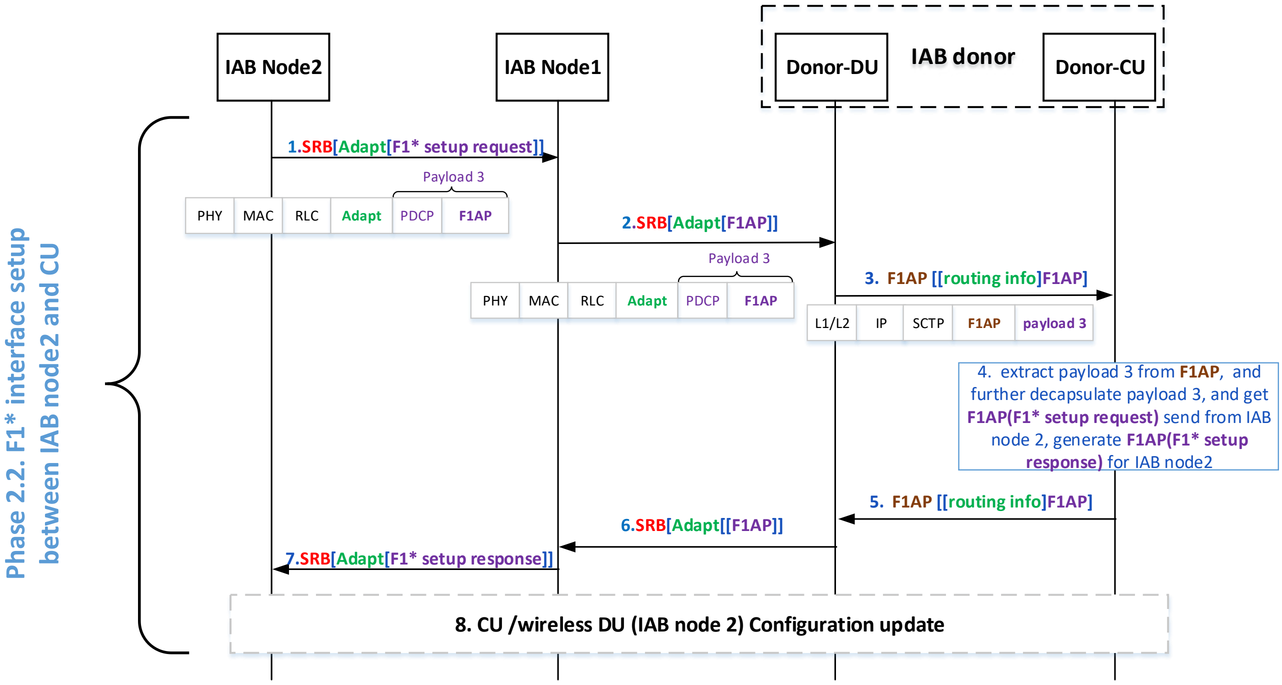

Figure 9.3-2(c): IAB-node's Integration Procedure Phase 2-2

IAB-node's integration procedure phase 2-2: IAB-node DU part setup

In this phase, the IAB-node DU part is setup via F1 interface setup procedure between IAB-node and Donor CU.

1. IAB-node2 DU part generates F1AP message and does security protection in PDCP layer to get payload 3, then adds routing information (e.g. IAB-node2's address, Donor-CU's address) in adaptation layer. After that, the IAB-node2 MT part sends the Adapt PDU to IAB-node 1 via SRB.

2. IAB-node1 forwards the payload3 towards Donor-DU according to the routing information contained in the adaptation layer header.

3. Donor-DU encapsulates the payload3 in its F1AP message and sends the F1AP message to Donor-CU.

4. Donor-CU extracts payload3, and gets the inner F1AP message (i.e. F1 setup request) sent from IAB-node 2, then generates DL F1AP message (i.e. F1 setup response) in response to the IAB-node 2's connection request, and encapsulates it to another outer DL F1AP message towards Donor DU.

5. Donor-CU sends the nested F1AP message to Donor DU.

6. Donor-DU extracts the inner DL F1AP message and adds routing information in the adaptation layer header, and then forwards the Adapt PDU to IAB-node 1 via SRB.

7. IAB-node1 DU part forwards the DL F1AP message to IAB-node2 MT part via SRB.

8. CU/ IAB-node2's configuration update.

9.4 Modifications to CU/DU architecture

9.4.1 Modifications of IAB-donor/IAB-node DU and IAB-donor CU for architecture group 1

The study assumes that Rel. 15 F1-U is considered as the baseline between the IAB-donor DU and the IAB-donor CU. If this baseline does not meet the requirements of the SI, then potential modifications to Rel 15 F1-U will be considered.

The study further considers modifications to the IAB-node DU that are necessary to support F1*-U over the wireless NR backhaul.

9.5 Backhaul bearer setup for architecture group 1

9.5.1 Satisfying the QoS requirements

IAB mode of operation may impose additional requirements on the RAN design, in order for the RAN to support the QoS profiles imposed by the Core network. These additional requirements may be due to e.g. the latency associated with multiple hops, congestion and failure of wireless backhaul links. However, in both IAB and non-IAB mode of operation, RAN may not always be able to meet the QoS profiles requested by the core network. To handle this scenario, the TS 23.502 [6] in Section 4.3.2. defines an N2 procedure which allows the RAN to reject the QoS profiles requested by the core network, in case the RAN cannot meet these QoS profiles. This N2 procedure is applicable to both IAB and non-IAB mode of operation.

With regards to the aforementioned N2 procedure, after receiving a flow QoS request from the core network, the IAB-donor CU may inform, via F1-AP, the corresponding access-IAB-node DU and some or all intermediate IAB-node DUs about this flow and its QoS requirement. The inquired DUs may accept/reject the request. In order to guarantee latency bounds, the CU may include in the QoS request to the DUs, some assistance information (e.g. some hop-count-related information pertaining to the route to the access-IAB-node DU).

Since the IAB-specific constraints on QoS depend on the particular IAB architecture option, the study captures the tradeoff among the various IAB architecture options with respect to their impact on QoS.

9.5.2 Signalling Procedures

For architecture group 1, the backhaul bearer corresponds to the RLC channel used for backhauling (between IAB-node and donor DU, or between different IAB-nodes). Backhaul RLC channels are setup and configured on the intermediate IAB-nodes along the UE's data forwarding path by the donor CU when the UE's DRB and PDU session is configured, or before that. Backhaul RLC channels are modified when the data forwarding routes change due to topology adaptation or UE handover. Moreover, the backhaul RLC channel might be modified/released on intermediate IAB-nodes when the UE bearer or the route changes.

The donor CU will initiate the backhaul RLC channel setup/modify procedure. As shown in Figure 9.5-1, the UE is served by the DU of IAB-node 1, the MT part of IAB-node 1 is served by the DU of IAB-node 2, and the MT part of IAB-node 2 is served by donor DU. Figure 9.5-1 provides an example of how backhaul RLC channels are setup or modified as the result of the establishment or modification of a PDU session for the UE in the following steps:

1. The UE or network initiates the PDU session establishment/modify procedure and a set of new or modified QoS flows needs to be supported for the access UE. The NGC sends the PDU session resource setup/modify request message to donor CU.

2. Upon receiving the PDU session resource setup/modify request message, the Donor CU establishes/modifies one or more UE DRBs, and associates each accepted QoS flow of the PDU session to a DRB. The donor CU determines the backhaul RLC channels that need to be established or modified on the intermediate IAB-node to support these QoS flows along the data path.

3. The donor CU configures the UE context and backhaul RLC channels at the Donor DU using F1 procedures, and configures corresponding RLC channels at the MT of IAB-node 2 using RRC procedures.

4. The donor CU configures the UE context and backhaul RLC channels at the DU of IAB-node 2 using F1 procedures, and configures corresponding RLC channels at the MT of IAB-node 1 using RRC procedures.

5. The donor CU configures the UE context and UE DRBs at the DU of IAB-node 1 using F1 procedures, and configures corresponding DRBs at the UE using RRC procedures.

6. The donor CU reports the PDU session resource setup/modify result to the NGC in the PDU session resource setup/modify response message.

NOTE: With N:1 bearer mapping, UE bearers and backhaul bearers may not be setup or modified at the same time

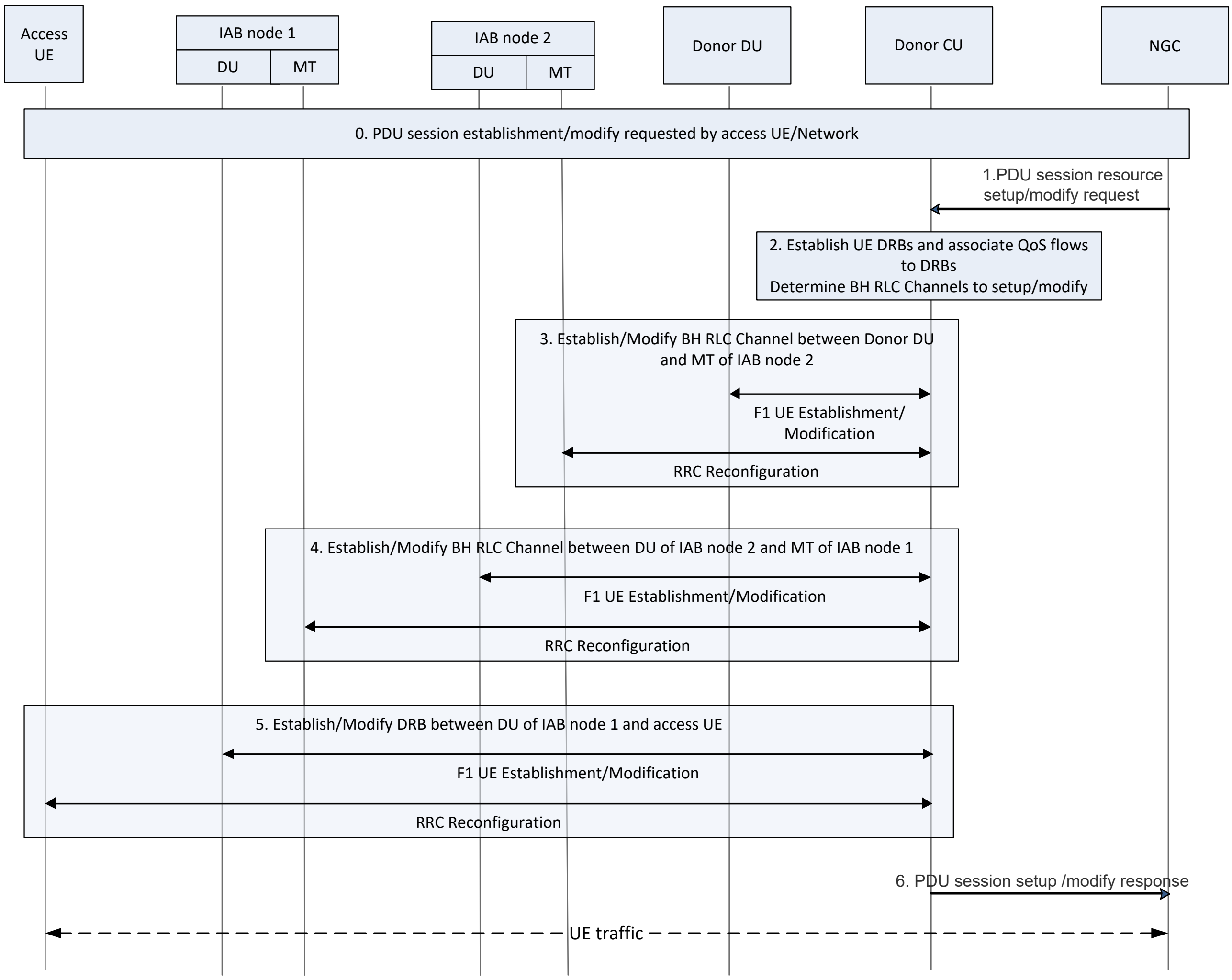

Figure 9.5.2-1: Example of backhaul bearer setup for Architecture 1

It is conceivable that there may be situations where not all the intermediate IAB-node could successfully establish/modify the backhaul RLC channels requested by donor CU (e.g. and IAB-node may not have sufficient resources to fulfill the requested QoS). For example, the set of backhaul RLC channels accepted at each intermediate IAB-node could be different. As a result, further enhancement may be necessary for the backhaul bearer setup/modify procedure between DU and CU.

9.5.3 QoS parameters

Establishment or modification of the UE context at the; Donor DU, the UE's access IAB-node, and intermediate IAB-nodes, identifies the configured QoS parameters for the UE's DRBs. The QoS profile for the UE and its bearers comprises a number of parameters that define different aspects that are considered, guaranteed, or enforced by the network nodes in order to provide the appropriate QoS treatment for each DRB. For example, a minimum bit rate should be insured by the IAB network for GBR bearers. Hence, it is important to understand which parameters of the QoS profile are relevant to the access IAB-node and intermediate IAB-nodes.

In the downlink, all the traffic first arrives at the IAB-donor, and the IAB-donor is able to control the maximum bitrate by flow control or other mechanisms. Hence, downlink UE-AMBR does not need to be enforced by the intermediate IAB-nodes, since it already enforced by the IAB-donor directly. For DL GBR bearers, similar to downlink UE-AMBR, the IAB-donor can ensure that the MFBR is not exceeded by controlling the transmission rate of the downlink GBR bearer on the Uu interface between Donor DU and MT of 1st IAB-node. Therefore, intermediate IAB-nodes may not need to enforce the MFBR for DL GBR bearers.

A similar mechanism can be applied for the uplink. The access IAB-node serving the UE ensures the UE-AMBR and MFBR are not exceeded on the Uu interface between the UE and its serving IAB-node. Thus, the UE-AMBR and MFBR also cannot be exceeded on upstream backhaul links. Consequently, intermediate IAB-nodes may not need to enforce uplink UE-AMBR nor MFBR for uplink GBR UE bearers.

For GFBR, the UE's access IAB-node guarantees the GFBR by appropriately scheduling of the UE. In order to guarantee the GFBR on backhaul links, the intermediate IAB-nodes should also be informed of the GFBR of a UE's bearer. However, for the case where many UE-bearers are mapped to the same BH RLC channel, GFBR per UE bearer may not need to be supported for the N:1 mapped bearers.

NOTE: Table 9.5.3-1 does not imply that signaling of QoS parameters needs to be optimized for intermediate IAB-nodes. Some QoS parameters may be signaled to intermediate IAB-nodes, even if this is not strictly required. The specifics of how QoS is supported at IAB-nodes is up to network implementation.

Table 9.5.3-1 below provides a summary of these QoS parameters, and potential impacts to intermediate IAB-nodes.

Table 9.5.3-1: QoS Parameters for Intermediate IAB-nodes

QoS related parameters	Description	Use at Intermediate IAB-nodes
UE AMBR-Downlink	The downlink maximum bitrate to be enforced for all non-GBR QoS flows per UE.	May not be critical to enforce UE AMBR-Downlink at intermediate IAB-node
UE AMBR-Uplink	The uplink maximum bitrate to be enforced for all non-GBR QoS flows per UE.	May not be critical to enforce UE AMBR-Uplink at intermediate IAB-node
Allocation and Retention Priority (ARP)	The QoS parameter ARP contains information about the priority level, the pre-emption capability and the pre-emption vulnerability. This allows a node to decide whether a new QoS Flow may be accepted or needs to be rejected in the case of resource limitations. It may also be used to decide which existing QoS Flows to pre-empt during periods of resource limitation.	Needed to correctly prioritize bearers for admission control or pre-emption
5QI	The characteristics of 5QI includes: Resource Type (GBR or Non-GBR), Priority level, Packet Delay Budget, Packet Error Rate, Averaging window, Maximum Data Burst Volume.	Needed to differentiate QoS treatment for bearers
Reflective QoS Attribute (RQA)	The Reflective QoS Attribute (RQA) is an optional parameter which indicates that certain traffic (not necessarily all) carried on this QoS Flow is subject to Reflective QoS.	Used at SDAP layer for reflective QoS functionality. Needed at least for bearers with SDAP at intermediate IAB-node (e.g. MT bearers)
GBR QoS Information	The GBR Flow Information includes: GFBR; MFBR; Notification Control; Maximum Packet Loss Rate.	Used to ensure bit rate requirements for GBR Type bearers. May not be critical to enforce MFBR at Intermediate IAB-nodes. GFBR per UE bearer may not need to be supported for the N:1 mapped bearers

9.6 IAB Topology Discovery

9.6.1 Discovery procedure for architecture group 1

In architecture group 1, topology-, route- and resource management is centrally managed by the CU-CP.

When an IAB-node attaches to the IAB-topology, the CU-CP learns from the new IAB-node-MT's RRC connection setup procedure about the parent, where the new MT connects.

When a DU on the new IAB-node subsequently launches its F1-AP connection with the CU-CP, the CU-CP has to learn about the DU's location within the IAB-topology, i.e. on which IAB-node it resides. The following options may be considered:

Option 1: The DU includes into an F1-AP message an identifier of the collocated MT. This may, for instance, be a TNL or RNL identifier. The identifier may have been assigned by the CU-CP to the MT before.

Option 2: The MT includes into an RRC message an identifier for the collocated DU. This identifier may have been assigned by the CU-CP to the DU before.

9.6.2 Discovery procedure for architecture group 2

One example to discover the IAB topology is based on each IAB-node determining a one-hop hierarchy, linking the IAB-node identifier with the node identifier of the serving upstream node. The node identifier may be cell ID, or other identifiers (to be further studied). The process is summarized as follows (using cell ID as an example, but other identifiers are not precluded):

1. The IAB-node MT obtains the Cell ID(s) of the upstream IAB-node or IAB-donor it is accessing (e.g. via cell broadcast).

2. The gNB part of the IAB-node is set up and the IAB-node MT obtains the Cell ID(s) of its collocated gNB.

3. The IAB-node then associates the Cell IDs of the upstream cells with the Cell IDs of its own gNB (obtained in step 1). This creates one or more (Upstream-Node-ID, Downstream-Node-ID)-associated cell pairs.

These first 3 steps are illustrated in figure 9.6.2-1, where NGCI is shown as the Cell ID. PCI and/or other identifiers may additionally be included.

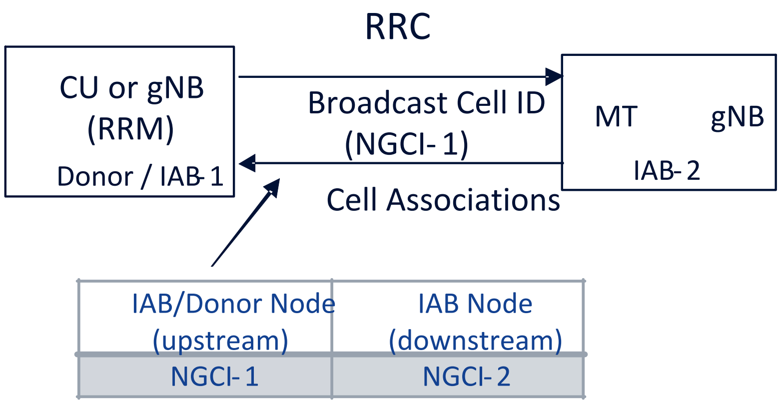

Figure 9.6.2-1: IAB-node-discovery steps 1-3

4. New Cell ID Pairs are sent by the IAB-node MT to the IAB-node's gNB via RRC messaging.

5. For architecture 2a, the IAB-node may contain the gNB serving one or more downstream IAB-nodes. In this case, the IAB-node MT additionally forwards to its CU any Cell ID pairs received from a downstream node.

6. If the IAB-node's gNB receiving the cell pair information is different form the IAB-donor gNB, then the IAB-node's gNB sends the received (Upstream-Node-ID, Downstream-Node-ID)-pairs to the IAB-donor (e.g: via Xn messaging).

When this process is repeated at each IAB-node and the cell pairs recorded for RRC-connected IAB-nodes, the result is an IAB-node topology table as shown in Figure 9.6.2-2. In this manner, each IAB-node and the IAB-donor maintain a complete view of the subtending IAB topology.

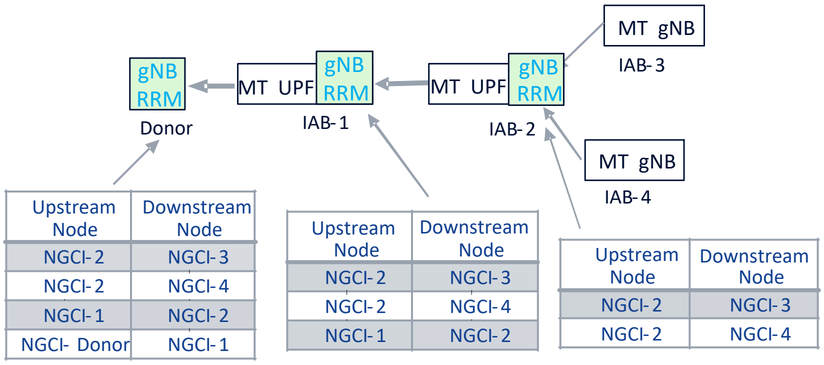

Figure 9.6.2-2: Example for topology tables

9.7 Topology adaptation

9.7.1 Goals of IAB topology adaptation

Topology adaptation has the goal to change the IAB-topology in order to ensure that the IAB-node can continue to operate (incl. providing coverage and end user service continuity) even if the current active backhaul path is degraded or lost.

It is also desirable to minimize service disruption and packet loss during topology adaptation.

IAB Topology adaptation can be triggered by integration of a IAB-node to the topology, detachment of an IAB-node from the topology, detection of backhaul link over load, deterioration of backhaul link quality or link failure, or other events.

9.7.2 Tasks pertaining to IAB topology adaptation

Topology adaptation includes the following tasks:

- Information collection
  - Information includes, e.g., backhaul link quality, link- and node-load, neighbor-node signal strength.
  - Collection applies to sufficiently large area of the IAB topology.
- Topology determination
  - Deciding best topology based on the collected info and following a performance objective.
- Topology reconfiguration
  - Adjusting topology based on topology determination, through e.g. establishing new connections, releasing other connections, changing routes, etc.

The following discussion mainly focuses on topology reconfiguration. In this discussion, it is assumed that existing Rel-15 procedures for measurements, handover, dual-connectivity and F1-interface management are baseline for topology reconfiguration in architecture 1. Furthermore, Rel-16 related procedures should be considered when these procedures are available.

9.7.3 Topologies considered for architecture 1a

Figure 9.2.1 considers two types of topologies:

- Spanning tree (ST) topology;
- Directed acyclic graph (DAG) topology.

In ST-topologies, there is only one route between each IAB-node and the IAB-donor. In architecture group 1, where the IAB-donor holds one CU with one or multiple DUs, the graph underneath each IAB-donor DU represents a separate ST.

In DAG-topologies, redundant routes are supported between each IAB-node and the CU. In architecture group 1, such route redundancy may involve multiple IAB-donor DUs. Topologically redundant routes may simultaneously run traffic. It is also possible to keep one route active and assign backup status to a redundant route. In order to separate this case from the ST topology which could be dynamically reconfigured, we assume at least control plane connectivity is simultaneously maintained on all paths in the DAG topology.

9.7.4 Topology adaptation scenarios in architecture 1a

1. Intra-Donor CU, Intra-Donor DU:

In this scenario, the IAB-node migrates from one parent node to another parent node under same IAB-donor DU as shown in Fig. 9.7.4-1.

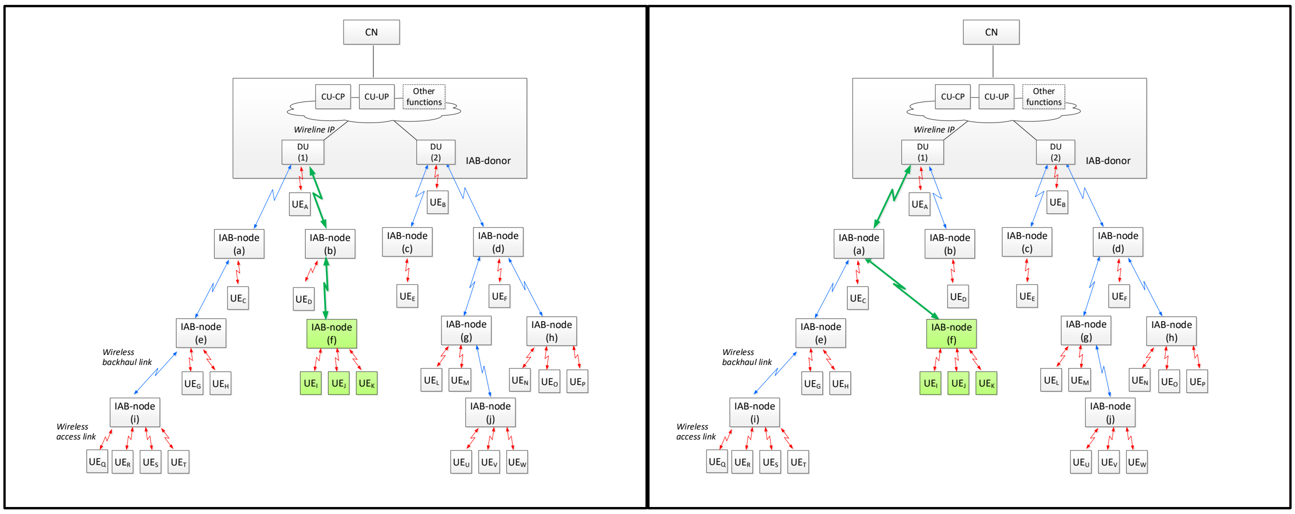

Figure 9.7.4-1: Topology Adaptation: Intra-Donor CU, Intra-Donor DU

The Donor-CU initiates the topology adaptation based on measurement reports from migrating IAB-node's MT and includes other IAB-node measurements within the configured topology.

This scenario triggers the following:

a. Establishment of new route between the migrating IAB-node and the IAB-donor DU. This includes the establishment or reconfiguration of RLC-channels.

b. Release the old routes and contexts.

2. Intra-Donor CU, Inter-Donor DU

In this scenario, the IAB-node migrates from a parent node served by one IAB-donor DU to a parent node served by a different IAB-donor DU, both connected to same IAB-donor-CU as shown in Fig 9.7.4-2.

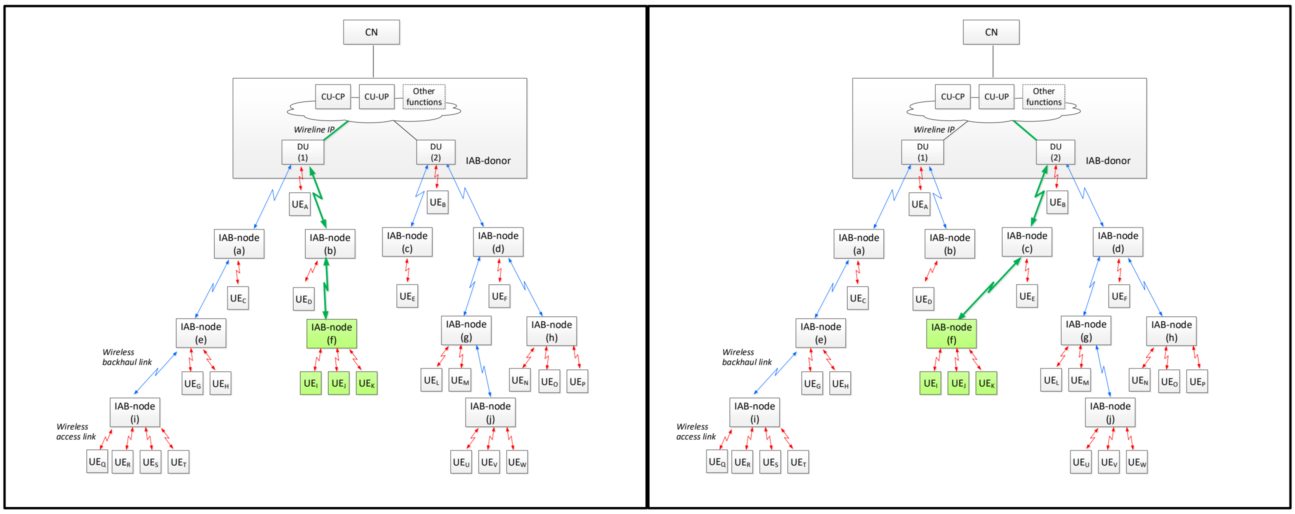

Figure 9.7.4-2: Topology Adaptation: Intra-Donor CU, Inter-Donor DU

The Donor-CU initiates topology adaptation based on measurement reports from migrating IAB-node's MT and includes other IAB-node measurements within the configured topology.

This scenario triggers the following:

a. Establishment of new route between the migrating IAB-node and the target IAB-donor DU. This includes the establishment or reconfiguration of RLC-channels.

b. Reconfiguration of F1-C association and F1-U tunnels. This involves the redirection of F1-U tunnels and F1-AP onto new routes.

c. Release of old routes and contexts.

3. Inter-Donor CU, Inter-Donor DU

In this scenario, the IAB-node migrates from a parent node served by one IAB-donor DU to a parent node served by a different IAB-donor DU connected to a different IAB-donor-CU, as shown in Fig. 9.7.4-3.

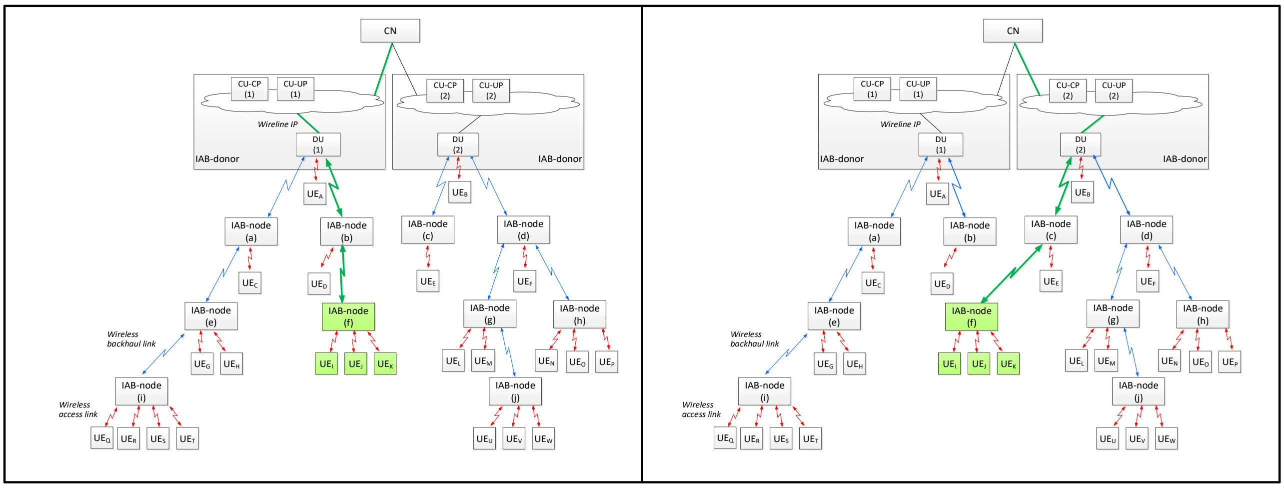

Figure 9.7.4-3: Topology Adaptation: Inter-Donor CU, Inter-Donor DU

The IAB-donor-CU initiates the topology adaptation based on measurement reports from migrating IAB-node's MT and includes measurements from other IAB-nodes within the configured topology.

This would be an inter-CU HO scenario that would result into the following:

a. Establishment of new F1-C association and F1-U tunnels between the migrating IAB-node and the target CU, while releasing the existing F1-C associations and F1-U tunnels with serving CU.

b. Establishment of new route between the migrating IAB-node and the target IAB-donor DU.

c. This may result into inter-CU handover of all access UEs and subtending IAB-nodes connected below the migrating IAB-node.

d. Release of old contexts and routes.

The 3rd scenario may need further analysis.

9.7.5 Principal steps of intra-CU topology adaptation in architecture 1a

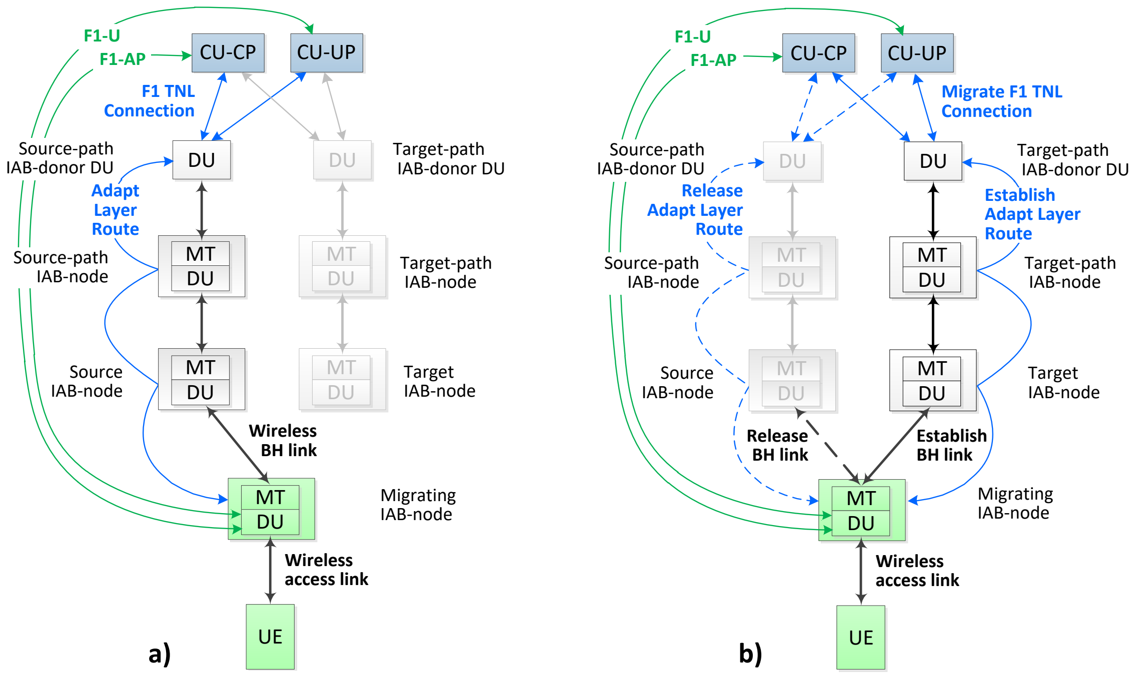

Figure 9.7.5-1: Topology adaptation in ST: The green IAB-node migrates from a source parent to a target parent.

The following discussion focuses on the procedure for topology adaptation within a ST using architecture 1a. This discussion only addresses topology changes underneath the IAB-donor.

Figure 9.7.5-1 shows a ST topology with five IAB-nodes connected to an IAB-donor which holds two DUs. One IAB-node in this topology, referred to as *migrating IAB-node*, changes its attachment point from a source parent node to a target parent node. The migrating IAB-node has one UE attached.

Figure 9.7.5-1a shows the topology before the migration. Figure 9.7.5-1b shows the topology after migration, and it indicates the links and routes that are established and released.

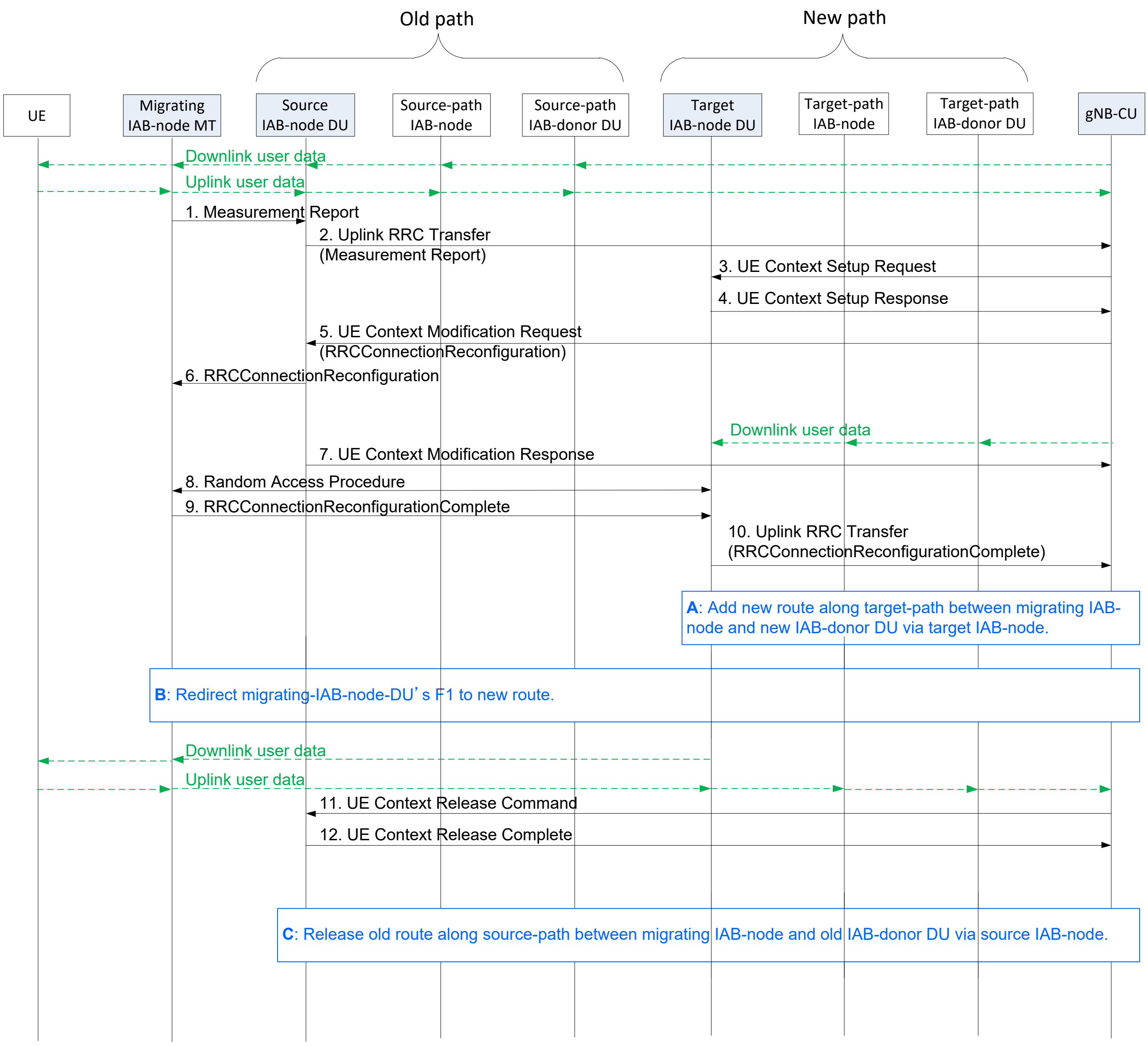

Figure 9.7.5-2: Procedure for adaptation of ST topology as shown in Figure 9.7.5-1

It is assumed that topology adaptation is initiated by the CU based on measurements reported by the migrating-IAB-node's MT. The CU's topology adaptation decision may include measurements by other IAB-nodes. The measurements may be based on a measurement configuration the IAB-nodes received from the CU before.

Figure 9.7.5-2 shows the topology adaptation procedure for the migrating IAB-node. In this procedure, the migrating IAB-nodes' MT applies the steps of *Inter-gNB-DU mobility* as described in TS 38.401 section 8.2.1.1 [7] (black and green arrows in Fig. 9.7.5-2). Additional signalling is supported for route changes of on-path IAB-nodes and on-path IAB-donor DUs (blue arrows in Fig. 9.7.5-1).

The procedure contains the following steps (all non-bold font is based on TS 38.401 section 8.2.1.1 [7]):

1. The MT sends a *Measurement Report* message to the source IAB-node DU. This report is based on a *Measurement Configuration* the migrating-IAB-node's MT received from the IAB-donor CU before.

2. The source IAB-node DU sends an Uplink RRC Transfer message to the gNB-CU to convey the received *Measurement Report*.

3. The gNB-CU sends an UE Context Setup Request message to the target IAB-node DU to create an MT context and setup one or more bearers.

- IAB-specific:
  - These bearers are used by the MT for its own data and signalling traffic.
  - In addition, one or more RLC-channels are established for backhauling.

4. The target IAB-node DU responds to the gNB-CU with an UE Context Setup Response message.
5. The gNB-CU sends a UE Context Modification Request message to the source IAB-node DU, which includes a generated *RRCConnectionReconfiguration* message and indicates to stop the data transmission for the MT.

- IAB-specific:
  - For IAB, the retransmission of PDCP PDUs and the use of Downlink Data Delivery Status as discussed in TS 38.425 clause 5.4.2 [8] are potentially relevant.

6. The source IAB-node DU forwards the received *RRCConnectionReconfiguration* message to the MT.
7. The source IAB-node DU responds to the gNB-CU with the UE Context Modification Response message.
8. A Random Access procedure is performed at the target IAB-node DU.
9. The MT responds to the target IAB-node -DU with an *RRCConnectionReconfigurationComplete* message.
10. The target IAB-node DU sends an Uplink RRC Transfer message to the gNB-CU to convey the received *RRCConnectionReconfigurationComplete* message. Downlink packets are sent to the MT. Also, uplink packets are sent from the MT, which are forwarded to the gNB-CU through the target IAB-node DU.

A. For IAB: The gNB-CU configures a new adaptation-layer route on the wireless backhaul between migrating IAB-node and IAB-donor DU via the target IAB-node. It further configures a forwarding entry between the fronthaul on the new route on the wireless backhaul. These configurations may be performed at an earlier stage, e.g. right after step 4. The details of this step depend on the particular UP and CP transport option (see below).

B. For IAB: The gNB-CU redirects all F1-U tunnels for the migrating-IAB-node DU from the old route to the new route. It further redirects F1-C for the migrating-IAB-node DU from the old route to the new route. While step B has to follow step A it may be performed at an earlier stage as described under step A. The details of this step depend on the particular UP and CP transport option (see below).

11. The gNB-CU sends an UE Context Release Command message to the source IAB-node DU.
12. The source IAB-node -DU releases the MT context and responds the gNB-CU with an UE Context Release Complete message.

C. For IAB: The gNB-CU releases the old adaptation-layer route on the wireless backhaul between migrating IAB-node and IAB-donor DU via the source IAB-node. It further releases the forwarding entry between the fronthaul on the old route on the wireless backhaul. The detailed steps depend on the particular UP and CP transport option (see below).

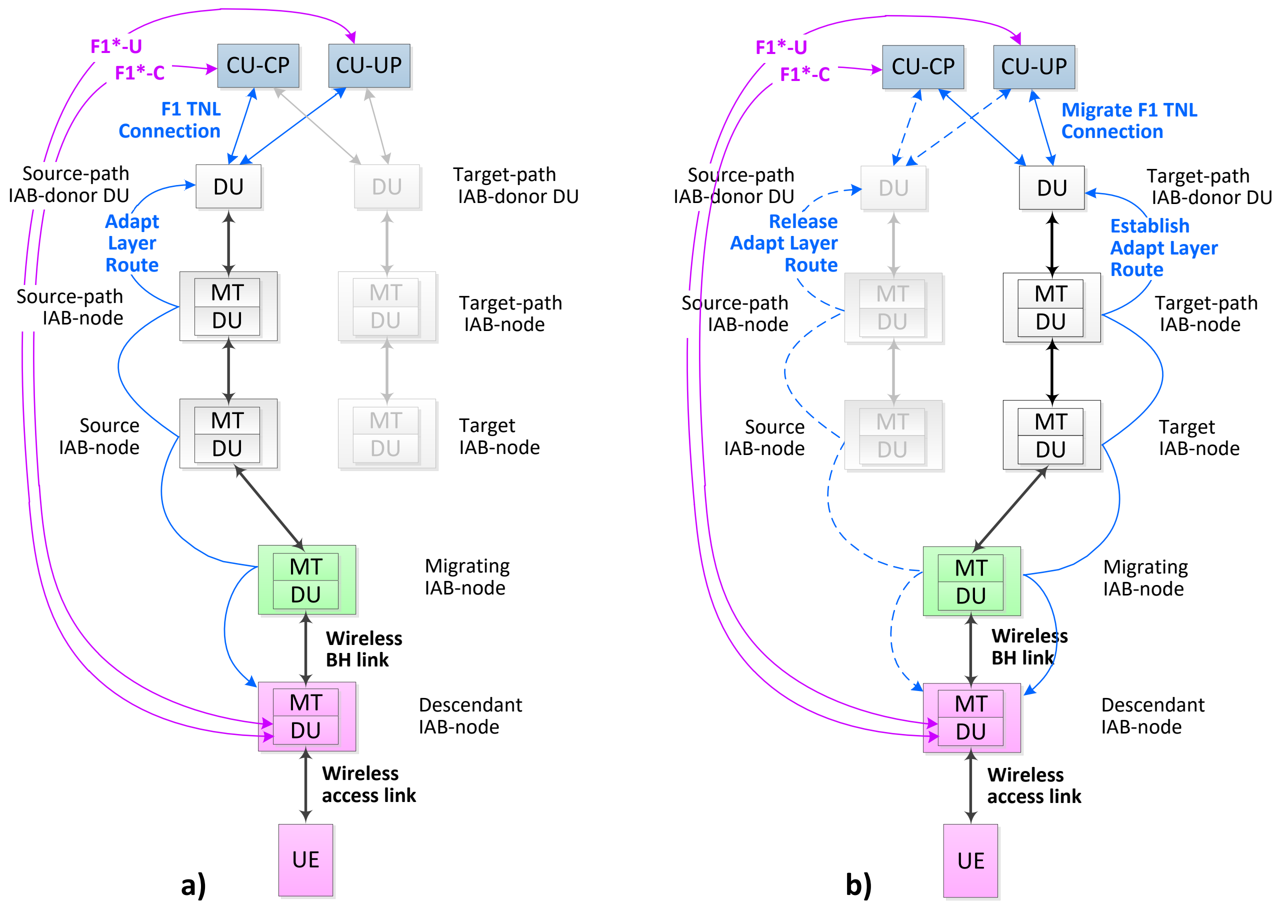

Figure 9.7.5-3: Topology adaptation in ST: The migrating IAB-node has a descendant IAB-node.

Figure 9.7.5-3 shows a ST topology where the migrating IAB-node has a descendant IAB-node. The figures illustrate that the above steps A, B, and C also have to be conducted for all IAB-nodes that are descendant to the migrating IAB-node.

9.7.6 Principal steps of inter-CU topology adaptation in architecture 1a

The following discussion focuses on the procedure for topology adaptation within a ST using architecture 1a. This discussion only addresses topology changes between IAB-donors.

The inter-CU topology adaptation procedure described may cause multiple subsequent RLFs for descendant IAB-nodes and UEs of the migrating IAB-node. This may cause long service interruption for the UEs. Further enhancement is needed to reduce this service interruption.

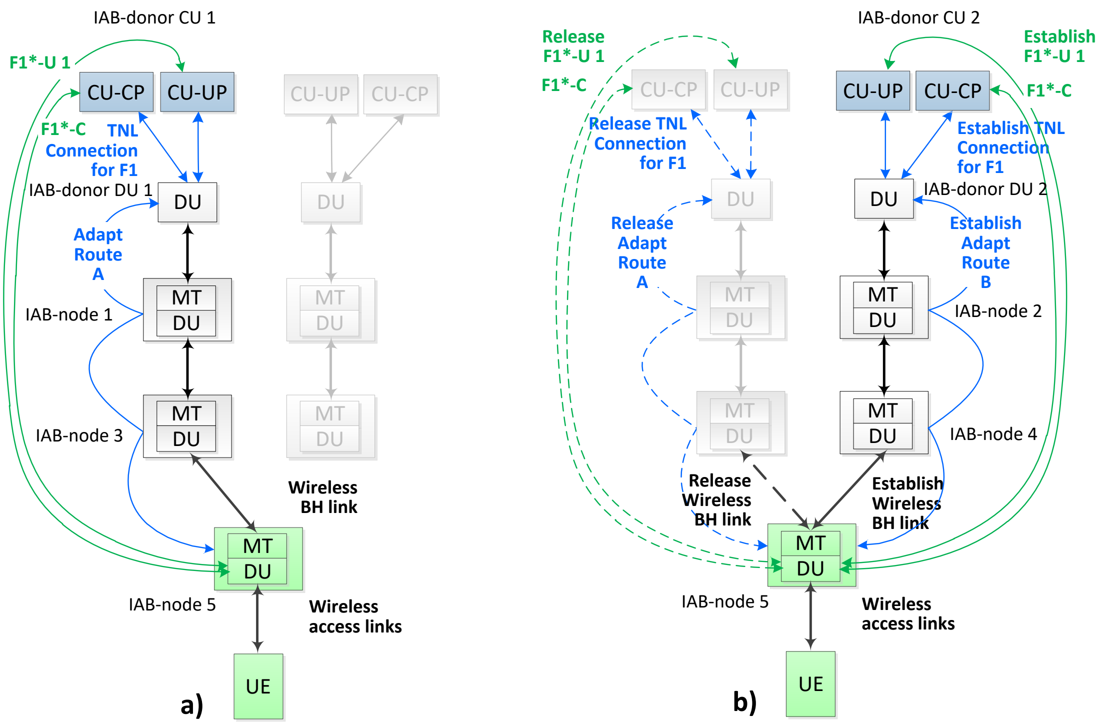

Figure 9.7.6-1: Topology adaptation in ST: The green IAB-node migrates from a source parent to a target parent of different CU.

Figure 9.7.6-1 shows a ST topology with five IAB-nodes connected to two IAB-donors. One IAB-node in this topology, referred to as *migrating IAB-node*, changes its attachment point from a source parent node connecting to a source IAB-donor to a target parent node connecting to a target IAB-donor. The migrating IAB-node has one UE attached.

Figure 9.7.6-1a shows the topology before the migration. Figure 9.7.5-1b shows the topology after migration, and it indicates the links and routes that are established and released.

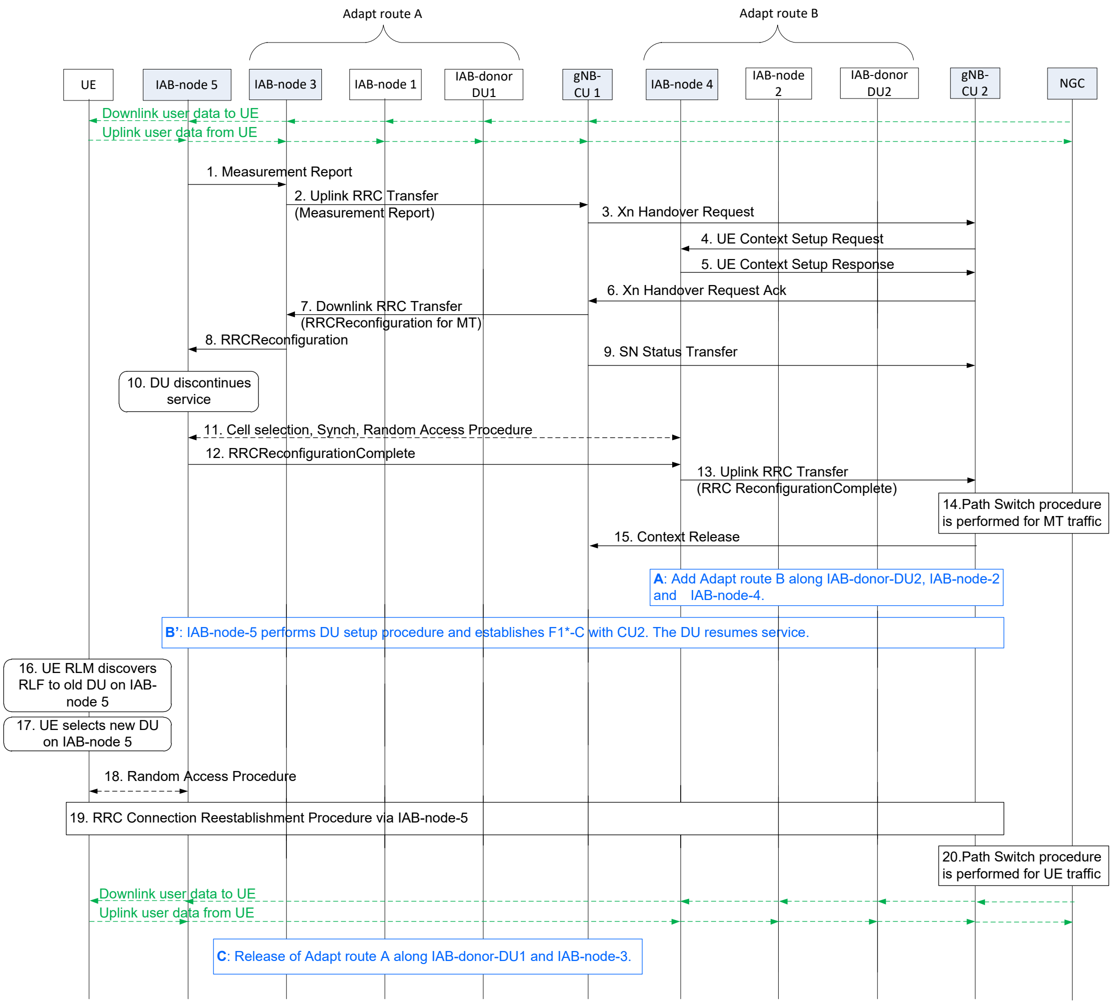

Figure 9.7.6-2: Procedure for adaptation of ST topology as shown in Figure 9.7.6-1

It is assumed that topology adaptation is initiated by the CU based on measurements reported by the migrating-IAB-node's MT. The CU's topology adaptation decision may include measurements by other IAB-nodes. The measurements may be based on a measurement configuration the IAB-nodes received from the CU before.

Figure 9.7.6-2 shows one example for the topology adaptation procedure for the migrating IAB-node. In this procedure, the migrating IAB-nodes' MT applies the steps of *Inter-gNB* handover as described in TS 38.401 section 8.9.4 [7] (black arrows of steps 1 to 8 and 10 to 14 in Fig. 9.7.6-2). Additional signalling is supported for route changes of on-path IAB-nodes and on-path IAB-donor DUs (blue boxes in Fig. 9.7.6-2).

When the migrating IAB-node's MT connects to the target CU during Inter-gNB handover, the IAB-node's DU has to discontinue service since it loses connectivity to its source CU. Consequently, UEs connected to this DU observe RLF.

After the MT's handover has completed and a new route has been established, the migrating IAB-node's DU establishes a new F1*-C connection to the target CU, receives configuration information and re-establishes service. This allows the UE to perform RRC Connection Reestablishment with the target CU via the reconfigured DU.

The procedure contains the following steps (all non-bold font is based on TS 38.401 section 8.2.1.1 [7]):

1. The MT sends a *Measurement Report* message to the source IAB-node DU. This report is based on a *Measurement Configuration* the migrating-IAB-node's MT received from the gNB-CU1 before.

2. The source IAB-node DU sends an Uplink RRC Transfer message to the gNB-CU1 to convey the received *Measurement Report*.

3. The gNB-CU1 sends an Xn Handover Request message to gNB-CU2 to initiate handover preparation. The handover preparation is also performed for all access UEs and subtend IAB-MTs.

4. The gNB-CU2 sends an UE Context Setup Request message to the target IAB-node DU to create an MT context and setup one or more bearers.

   IAB-specific:

   - **These bearers are used by the MT for its own data and signalling traffic.**
   - **In addition, one or more RLC-channels are included for backhauling.**

5. The target IAB-node-4-DU responds to the gNB-CU2 with an UE Context Setup Response message.
6. The gNB-CU2 responses to the gNB-CU1 with a Xn Handover Request Acknowledge message.
7. The gNB-CU1 sends a UE Context Modification Request message to the IAB-node 3, which includes a generated *RRCReconfiguration* message for the MT.
8. The IAB-node 3 forwards the received *RRCReconfiguration* message to the MT. The MT recognizes that the *RRCReconfiguration* is association with migration to a different IAB-donor CU.
9. The gNB-CU1 sends an SN Status Transfer message to gNB-CU2.
10. The DU on IAB-node-5 discontinues service since it loses F1*-C connectivity to gNB-CU-1.
11. The IAB-node-5-MT discovers IAB-node-4-DU, synchronizes and conducts Random Access Procedure.
12. The IAB-node-5-MT sends *RRCReconfigurationComplete* to IAB-node-4-DU.
13. IAB-node-4-DU forwards the *RRCReconfigurationComplete* message via Uplink RRC Transfer to gNB-CU2.
14. gNB-CU2 performs path-switch procedure for the IAB-node-5-MT with the NGC.
15. gNB-CU2 sends context-release request to gNB-CU1.

A. For IAB: The gNB-CU configures a new adaptation-layer route on the wireless backhaul between migrating IAB-node and IAB-donor DU via the target IAB-node. It further configures a forwarding entry between the fronthaul on the new route on the wireless backhaul. These configurations may be performed at an earlier stage, e.g. right after step 4. The details of this step depend on the particular UP and CP transport option (see below).

B. The DU on IAB-node-5 initiates a new F1*-C connection to the new CU-CP. This procedure is the same as IAB-node setup phase 2.2 described in section 9.3. The DU will obtain a new configuration during that procedure which, e.g., a new PCI. After that, the DU resumes service.

NOTE: Another possibility is to replace steps 11 to B' with the IAB-node's integration procedure as discussed in section 9.3.

16. The UE discovers RLF to the old DU.
17. The UE discovers and selects the new DU configured on IAB-node-5 (or any other DU).
18. The UE conducts random access procedure with this DU.
19. The UE and the CU-2 conducts *RRCConnectionReestablishment* procedure via IAB-node 5.
20. gNB-CU2 performs path-switch procedure for the UE with the NGC.

C. For IAB: The gNB-CU1 releases the old adaptation-layer route on the wireless backhaul between migrating IAB-node and IAB-donor DU via the source IAB-node. It further releases the forwarding entry between the fronthaul on the old route on the wireless backhaul. The detailed steps depend on the particular UP and CP transport option (see below).

Descendent IAB-nodes of IAB-node-5 and their UEs undergo BH RLF-recovery procedure as shown for the UE in the above procedure. The source CU can avoid such BH RLF-recovery procedure for descendant nodes by only migrating the leaf nodes of its topology.

9.7.7 Detailed steps of topology adaptation in architecture 1a

The IAB-related steps A, B and C depend on the particular UP and CP transport option chosen. Some details related to these UP and CP options are provided here:

Step A: Establishment of new route:

- Route establishment uses the same procedure as during IAB-node setup. Routing entries need to be configured on at least all IAB-nodes that reside on the section of the new path that does not overlap with the old path. In case new routing identifiers are used for the new route, all IAB-nodes on the new path need to be configured.
- A forwarding entry needs to be configured on the new IAB-donor DU to interconnect the TNL between IAB-donor DU and CU with the new adaptation-layer route between the new IAB-donor DU and the migrating IAB-node. The details of this forwarding entry depend on the identifiers used for routing on the wireless backhaul.
    - In case the migrating IAB-node supports an IP-address on the adaptation layer (e.g. CP alternative 4), which is derived from a fronthaul IP-prefix owned by the IAB-donor DU, the IAB-node needs to obtain a new IP address when the IAB-donor DU changes. The new IP address can be obtained in the same manner as during IAB-node setup.
- In case end-to-end RLC is supported between UE and IAB-donor DU, IAB-topology adaptation as discussed in this context can be accomplished in the following manner:
    - Option 1: The entire RLC-state is migrated from the old IAB-donor DU to the new IAB-donor DU, which can remain transparent to the UE.
    - Option 2: The RLCs of all the bearers of all the UEs under the migrating IAB-node and the UEs under the descendant IAB-nodes of the migrating IAB-node are reset and re-established, which is not transparent to the UEs.
- In case hop-by-hop RLC is supported between UE and IAB-donor DU, IAB-topology adaptation as discussed in this context may lead to data loss for UL traffic. TR 38.874 section 8.2.3 discusses potential remedies.

Step B: Redirection of F1-U tunnels and F1-AP onto new route:

- In case the IAB-donor DU changes during topology adaptation, the downlink F1-TNL-end points have to be reconfigured. The TNL addresses for F1 are either those of the IAB-donor DU (CP alternative 1, 2, and 3) or of the migrating IAB-node (CP alternative 4). In this latter case, the migrating IAB-node's IP address changes during topology adaptation as discussed under Step A.
    - In case the GTP-U tunnels for the IAB-node are terminated at the IAB-donor DU (e.g. UP alternative a, b and c) these tunnels need to be moved to the target IAB-donor DU. It is assumed this can be done by allocating new GTP TEIDs when the forwarding is updated in the target IAB-donor DU.
    - In case an F1-AP/SCTP connection between the CU and donor-DU is used to deliver CP message towards the IAB-node (e.g. CP alternative 1-3), the F1-AP/SCTP connection between the CU and the target IAB-donor DU need to be updated to allow forwarding of CP message to the IAB-node.

Step C: Release of old route:

- Routing entries of the old route are released as long as they are not used for forwarding on the new path.
- Also, forwarding entries are released on the old IAB-donor DU that interconnect the TNL between IAB-donor DU and CU with the old adaptation-layer route. The details of this forwarding entry depend on the identifiers used for routing on the wireless backhaul.

9.7.8 Goals of Topological Redundancy

Topological redundancy has the goal to enable robust operation, e.g., in case of backhaul link blockage, and to balance load across backhaul links. Establishment and management of topological redundancy is part of topology adaptation.

Mechanisms for topology adaptation for IAB should be designed to ensure support of various multi-connectivity options of the IAB architecture design as described in section 9.2. Under a single IAB-donor DU the following two cases for multi-connectivity in an IAB deployment should be considered. Note that multi-connectivity solutions could also be considered for the case where the redundant routes are to different IAB-donor DUs:

- Case 1: UE is multi-connected to the IAB-donor via redundant routes (traditional DC scenario).

- Case 2: IAB-node is multi-connected to the IAB-donor node via redundant routes.

Multi-connectivity of IAB-node (Case 2 above) can be supported by:

- using a single MT function in the IAB-node,

- using several independent MT functions in the IAB-node, where each MT function makes an independent connection to the network (using normal MT setup).

Regardless of whether a single MT or multiple MT connections are used, the IAB-node will be configured with multiple backhaul RLC-channels associated with the different paths.

Multi-connectivity solutions designed for IAB should take into account the protocol stacks available at the IAB-node and IAB-donor depending on the architecture. This means that, for example, in some alternatives for architecture group 1a, a multi-path framework needs to be designed potentially based on the adaptation layer.

9.7.9 Adding redundant routes in architecture 1a

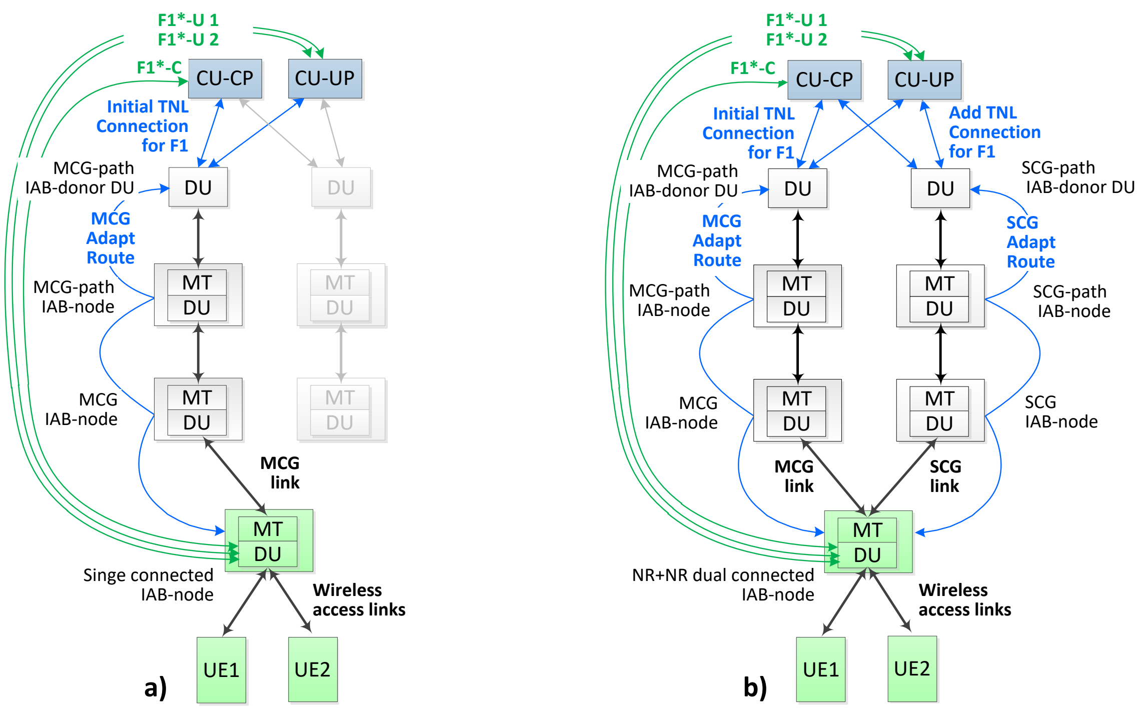

Figure 9.7.9-1: Topology adaptation to create redundant routes for green IAB-node.

NOTE: For the purpose of explanation, the MCG-path and SCG-path in this section are used as an example to indicate two different paths.

Figure 9.7.9-1 shows a ST topology with five IAB-nodes connected to an IAB-donor which holds two DUs. One IAB-node in this topology, referred to as *dual-connecting IAB-node*, starts out with an MCG-link to a parent IAB-node DU and it adds an SCG-link to another IAB-node DU. In this example, the dual-connecting IAB-node has two UE attached, where each UE has a default-bearer established with F1-U GTP-U 1 and F1-U GTP-U 2, respectively. After connecting to the SCG, an additional route is established between the dual-connecting IAB-node DU and the CU via the SCG-path.

Since the new route uses a different IAB-donor DU, its southbound end point is associated with a different IP address on the wireline fronthaul. The CU can add this IP address as an alternative SCTP endpoint for F1-C to the dual-connecting IAB-node DU. This is one example of achieving enhanced CP robustness can be achieved for the dual-connecting IAB-node DU.

In this example, the CU further migrates traffic for UE 2 to the new route while it keeps traffic for UE1 at the initial route. In this manner, load is balanced over both routes.

Figure 9.7.9-1a shows the topology before addition of the SCG. Figure 9.7.9-1b shows the topology after establishment of SCG link and additional route.

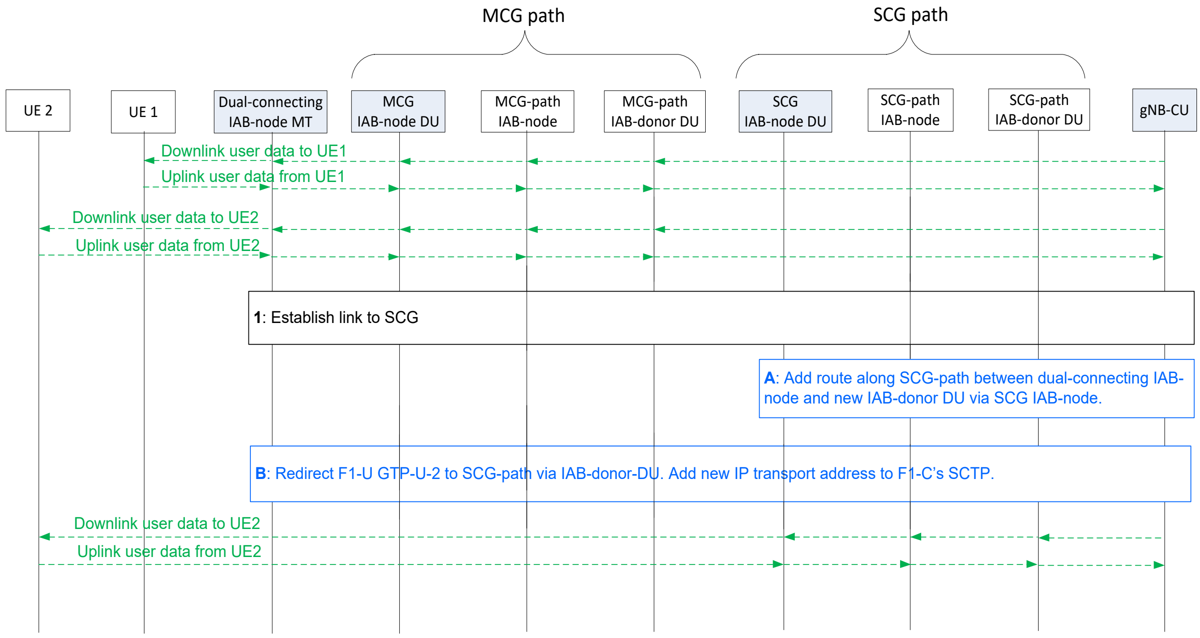

Figure 9.7.9-2: Procedure for adding SCG link and redundant route to dual-connecting IAB-node shown in Figure 9.7.9-1

It is assumed that topology adaptation is initiated by the CU based on measurements reported by the dual-connecting-IAB-node MT. The CU's topology adaptation decision may include measurements by other IAB-nodes. The measurements may be based on a measurement configuration the IAB-nodes received from the CU before.

Figure 9.7.9-2 shows the topology adaptation procedure for the dual-connecting IAB-node. This procedure leverages signalling for adding a link to a SCG as defined for NR in Rel-15 (black box in Fig. 9.7.9-2). Additional signalling is supported for route addition (blue box in Fig. 9.7.9-2).

The procedure contains the following steps:

1. A connection to the SCG on established for the dual-connecting IAB-node MT using Rel-15 NR procedures.

A. The gNB-CU configures a new adaptation-layer route (SCG-route) on the wireless backhaul between dual-connecting IAB-node and IAB-donor DU via the SCG IAB-node. It further configures a forwarding entry between the fronthaul and the new route on the wireless backhaul. The detailed steps depend on the particular UP and CP transport option (see below).

B. For IAB: The gNB-CU adds an alternative SCTP path for F1-C of the dual-connecting-IAB-node DU. The detailed steps depend on the particular CP transport option (see below). The gNB-CU further redirects the F1-U tunnel for UE 2 from the old route to the new route.

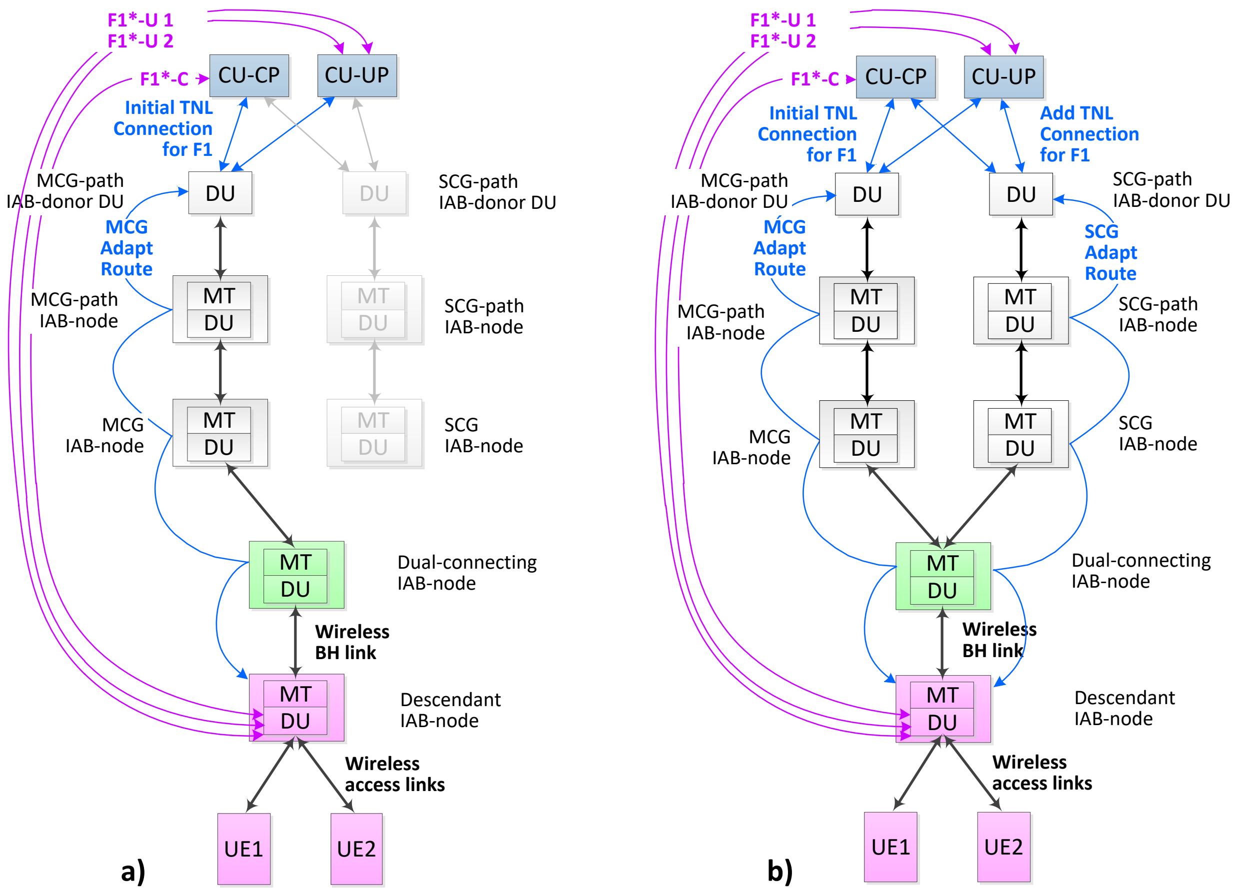

Figure 9.7.9-3: Procedure for adding SCG link and redundant route to a descendant IAB-node

Figure 9.7.9-3 shows establishment of route redundancy for a descendant IAB-node (pink) of the dual-connecting IAB-node (green). The figure illustrates that the above steps A and B also have to be conducted for this descendant IAB-node.

9.7.10 Detailed steps of route addition in architecture 1a

The IAB-related steps A and B depend on the particular UP and CP transport option chosen. Some details related to these UP and CP options are provided here:

Step A: Establishment of new route:

- Route establishment uses the same procedure as during IAB-node setup. Routing entries need to be configured on at least all IAB-nodes that reside on the section of the new path that does not overlap with the old path. In case new routing identifiers are used for the new route, all IAB-nodes on the new path need to be configured.

- A forwarding entry needs to be configured on the new IAB-donor DU to interconnect the TNL between IAB-donor DU and CU with the new adaptation-layer route between the new IAB-donor DU and the migrating IAB-node. The details of this forwarding entry depend on the identifiers used for routing on the wireless backhaul.

- In case the migrating IAB-node supports an IP-address on the adaptation layer (e.g. CP alternative 4), which is derived from a fronthaul IP-prefix owned by the IAB-donor DU, the IAB-node needs to obtain a new IP address when the IAB-donor DU changes. The new IP address can be obtained in the same manner as during IAB-node setup.

- In case end-to-end RLC is supported between UE and IAB-donor DU, migration of the UE-bearer to the new route as discussed in this context can be accomplished in the following manner:

    - Option 1: The entire RLC-state is migrated from the old path IAB-donor DU to the new path IAB-donor DU, which can remain transparent to the UE.

    - Option 2: RLC is reset and re-established, which is not transparent to the UE.

- In case hop-by-hop RLC is supported between UE and IAB-donor DU, migration of the UE-bearer as discussed in this context may lead to data loss for UL traffic. TR 38.974 section 8.2.3 discusses potential remedies.

Step B: Redirection of F1-U tunnels and F1-AP onto new route:

- In case the IAB-donor DU is different for the SCG route that the MCG route, the F1-TNL-end points have to be reconfigured. The TNL addresses for F1 are either those of the IAB-donor DU (CP alternative 1, 2, and 3) or of the migrating IAB-node (CP alternative 4). In this latter case, the migrating IAB-node's IP address changes during topology adaptation as discussed under Step A.

    - For UP, the CU configures new F1*-U tunnels with the dual-connecting-IAB-node's DU via UE Context Modification Request/Response handshake.

    - For CP, the CU can add the new F1-C TNL address as an alternative IP-address to the F1-C's SCTP layer.

9.7.11 Route Management

In case of multiple hops, routing in the RAN part is an important issue that enables a packet to be forwarded via multiple intermediate IAB-nodes between the IAB-donor and a specific UE. This includes establishment of routes, e.g. when the IAB-node connects to the network or when the topology changes. It further includes the selection of a route in case multiple concurrent routes exist between the same end points, e.g. IAB-donor DU and IAB-node. One possible solution is destination-address-based routing, which has the following characteristics:

- A routing table including routing information is configured on each node, such as IAB-donor DU or IAB-node. This routing table can be configured by the CU-CP (e.g. via F1-AP or RRC). The routing information may contain:

    - destination address;

    - next-hop node, BH link or BH RLC channel where packet is forwarded;

    - cost metric.

- The destination address is carried in the packet header. For downlink data transmissions, this destination address is added by the IAB-donor DU and the destination address could be the target IAB-node-ID or UE-ID. For uplink data transmissions, the destination address may be the donor-DU address.

- For each packet, an intermediate IAB-node selects the next hop node for data transmission according to the routing table and the destination address carried in the packet's adaptation info. In case the routing table holds multiple next-hop entries for the same destination address, it selects the next hop based on the cost metric.

One example of route selection in a redundant topology is provided in Figure 9.7.11-1.

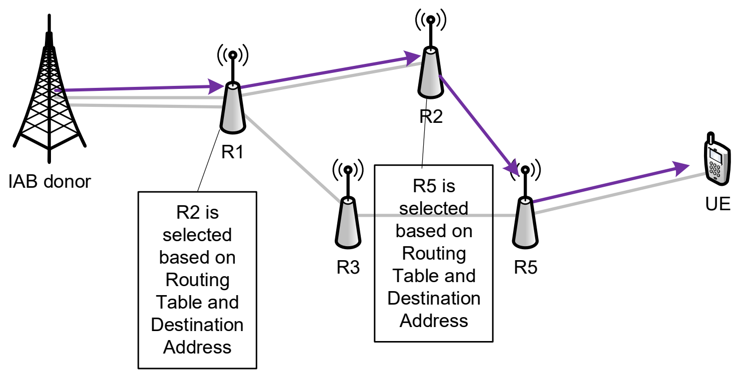

Figure 9.7.11-1: An example of route selection

Since IAB backhaul-link-failure (BH RLF) and node congestion may occur frequently and swiftly in IAB networks, route selection under multi-connectivity (topological redundancy) can achieve a fast response to RLF and overloading of IAB-nodes. In essence, route selection can deal with short-term changes in IAB networks, whereas topology adaptation can only deal with long-term changes.

The cost metric can be defined based on the average (long-term) cost of sending a packet between the two IAB-nodes in the current topology. The next-hop node can be selected at every IAB-node with the least cost metrics to the destination node, under the current conditions of satisfied link quality and buffer load.

The cost metric can be either calculated by the CU and signalled to the IAB-node, or it can be calculated or updated locally at every IAB-nodes.

Since consecutive UE packets may take different or opportunistic UL and DL routes in reaching the destination, mechanisms for dealing with out-of-order packets can be supported.

9.7.12 Backhaul-link-failure recovery scenarios

Due to various reasons, different scenarios of backhaul-link failure may happen in IAB networks. In the following, some example scenarios are illustrated for backhaul-link failure. Each scenario is depicted with an illustrative figure (Figures 9.7.12-1 to 9.7.12-3) aiming at establishing a route between IAB-donor and IAB-node D after BH-link failure, where:

- Nodes A1 and A2 are IAB-donor nodes; nodes B to H are IAB-nodes;
- The blue dashed line represents the established connection between two nodes;
- The red arrow represents the established route after BH-link failure, and the red dashed line represents the new established connection.

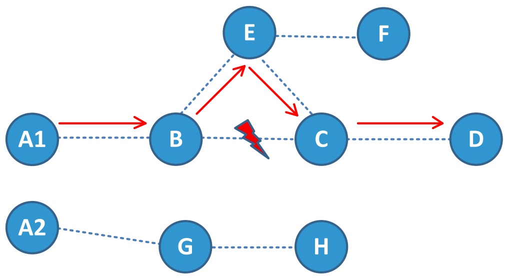

Figure 9.7.12-1: Example of backhaul-link failure scenario 1

Scenario 1

In this scenario (depicted in Figure 9.7.12-1), the backhaul-link failure occurs between on upstream IAB-node (e.g., IAB-node C) and one of its parent IAB-nodes (e.g. IAB-node B), where the upstream IAB-node (IAB-node C) has an additional link established to another parent node (IAB-node E).

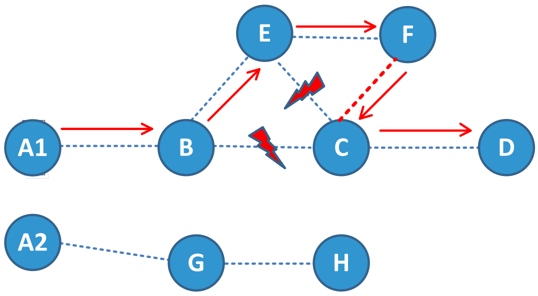

Figure 9.7.12-2: Example backhaul-link failure scenario 2

Scenario 2

In this scenario (depicted in Figure 9.7.12-2), the backhaul-link failure occurs between an upstream IAB-node (e.g. IAB-node C) and all its parent IAB-nodes (e.g. IAB-nodes B and E). The upstream IAB-node (IAB-node C) has to reconnect to a new parent node (e.g. IAB-node F), and the connection between IAB-node F and IAB-node C is newly established).

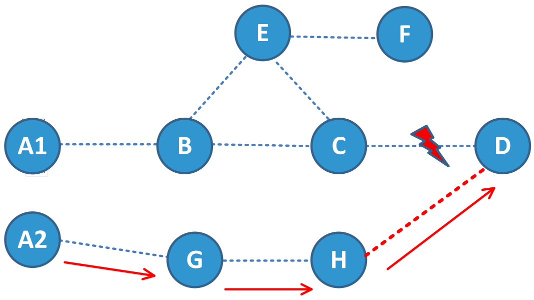

Figure 9.7.12-3: Example backhaul-link failure scenario 3

Scenario 3

In this scenario (depicted in Figure 9.7.12-3), the backhaul-link failure occurs between IAB-node C and IAB-node D. IAB-node D has to reconnect to the new IAB-donor (e.g. IAB-donor A2) via a new route.

9.7.13 Principal steps of BH RLF recovery in architecture 1a

In the following, three scenarios of backhaul RLF and subsequent recovery are discussed:

- Scenario 1: Recovery via an existing BH link (Figures 9.7.13-1, -2).
- Scenario 2: Recovery via a newly established BH link using the same IAB-donor CU (Figures 9.7.13-3, -4).
- Scenario 3: Recovery via a newly established BH link using a different IAB-donor CU (Figures 9.7.13-5, -6).

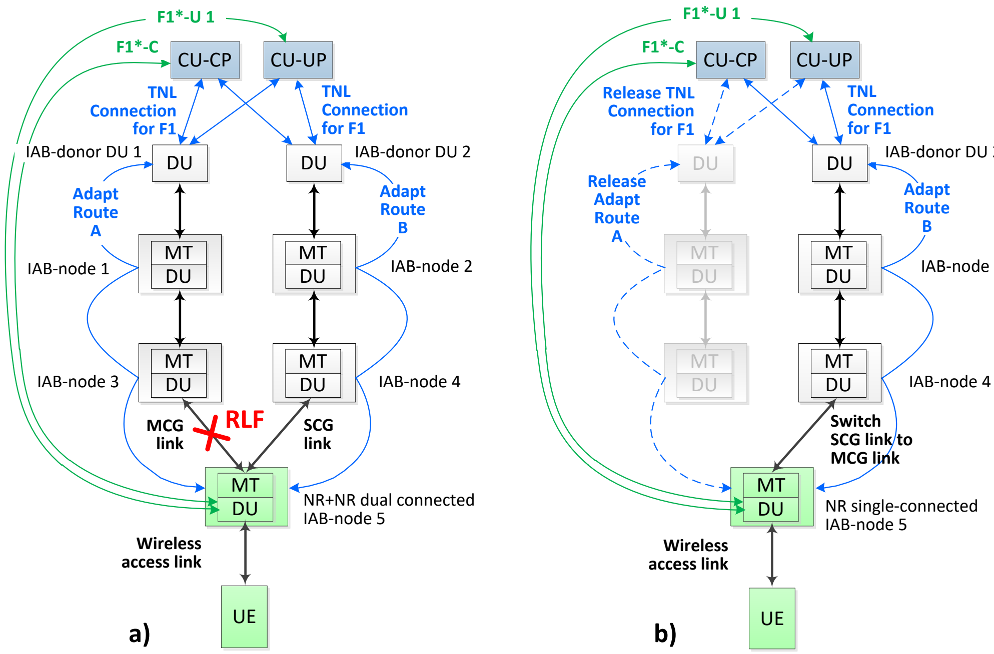

Figure 9.7.13-1: Scenario 1: BH topology with BH RLF (1a) and after recovery using existing backup link (1b)

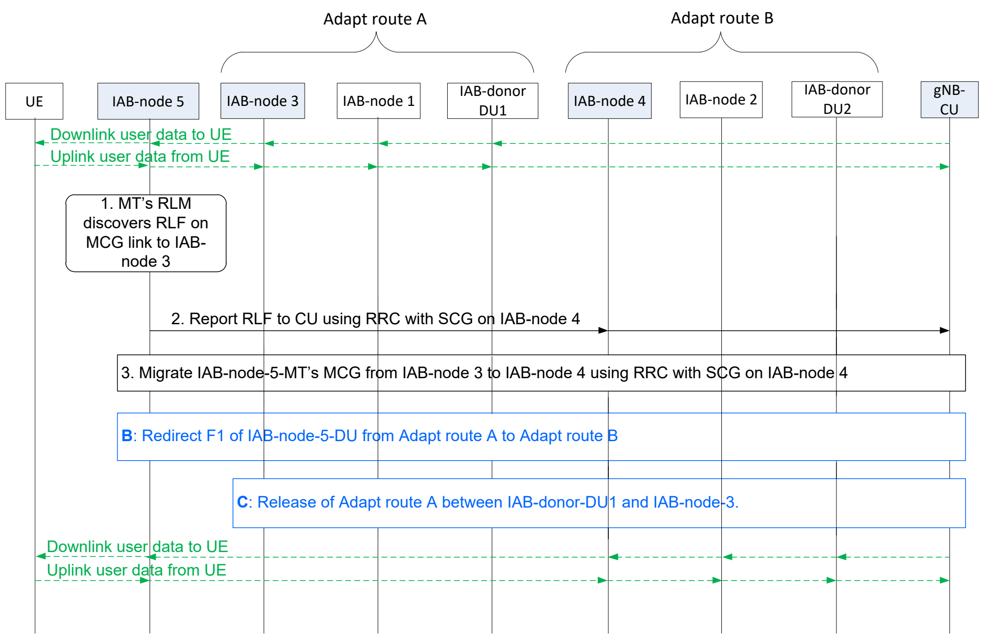

Figure 9.7.13-2: Scenario 1: Procedure for BH RLF recovery using existing backhaul link

In scenario 1 (Figs. 9.7.13-1, -2), the MT on IAB-node-5 is dual-connected to IAB-node-3 and IAB-node-4, which hold MCG and SCG, respectively. Two adaptation layer routes have been established, one referred to as *Adapt route A* via IAB-node-3, and the other referred to as *Adapt route B* via IAB-node 4. It is assumed that *Adapt route A* is used for backhauling of access traffic for the UE attached to IAB-node-5. The RLF is further assumed to occur on the link to the MCG on IAB-node-3. The SCG link to IAB-node-5 may further be in RRC-inactive state.

Figure 9.7.13-2 shows one example for the recovery procedure for scenario 1:

1. The MT on IAB-node-5 conducts RLM on both links and discovers RLF on the link to MCG on IAB-node-3.

2. The MT may report MCG RLF over SCG RRC to the CU-CP using NR DC procedures. This step implies that such reporting is supported by NR DC. In case the SCG link is in RRC inactive state the MT will resume the RRC connection on this link.

3. The CU-CP migrates the MT's MCG from IAB-node-3 to IAB-node-4 using NR DC procedures. This step implies that such procedure is supported by NR DC.

B. The CU-CP migrates the F1*-U connection with the DU on IAB-node-5 to *Adapt route B*. It further uses *Adapt route B* for F1*-C signalling with the DU on IAB-node-5. This procedure is described in sections 9.7.8 and 9.7.9. This step also has to be applied to all descendent IAB-nodes of IAB-node-5.

C. The CU-CP may release *Adapt route A*. This procedure is described in 9.7.5 and 9.7.7.

After BH RLF recovery, the CU-CP can add topologically redundant BH links and routes as discussed in sections 9.7.8 and 9.7.9 to improve robustness.

NOTE: While the Scenario 1 recovery procedure is presented for the case of multi-connectivity of single-MT IAB-nodes, it is expected that a similar solution is applicable to the case of multi-connected multi-MT IAB-nodes.

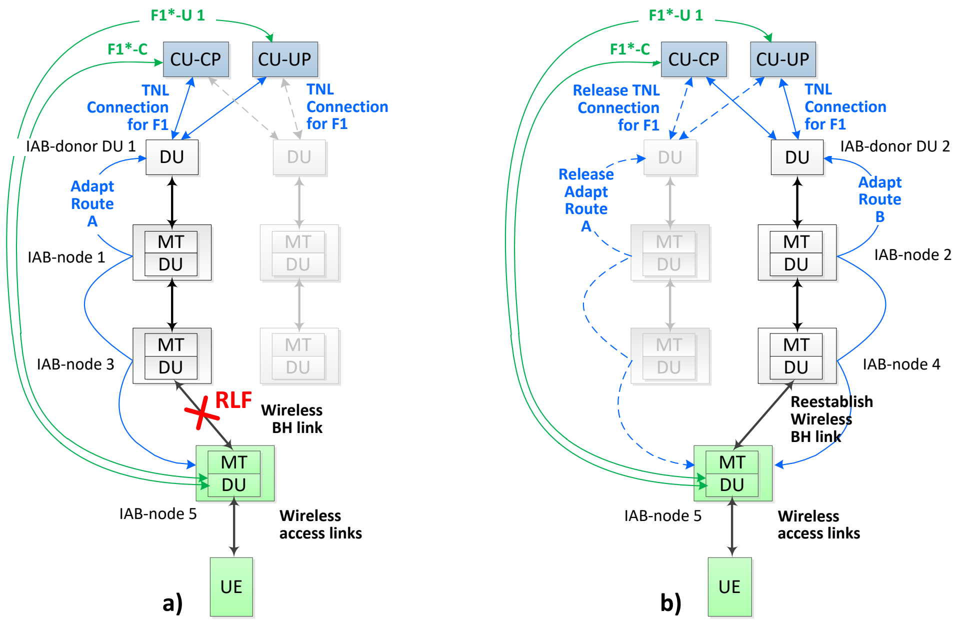

Figure 9.7.13-3: Scenario 2: BH topology with BH RLF (3a) and after recovery via new BH link using <u>same</u> CU (3b)

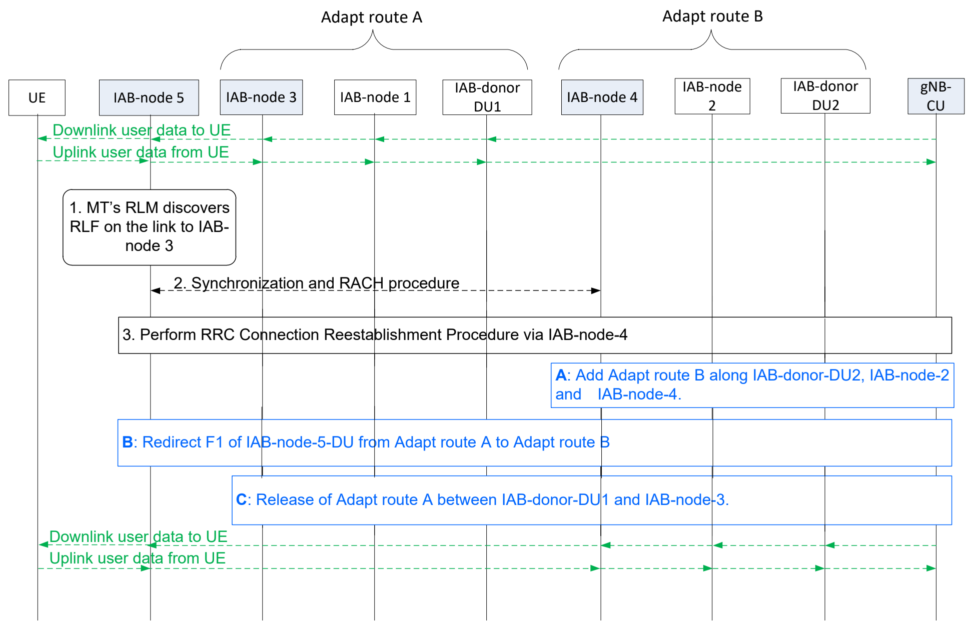

Figure 9.7.13-4: Scenario 2: Procedure for BH RLF recovery using new BH link using <u>same</u> CU

In scenario 2 (Figs. 9.7.13-3, -4), the MT on IAB-node-5 is single connected to IAB-node-3. One adaptation layer route has been established via IAB-node-3 referred to as *Adapt route A*. The RLF is assumed to occur on the link between IAB-node-5 and its parent node IAB-node-3.

Figure 9.7.13-4 shows one example the recovery procedure for scenario 2:

1. The MT on IAB-node-5 conducts RLM on the link to its parent and discovers RLF.

2. The MT on IAB-node-5 synchronizes with the DU on IAB-node-4 and performs RACH procedure.

3. The MT on IAB-node-5 initiates RRC-Connection-Reestablishment leveraging existing NR procedures. Since the CU is the <u>same</u> as before, it has all context of this MT. IAB-node-5 discovers that the CU has not changed through a CU-specific identifier provided to the MT. Consequently, IAB-node-5's DU can keep the existing F1-AP with the CU.

A. The CU-CP establishes *Adapt route B* to IAB-node-5 via IAB-donor DU2, IAB-node-2 and IAB-node-4. This procedure is described in 9.7.5 and 9.7.6.

B. The CU-CP migrates F1*-U with the DU on IAB-node-5 to *Adapt route B*. It further uses *Adapt route B* for F1*-C signalling with the DU on IAB-node-5. This procedure is described in sections 9.7.5 and 9.7.7. This step also has to be applied to all descendent IAB-nodes of IAB-node-5.

C. The CU-CP may release *Adapt route A*. This procedure is described in 9.7.5 and 9.7.6.

After BH RLF recovery, the CU-CP can add topologically redundant BH links and routes as discussed in sections 9.7.8 and 9.7.10 to improve robustness.

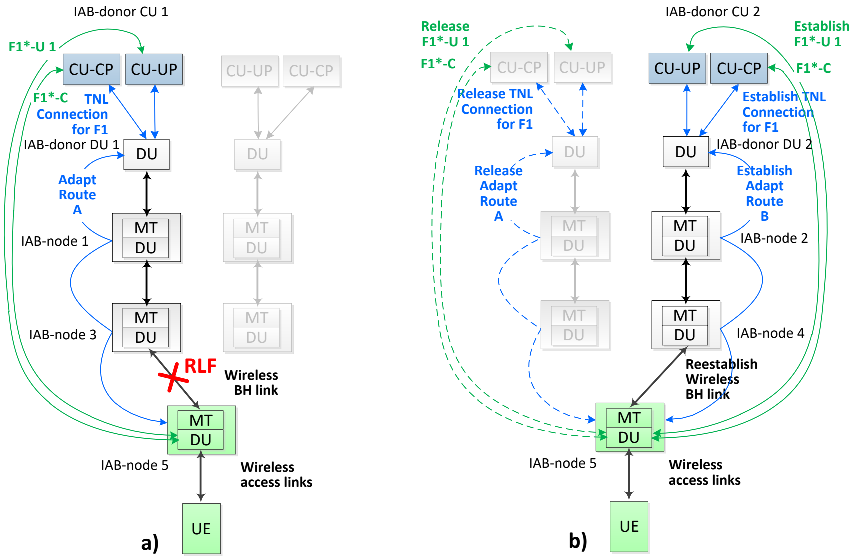

Figure 9.7.13-5. Scenario 3: BH topology with BH RLF (5a) and after recovery via new BH link with <u>different</u> CU (5b)

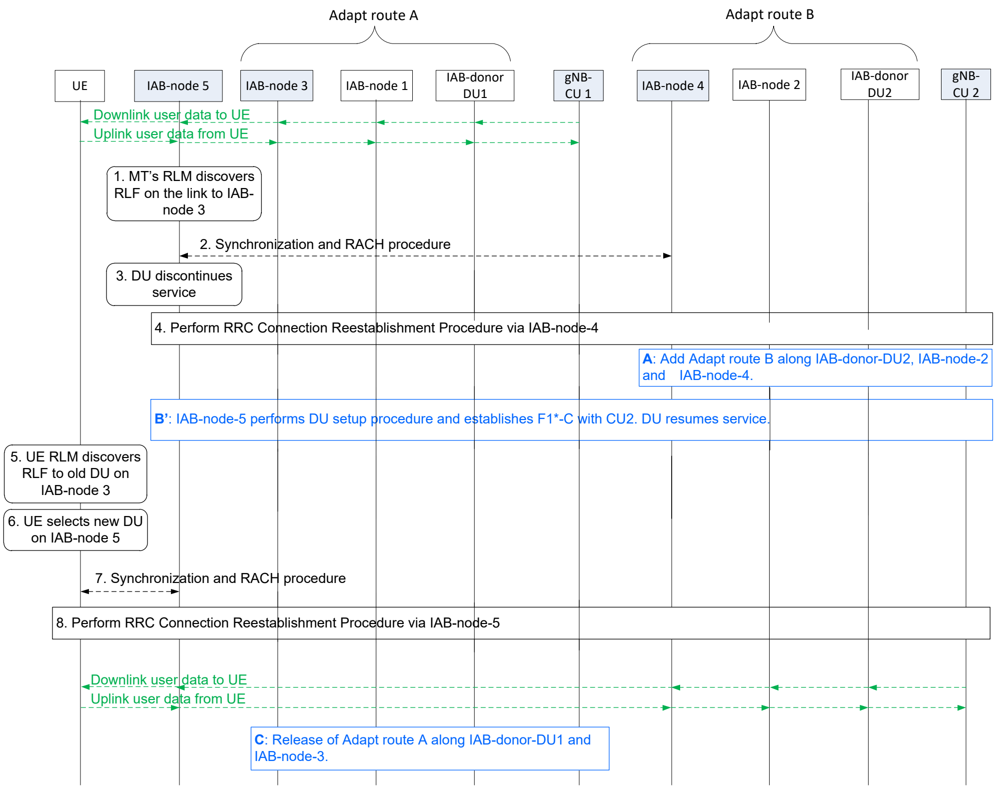

Figure 9.7.13-6. Scenario 3: Procedure for BH RLF recovery using new BH link with <u>different</u> CU

In scenario 3 (Figs. 9.7.13-5, -6), the MT on IAB-node-5 is single-connected to IAB-node-3. One adaptation layer route has been established via IAB-node-3 referred to as *Adapt route A*. The RLF is assumed to occur on the link between IAB-node-5 and its parent node IAB-node-3.

Figure 9.7.13-6 shows one example for the recovery procedure for scenario 3:

1. The MT on IAB-node-5 conducts RLM on the link to its parent and discovers RLF.
2. The MT on IAB-node-5 synchronizes with the DU on IAB-node-4 and performs RACH procedure.
3. The DU on IAB-node-5 discontinues service since it has lost F1*-C connectivity to gNB-CU-1.
4. The MT on IAB-node-5 initiates RRC-Connection-Reestablishment leveraging existing NR procedures. Since the CU is the <u>different</u>, it may or may not be able to fetch the context of this MT. IAB-node-5 discovers that the CU has changed from a CU-specific identifier provided to the MT. Consequently, IAB-node-5 has to restart F1-AP from its DU to the new CU.

A. The new CU-CP establishes *Adapt route B* to IAB-node-5 via IAB-donor DU2, IAB-node-2 and IAB-node-4. This procedure is described in TR 38.874, sections 9.7.5 and 9.7.7.

B'. The DU on IAB-node-5 initiates a new F1*-C connection to the new CU-CP. This procedure is the same as IAB-node setup phase 2.2 described in section 9.3. The DU will obtain a new configuration during that procedure which, e.g., a new PCI. After that, the DU resumes service.

5. The UE determines RLF with the prior DU on IAB-node-5.
6. The UE discovers and selects the new DU on IAB-node-5
7. The UE conducts random access procedure with this new DU on IAB-node-5.
8. The UE initiates RRC-Connection-Reestablishment with the new CU-CP leveraging NR procedures. The new CU-CP may or may not be able to fetch the UE's context from the old CU-CP. The new CU-CP will set up F1*-U for the UE with the new DU on IAB-node-5 following NR procedures.

C. The CU-CP releases *Adapt route A*. This release may be based on F1*-C failure detection. The procedure for the release is described in TR 38.874, sections 9.7.5 and 9.7.7.

After BH RLF recovery, the CU-CP can add topologically redundant BH links and routes as discussed in sections 9.7.8 and 9.7.9 to improve robustness.

Steps 3, 4, A, B', C and potentially steps 1 and 2 also have to be applied by for all descendant IAB-nodes of IAB-node-5. Further, steps 4, 5 and 6 will also be applied by all UEs connected to descendant IAB-nodes of IAB-node-5.

As these steps show, the BH RLF recovery procedure to a different CU may cause multiple subsequent RLFs for descendant IAB-nodes and UEs. This may cause long service interruption for UEs. Further enhancements are needed to reduce this service interruption.

9.7.14 Downstream notification of BH RLF in architecture 1a

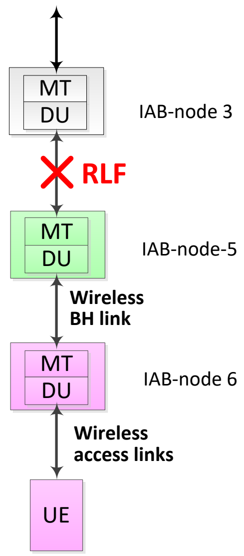

Figure 9.7.14-1: Topology with multiple IAB-node generations below BH RLF

When the IAB-node observes RLF on its parent link, it cannot provide further backhaul service to downstream IAB-nodes. Also, child IAB-nodes cannot further serve their descendant IAB-nodes. One example is shown in Fig. 9.7.14-1, where IAB-node-5 observes RLF to its parent IAB-node-3 and subsequently cannot provide backhaul service to its child node, i.e., IAB-node-6.

While the IAB-node observing RLF is aware about backhaul connectivity loss, the descendent IAB-nodes do not have explicit means to identify this upstream backhaul connectivity loss. In case the RLF can be recovered swiftly, as it can be expected for BH-RLF-recovery scenario 1, there may be no need to explicitly inform the descendant IAB-nodes about the temporary BH connectivity loss. When the BH RLF cannot be recovered swiftly, it may be beneficial to release backhaul connectivity to descendant IAB-nodes so that they themselves can seek means to recover from the BH RLF. For this purpose, three options may be considered:

- Option 1: The IAB-node DU discontinues service. Consequently, the child nodes will also determine BH RLF and follow through the above procedures to recover.

- Option 2: The IAB-node DU explicitly alerts child IAB-nodes about the upstream RLF. Child IAB-nodes receiving this alert can forward the alert further downstream. Each IAB-node receiving such alert initiates BH-RLF recovery as discussed above.

- Option 3: Every IAB-node can regularly share information on, e.g., BH quality, to its child or parent IAB-nodes. In this manner, downstream or upstream RLF can be sensed without taking explicit actions.

In case a descendant IAB-node (such as IAB-node 6) can recover from such an upstream RLF by using one of the procedures described above, its DU can provide BH RLF-recovery for former ancestor nodes (such as IAB-node 5).

9.7.15 Efficient backhaul-link-failure recovery

The recovery procedure for backhaul failure scenarios 2 and 3 consists of identifying an alternate parent node and establishing/re-establishing control plane and user plane through the alternate parent node. However, identifying and attaching to an alternate node can take a significant amount of time and also may not always be possible, e.g due to lost connectivity with Donor CU or due to lack of alternative parent nodes (especially in millimeter-wave deployments). It may be necessary to consider how the IAB network is reorganized when there is a backhaul failure in a way that minimizes interruption time of connection with the IAB-donor.

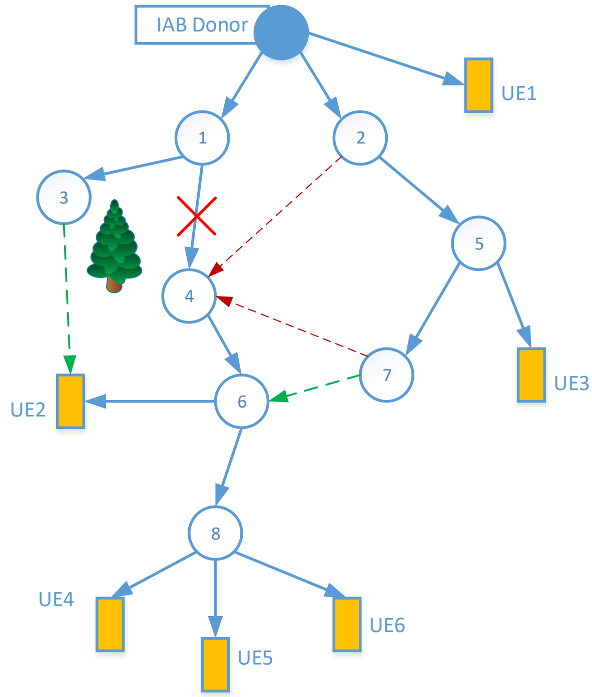

Figure 9.7.15-1: Example for a recovery after BH RLF in an IAB network

Figure 9.7.15-1 illustrates a scenario of a backhaul failure on one of the links in an IAB network. In such scenarios, many IAB-nodes and UEs may be left without a connection to the IAB-donor and may need to find alternate parent nodes. Downstream IAB-nodes (e.g. IAB-nodes 4, 6 in the figure) and the IAB-donor may need to be informed of the backhaul failure. Furthermore, if all the affected IAB-nodes simultaneously try to find alternate parent nodes, the resulting topology may be inefficient.

The following can be considered for recovery from backhaul failures:

- Information can be provided to downstream IAB-nodes regarding backhaul failure including a list of nodes that cannot serve as parent nodes due to the backhaul failure.

- Preparation of alternative backhaul links and routes in advance (i.e. before occurrence of RLF).

9.8 LTE-access over NR backhaul

LTE access over NR backhaul is an important scenario, which allows (legacy) E-UTRAN UEs to use NR backhaul. On the other side, the backhaul link is NR which can provide several benefits e.g. utilize higher frequency bands for backhaul, larger bandwidth, higher throughput, lower latency, etc. IAB should also take into account this deployment scenario. Support of LTE access over NR backhaul needs further discussion.

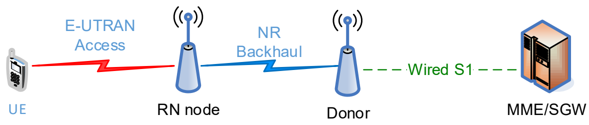

Figure 9.8-1: E-UTRAN access over NR backhaul

10 Comparison

10.1 Comparison of IAB architectures

The following table compares architectures 1a, 1b and 2a.

Table 10.1-1: Comparison among IAB architectures

<table>
<tr><th>Classification</th><th>KPI</th><th>Architecture 1a</th><th>Architecture 1b</th><th>Architecture 2a</th><th>Advantage</th></tr>
<tr><td>Functionality</td><td>Backhaul transport</td><td colspan="2">Over RLC channel</td><td>Over PDU session</td><td>-</td></tr>
<tr><td>Functionality</td><td>Security</td><td colspan="2">End-to-end security between UE and donor CU node</td><td>Hop by hop security in each access link and backhaul link</td><td>-</td></tr>
<tr><td>Functionality</td><td>Termination of UE's NG-U tunnel</td><td colspan="2">At donor CU</td><td>At UE's serving IAB-node</td><td>-</td></tr>
<tr><td>Functionality</td><td>Termination of UE's NG-C connection</td><td colspan="2">At donor CU</td><td>At UE's serving IAB-node</td><td>-</td></tr>
<tr><td>Specification</td><td>Specification for topology discovery</td><td colspan="2">Centralized control via CU-CP with RRC/F1-AP for signalling as well as distributed control via IAB-node</td><td>Distributed protocol by propagation link-end-point-ID pairs toward the donor via RRC</td><td>-</td></tr>
<tr><td>Specification</td><td>Specification for topology management</td><td colspan="2">Centralized control via CU-CP with RRC/F1-AP for signalling as well as distributed control via IAB-node</td><td>Has not been studied</td><td>Architecure1a/1b</td></tr>
<tr><td>Specification</td><td>Specification for route management</td><td colspan="2">Same as for topology management above</td><td>Has not been studied</td><td>Architecure1a/1b</td></tr>
<tr><td>Specification</td><td>Specification for resource management to address half-duplexing constraint and inter-link interference across topology</td><td colspan="2">Same as for topology management above</td><td>Has not been studied</td><td>Architecure1a/1b</td></tr>
<tr><td>Specification</td><td>Core network specification</td><td>Lower
No CN specification needed for UPF/GW.</td><td colspan="2">Minimally higher
CN specification needed for UPF/GW support on IAB-donor and IAB-node.</td><td>Architecure1a</td></tr>
<tr><td>Specification</td><td>RAN specification</td><td colspan="2">Needed
Modification of protocol layers for L2 transport</td><td>Not needed</td><td>Architecure2a</td></tr>
<tr><td>Specification</td><td>Standards Areas Impacted</td><td colspan="2">Mostly RAN</td><td>RAN and also NGC/EPC due to need of UPF/GW</td><td>-</td></tr>
<tr><td>Deployment</td><td>CP scalability with the number of IAB-nodes</td><td colspan="2">Lower
Donor CU-CP is responsible for the RRC connection and DRB management of all the UEs served by the donor DU as well as downstream IAB-nodes. So, donor CU-CP may become bottleneck with more IAB-nodes aggregated.
.</td><td>Higher
Each IAB-node manages the RRC connection and DRBs of its own access UE. Donor IAB-node is only responsible for the RRC connection and DRB management of directly connected UEs.</td><td>Architecure1a/1b</td></tr>
<tr><td>Deployment</td><td>Transport of LTE access & non-3GPP access</td><td>Supported
Over PDU session to UPF, which needs to be deployed</td><td>Supported
Over PDU session to UPF on donor</td><td>Supported
Over PDU session to UPF on parent IAB-node</td><td>-</td></tr>
<tr><td>Deployment</td><td>Compliance with DU/CU deployments</td><td colspan="2">Supported for IAB-node and donor</td><td>Supported for donor</td><td>-</td></tr>
<tr><td>Complexity</td><td>Number of termination points of gNB external interfaces in IAB-node (F1, N2/3, Xn, etc.)</td><td colspan="2">Lower
Only one F1 to donor</td><td>Higher
N2/3 and Xn to surrounding IAB-nodes</td><td>Architecure1a/1b</td></tr>
<tr><td>Complexity</td><td>Need for packet forwarding at</td><td colspan="2">Not needed for intra-CU handover, only needed for inter-CU handover</td><td>Needed for every handover since each IAB-node holds a</td><td>Architecure1a/1b</td></tr>
</table>

	handover to/from IAB-node			CU	
Complexity	Functions supported in IAB-node	MT + DU		MT + DU + CU + UPF	Architecure1a/1b
Security	Vulnerability of IAB-nodes to security attacks (e.g. due to tampering with node)	UE security is not terminated at IAB-node		UE security is terminated at IAB-node	Architecure2a
Processing	Packet processing in intermediate IAB-nodes	Lower No BH PDCP processing		Higher BH PDCP has to be processed on every BH interface	Architecure1a/1b
Processing	Core network signalling during topology adaptation	Lower No UPF or GW has to be configured on IAB-donor or IAB-node.	Slightly higher For inter-CU topology adaption, UPF or GW has to be configured on IAB-donor for topology adaptation	Higher For any topology adaption, establishing new BH link, UPF or GW has to be configured on IAB-donor for topology adaptation	Architecure1a
Performance	CN signaling overhead due to UE mobility	Lower No CN signaling for intra-donor CU node mobility		Higher CN signaling for intra-donor mobility	Architecure1a/1b
Performance	Protocol overhead	BH link contains PHY-MAC-RLC (potentially also IP-UDP-GTP-U)		BH connection contains MAC-RLC-PDCP-SDAP-IP-UDP-GTP-U	-
Performance	QoS	Per-UE-bearer QoS supported on backhaul	QoS only supported per QoS profile on backhaul Per-UE-bearer QoS has not been studied		Architecure1a
Performance	Core network signalling overhead	Only during IAB-node integration and inter-CU RLF recovery.		Also, during every topology adaptation procedure that establishes or releases a BH link.	Architecure1a/1b
Performance	RRC latency	Higher Multi-hop to donor	Lower Single hop to parent		Architecure1a
Performance	Packet processing overhead	Smaller since there is no PDCP/SDAP stack to be processed for backhauling.	Slightly higher since PDCP/SDAP stack needs to be processed for backhauling on access IAB-node and IAB-donor.	Higher since PDCP/SDAP stack needs to be processed for backhauling on each hop.	Architecure1a

Advantages:

- Architecture1a has advantages in 14 KPIs
- Architecture1b has advantages in 9 KPIs
- Architecture2 has advantages in 2 KPIs

Recommendation:

Based on the above comparison, it is feasible to adopt Archtecture1a.

10.2 Comparison of CP alternatives for IAB architectures 1a

Table 10.2 provides a comparison analysis of the five CP alternatives discussed in section 8.3.5. More comparison aspects are not excluded.

Only CP alternatives 2 and 4 are further considered in this study.

Table 10.2-1: Comparison of the five CP alternatives of architecture 1a

Comparison aspects		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Comparison analysis
Transport for CP signaling on wireless plane	UE/IAB-MT's RRC	SRB in access link, SRB over RLC channel in backhaul links	Same as alt 1	Same as alt 1	Same as alt 1	Same as alt 1	SRB is recommended to carry UE/IAB-MT's RRC signaling in all the alternatives. Use of SRB to carry IAB-DU's F1AP may require definition of new SRB(s). Use of DRB to carry IAB-DU's F1AP configures the DRB with high priority.
	IAB-DU's F1AP	SRB of collocated MT	Same as alt 1	Same as alt 1	RLC channel	DRB	
Encapsulation on the wireless plane	UE/IAB-MT's RRC	Within PDCP but without encapsulation in F1-AP of serving IAB-node	Within PDCP and F1-AP of serving IAB-node	Same as alt 1	Same as alt 2	Same with alt 1	The case without encapsulating RRC message into F1-AP message has an impact since the F1 (i.e. non-RRC) information need to be transferred in some other way to the IAB-node.
	IAB-DU's F1AP	Within RRC of collocated MT	Within PDCP of collocated MT	Same as Alt 2	Within DTLS/SCTP/IP above RLC channel	Within PDCP of collocated MT	All options has some protocol impacts compared to normal Uu stack carrying IP packets over PDCP.
Encapsulation (over the wired donor CU-DU link)	UE/IAB-MT's RRC	Native F1-C to donor DU	Within end to end F1-AP/PDCP and Native F1-C to donor DU	Same as Alt1	Native end to end F1-C	Same as Alt1	On alternative 1, 3, 5 the F1-C is terminated in the Donor-DU meaning that the F1-C information related to RRC message need to be transferred in some other way to IAB-node. In alternative 2 the donor DU has some new F1-C transparent tunnelling mechanism where PDCP packets are forwarded to RLC channels. In alternative 4 the donor DU forward IP packets destined for the IAB-node to the RLC channel.
	IAB-DU's F1AP	Within end to end RRC/PDCP and Native F1-C to donor DU	Within end to end PDCP and Native F1-C to donor DU	Same as Alt2	Native end to end IP	Within end to end PDCP and GTP-U to the donor	In all solutions the F1-AP protocol is terminated in IAB-node.
Security of F1AP		Protected by PDCP	Same as alt 1	Same as alt 1	Protected by DTLS	Same as alt 1	Using PDCP for F1-AP security incurs less overhead. The total overhead of F1-AP signalling may be insignificant compared to F1-U traffic.
Routing of control plane PDUs		Adaptation layer is responsible for routing	Same as alt 1	Same as alt 1	Same as alt 1	Same as alt 1	In all alternatives, the adaptation layer is used for routing.
Impact to IAB-donor CU		Support of using donor F1-AP to directly transfer RRC messages to UE or IAB MT Support of using donor F1-AP to transfer end to end F1-AP to IAB DU.	Support of using donor F1-AP to transfer F1-AP messages to the IAB-node	Same as alt 1 for RRC messages to UE or IAB MT Same as alt2 for F1-AP to IAB DU	Support for DTLS	Same as alt 1 for RRC messages to UE or IAB MT Support for transport of F1-AP messages over E1	

Impact to IAB-donor DU	Support for mapping F1-AP messages to the proper adaptation layer address	Same as alt1	Same as alt1	Support for IP routing function (the same functionality as in UP option e)	Same as alt1 for RRC messages to UEs and IAB's MT Support for mapping GTP-U tunnels to the proper adaptation layer address (for F1-AP to IAB DU)	
The transport of RRC-related and non-RRC-related F1-AP messages.	No	Yes	No	Yes	No	Solution 1, 3, 5 transmit F1-AP and RRC messages in different w ays, thereby not being able to transport F1-AP messages to the IAB-node that have embedded RRC message to the UE.

11 Conclusion

The study of Integrated Access and Backhaul for NR considered five architectures referred to as 1a, 1b, 2a, 2b, and 2c.

RAN-3 recommends architecture 1a for a future normative phase. This may not preclude support of architecture 1b, e.g., by implementation.

After studying various IAB design aspects, it is concluded that it is feasible to support the following requirements and functionalities with the recommended IAB architecture:

- Physically fixed IAB-nodes;
- In-band and out-of-band scenarios;
- NR backhauling of NR access traffic;
- SA and NSA mode for the UE and for the IAB-node;
- Multi-hop backhauling;
- Topology adaptation;
- Network synchronization of IAB-nodes.

For architecture 1a, RAN2 studied many-to-one and one-to-one bearer mapping options. An IAB system that supports both bearer mapping options is recommended for Rel.16 work item.

RAN2 studied design examples, which support both bearer mapping options. Design example 1 (section 8.2.10.1) is recommended for the work item. In this design, the adaptation layer resides above RLC, and LCID extension is used to increase the number of UE-bearers supported by the IAB-node with one-to-one bearer mapping. This LCID extension only applies to backhaul RLC channels.

RAN2 studied hop-by-hop and end-to-end RLC ARQ. It is recommended to only support hop-by-hop ARQ in Rel-16.

RAN2 investigated termination of IP at the access IAB-node vs. IAB-donor DU. IP termination at the access IAB-node is recommended for the work item. In this solution, GTP-U is included in the UP stack for F1-U.

The following physical layer features and solutions are recommended to be specified as part of a Rel.16 IAB WI from a RAN1 perspective:

- SSB/RMSI periodicity values assumed by the IAB-node MT for initial access;

- Enhancements for use of SSBs which are orthogonal (TDM and/or FDM) with SSBs used for access UEs, including new periodicities and time-domain mapping/muting patterns;
- Enhancements to support configuration of backhaul RACH resources with different occasion and longer RACH periodicities, compared to access RACH resources without impacting Rel-15 UEs;
- Efficient mechanisms for multiplexing access and backhaul traffic:
  - Semi-static configuration for IAB-node DU resources in case of TDM operation subject to a half-duplex constraint, with further consideration for forward compatibility for potential support of FDM/SDM operation;
  - Case 1 signaling and IAB-node behavior is supported in Rel. 16.
- Dynamic indication (L1 signalling) to an IAB-node of the availability of soft resources for an IAB-node DU;
- In addition, as a secondary priority;
- Enhancements to support additional preamble formats for PRACH allowing for longer RTT, without impacting Rel-15 UEs;
- Efficient mechanisms for multiplexing access and backhaul traffic:
  - Semi-static configuration for IAB-node DU resources in case of FDM/SDM operation is additionally supported.
- Inter-IAB-node CLI measurement coordination/configuration:
  - It is expected that the definition of CLI measurements will be specified in a different WI and can be utilized for Inter-IAB-node CLI measurement.

Annex A: Evaluation methodology

A.1 Evaluation assumptions

This subclause describes the simulation assumptions for evaluating IAB. The system level evaluation assumptions for IAB are provided in Table A.1.1-1.

The reference network for comparing the performance of IAB network is the network as defined in Table A.1.1-1, but without the IAB-nodes.

The following performance metrics should be considered in IAB evaluations:

- Area traffic capacity
- Geometry
  - Per-link Geometry per hop level
  - Min(Geometry) of all links for a given UE route (access and one or more backhaul links) between a donor and UE
- Resource utilization
  - Average RU over nodes per hop level for access traffic is reported
  - Average RU over nodes per hop level for backhaul traffic is reported
- User plane latency (from the donor to the access UE)
- User perceived throughput (UPT) for bursty traffic: the unfinished bursts should be incorporated in the UPT calculation

  - UEs in outage (which is defined as when UEs with traffic to be served but no packets have been delivered to higher layers by the end of the simulation) are included in the CDF for UPT.

- Distribution of minimum backhaul link RSRP of a given route between an IAB-node and IAB-donor
- Distribution of number of child IAB-nodes per IAB-node and per IAB-donor
- Distribution of number of access UEs per IAB-donor
- Hop count distribution

Table A.1-1: System level evaluation assumptions for integrated access and backhaul

<table>
<tr><th>Parameters</th><th>Heterogeneous scenario (dense urban)</th><th>Homogeneous scenario (urban micro)</th></tr>
<tr><td>Layout</td><td><u>Two layer</u>
Macro layer: Hex. Grid (all macro BSs are IAB-donors)
7 sites

Micro layer: Random drop (All micro BSs are all outdoor and are IAB-nodes)
- 1 micro BSs per macro BS
- 3 micro BSs per macro BS

See Figures A.2.1-3 of TR 38.802

IAB-node is assumed to have 3 panels with 120 degree shift relative to each other. Companies can simulate either panel orientation options below.
Option 1: The panel for IAB-node is oriented in a suitable direction after the topology formation (e.g. in the direction of the parent node)
Option 2: Random orientation (independent of topology)
Panel orientation is assumed fixed for a simulation run.</td><td><u>Single layer</u>
Micro layer: Hex. Grid
19 sites

Number of IAB-donors (Ndonor)
1, 3 and 7

Number of IAB-nodes is
19 – Ndonor</td></tr>
<tr><td>Inter-BS distance</td><td>Macro layer: 200m, 500m</td><td>200m</td></tr>
<tr><td>Min distance</td><td><table><tr><td>Distance</td><td>ISD 500m</td><td>ISD 200m</td></tr><tr><td>Minimum distance between Micro TRPs</td><td>40m</td><td>40m</td></tr><tr><td>Minimum distance between Macro TRP and UE</td><td>35m</td><td>10m</td></tr><tr><td>Minimum distance between Micro TRP and UE</td><td>10m</td><td>10m</td></tr><tr><td>Minimum distance between Micro TRPs and Macro TRP</td><td>40 m</td><td>20m</td></tr></table></td><td>N/A</td></tr>
<tr><td>Topology formation</td><td colspan="2">The following factors can be considered as input to the IAB-node parent-node selection, in addition to parent-node RSRP as measured by the IAB-node:
Number of hops to between the candidate parent node to the donor node
"Capacity" measures (downlink and uplink) of links on the path between the candidate parent node to the donor node
e.g. min RSRP of a route, harmonic mean of RSRP, Shannon capacity of the link, IAB-node capability
Load (downlink and uplink) of the candidate parent node as well as nodes on the paths between the candidate parent node to the donor node
Examples: Number of IAB-nodes and access UEs served by a certain node

Note: Other factors to avoid the backhaul link congestion can also be included for parent node selection. The detailed algorithm is up to companies' choice and should be reported by companies.</td></tr>
<tr><td>Carrier frequency</td><td>4 GHz and 30GHz</td><td>4 GHz and 30GHz</td></tr>
<tr><td>Duplex mode</td><td>TDD</td><td>TDD</td></tr>
<tr><td>Aggregated system bandwidth (access + backhaul)</td><td>4GHz: Up to 100MHz (DL+UL)
30GHz: Up to 400MHz (DL+UL)</td><td>4GHz: Up to 100 MHz (DL+UL)
30GHz: Up to 400MHz (DL+UL)</td></tr>
<tr><td>Simulation bandwidth</td><td colspan="2">Per CC BW is up to company (up to 400MHz for 30GHz and up to 100MHz for 4GHz)</td></tr>
</table>

Large-scale channel parameters	Below 6GHz: - Macro-to-UE: 3D UMa - Micro-to-UE: 3D UMi - Macro-to-Micro: 3D UMa (h_{UE} =10m) - Micro-to-Micro: 3D UMi (h_{UE} =10m) - UE-to-UE: A.2.1.2 in TR36.843(***), penetration loss between UEs follows Table A.2.1-13 of TR38.802 Above 6GHz: - Macro-to-UE: 5GCM UMa - Micro-to-UE: UMi-Street canyon - Macro-to-Macro: 5GCM UMa (h_{UE} =25m) - Macro-to-Micro: 5GCM UMa (h_{UE} =10m) - Micro-to-Micro: UMi-Street canyon (h_{UE} =10m) - UE-to-UE: UMi-Street canyon (h_{BS} =1.5m ~ 22.5m), penetration loss between UEs follows Table A.2.1-12 of TR38.802 The path loss for links between the IAB-node and candidate serving IAB-nodes/donors is determined based on N =3 independent large-scale channel realizations (taking into account LOS/NLOS probability and shadow fading). The realization that results in the minimum pathloss between the IAB-node and the associated serving IAB-node/donor is selected.	Below 6GHz: - Micro-to-UE: 3D UMi - Micro-to-Micro: 3D UMi (h_{UE} =10m) - UE-to-UE: A.2.1.2 in TR36.843(***), penetration loss between UEs follows Table A.2.1-13 of TR38.802 Above 6GHz: - Micro-to-UE: UMi-Street canyon - Micro-to-Micro: UMi-Street canyon (h_{UE} =10m) - UE-to-UE: UMi-Street canyon (h_{BS} =1.5m ~ 22.5m), penetration loss between UEs follows Table A.2.1-12 of TR38.802 The path loss for links between the IAB-node and candidate serving IAB-nodes/donors is determined based on N =3 independent large-scale channel realizations (taking into account LOS/NLOS probability and shadow fading). The realization that results in the minimum pathloss between the IAB-node and the associated serving IAB-node/donor is selected.
Fast fading parameters	Below 6GHz: - Macro-to-UE: 3D UMa - Micro-to-UE: 3D UMi - Macro to Macro: 3D UMa O-to-O (h_{UE} =25m); ASA and ZSA statistics(**) updated to be the same as ASD and ZSD; ZoD offset = 0 - Macro to Micro: 3D UMa O-to-O; ASA and ZSA statistics updated to be the same as ASD and ZSD for UMi-Street canyon; ZoD offset = 0 - Micro to Micro: 3D UMi O-to-O (h_{UE} =10m); ASA and ZSA statistics updated to be the same as ASD and ZSD; ZoD offset = 0 - UE to UE: InH for indoor to indoor, and 3D UMi for other cases. ASD and ZSD statistics updated to be the same as ASA and ZSA. Dual mobility support. Above 6GHz: - Macro-to-UE: 5GCM UMa - Micro-to-UE: UMi-Street canyon - Macro to macro: 5GCM UMa O-to-O (h_{UE} =25m); ASA and ZSA statistics updated to be the same as ASD and ZSD; ZoD offset = 0 - Macro to micro: 5GCM UMa O-to-O; ASA and ZSA statistics updated to be the same as ASD and ZSD for UMi-Street canyon; ZoD offset = 0 - Micro to Micro: UMi-Street canyon O-to-O (h_{UE} =10m); ASA and ZSA statistics updated to be the same as ASD and ZSD; ZoD offset = 0 - UE to UE: UMi-Street canyon; ASD and ZSD statistics updated to be the same as ASA and ZSA. Dual mobility support.	Below 6GHz: - Micro-to-UE: 3D UMi - Micro to Micro: 3D UMi O-to-O (h_{UE} =10m); ASA and ZSA statistics updated to be the same as ASD and ZSD; ZoD offset = 0 - UE to UE: InH for indoor to indoor, and 3D UMi for other cases. ASD and ZSD statistics updated to be the same as ASA and ZSA. Dual mobility support. Above 6GHz: - Micro-to-UE: UMi-Street canyon - Micro to Micro: UMi-Street canyon O-to-O (h_{UE} =10m); ASA and ZSA statistics updated to be the same as ASD and ZSD; ZoD offset = 0 - UE to UE: UMi-Street canyon; ASD and ZSD statistics updated to be the same as ASA and ZSA. Dual mobility support.
BS Tx power	Macro layer: Below 6GHz: 44 dBm PA scaled down with simulation BW when system BW is higher than simulation BW. Otherwise, 44 dBm Above 6GHz: 40 dBm PA scaled down with simulation BW when system BW is higher than simulation BW. Otherwise, 40 dBm Micro layer: 4 GHz: 33dBm for 20MHz system bandwidth Above 6GHz: 33 dBm PA scaled down with simulation BW when system BW is higher than simulation BW. Otherwise, 33 dBm.	Below 6GHz: 33dBm PA scaled down with simulation BW when system BW is higher than simulation BW. Otherwise, 33dBm Above 6GHz: 33dBm PA scaled down with simulation BW when system BW is higher than simulation BW. Otherwise, 33dBm EIRP should not exceed 68 dBm (*)

	EIRP should not exceed 73 dBm and 68 dBm for the macro and micro layers respectively(*)	
UE Tx power	Below 6GHz: 23dBm 30GHz: 23dBm EIRP should not exceed 43 dBm (Note1)	
BS antenna configurations	See Table A.2.1-4 of TR38.802. At least for the purpose of IAB evaluations, when the IAB-node has multiple panels, access and backhaul traffic can be sent on any panel, subject to the per IAB-node half duplex constraint.	
BS antenna height	25m for macro cells and 10m for micro cells	10 m
BS antenna element gain + connector loss	See Table A.2.1-4 of TR38.802	
BS receiver noise figure	Below 6GHz: 5dB Above 6GHz: 7dB	
UE antenna configuration	See Table A.2.1-4 of TR8.802.	
UE antenna height	Follow TR36.873	
UE antenna gain	Follow the modeling of TR36.873	
UE receiver noise figure	Below 6GHz: 9dB Above 6GHz: 13dB (baseline performance), 10dB (high performance)	
Traffic model	FTP model 3 with packet size [2]Mbytes. Ratio of access DL/UL traffic = {4:1} - Values can be revisited after tuning the lambda value to achieve target RU	
Traffic load (Resource utilization)	RU target of the donor nodes for the IAB deployment scenarios - Low (0-20%), medium (20 – 55%) and high (55 - 80%) For the non-IAB case: Baseline: The same FTP model parameter values are applied in the non-IAB case Optional: RU target for the non-IAB case: Low (0-20%), medium (20 – 55%) and high (55-80%)	
UE distribution	[30, 60] users per macro sector. UEs are dropped independently with uniform distribution. The number of UEs is fixed for cases with and without IAB-nodes. - 80% indoor (3km/h), 20% outdoor (30km/h) Mix of O2I penetration loss models for higher carrier frequency - Option1 - Low loss model – 80% - High-loss model – 20% - Option2 - Low loss model – 50% - High-loss model – 50%	10 users per sector. UEs are dropped independently with uniform distribution. The number of UEs is fixed for cases with and without IAB-nodes. - 80% indoor (3km/h), 20% outdoor (30km/h) Mix of O2I penetration loss models for higher carrier frequency - Option1 - Low loss model – 80% - High-loss model – 20% - Option2 - Low loss model – 50% - High-loss model – 50%
UE receiver	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.	
Feedback assumption	Realistic	
Channel estimation	Realistic	

Note 1:	See Appendix in R1-164383 and R1-167533 for the derivation of maximum allowed EIRP. EIRP limit is only used for evaluation purpose in RAN1.

A.2 Evaluation results

This section contains references to contributions submitted during the IAB SI containing evaluation results for IAB based on the simulation assumptions provided in Section A.1. Details of the simulation parameters and observations can be found in the corresponding referenced contributions:

R1-1810691: Evaluation results for NR IAB, AT&T

R1-1812860: Evaluation results for NR IAB, AT&T

R1-1811514: Evaluation of topology formation for IAB, Ericsson

R1-1813573: Evaluation of multihop IAB networks, Ericsson

R1-1805924: IAB systemevaluation methodology and preliminary results, Huawei, Hisilicon

R1-1812199: System performance evaluation in multi-hop IAB network, Huawei, Hisilicon

R1-1812203: Consideration on cross-link interference in IAB, Huawei, Hisilicon

R1-1812204: On high order modulation in IAB, Huawei, Hisilicon

R1-1806551: PHY layer enhancement for NR IAB, Intel Corporation

R1-1808692: Evaluation methodology for IAB, Intel Corporation

R1-1812487: Evaluation methodology for IAB, Intel Corporation

R1-1812701: Evaluation of IAB, Nokia, Nokia Shanghai Bell

R1-1812707: On Cross-link Interference Management, Nokia, Nokia Shanghai Bell

R1-1813418: System Level Simulation Results for IAB Networks, Qualcomm

R1-1814060: Evaluation Results for NR IAB, Samsung

R1-1811196: IAB evaluations based on different topology constructions, ZTE, Sanechips

A.2.1 Performance gain of IAB

The following list of contributions contain simulation results for the following performance evaluations:

1) Comparison between network deployments which utilize IAB and deployments with only IAB-donor (i.e. wired backhaul) nodes to provide connectivity for access UEs: R1-1810691, R1-1812199, R1-1806551, R1-1808692, R1-1812701, R1-1813418, R1-1814060.

2) Comparison of different multiplexing approaches for IAB, including dynamic and static TDM and SDM of access and backhaul links: R1-1812199, R1-1812487, R1-1814060.

3) The impact of cross-link interference and benefit of mitigation approaches: R1-1810691, R1-1808692, R1-1812701, R1-1812707.

4) Use of higher order modulation up to 1024 QAM on backhaul links: R1-1812199, R1-1812204.

5) Comparison of single vs. multi-hop IAB networks: R1-1812487.

A.2.2 Topology formation for IAB

The following list of contributions, contain simulation results which investigate different topology formation methodologies, taking into account different factors including:

- Backhaul link RSRP/SINR: R1-1811514, R1-1805924, R1-1812487, R1-1813418, R1-1814060, R1-1811196
- Hop count: R1-1813418, R1-1814060, R1-1811196
- Number of descendent child nodes: R1-1811514, R1-1813418, R1-1814060, R1-1811196
- Traffic load: R1-1813418
- Antenna panel orientation: R1-1813418, R1-1814060
- Spanning tree vs. mesh topologies: R1-1813418
- End-to-End Quality: R1-1811514

A.2.3 Summary

From the results provided, the following conclusions can be made:

- IAB provides significant gains in downlink and uplink user perceived throughput and coverage compared to a baseline deployment without IAB-nodes and the same number of wired nodes. The gains are present for low, medium, and high load scenarios and different resource allocation approaches (including semi-static and dynamic TDM and SDM) which take into account a half-duplex constraint at the IAB-nodes.
- Multi-hop IAB deployments provide benefits at least in terms of link/route quality, between the UE and the serving IAB-donor comparing to a single-hop relay only scenario.
- Higher modulation order using 256QAM & 1024QAM has been evaluated and shown performance gains under the evaluated conditions for IAB.
- Topology adaption based on for example loading or interference, provides benefits compared to a static IAB topology.

Annex B: Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2018-01	RAN2#AH-1801	R2-1800418				TR skeleton	0.0.1
2018-02		R2-1801671				Including agreements of RAN1 AH1801	0.0.2
2018-02		R2-1801675				Including revisions based on email discussion	0.1.0
2018-03	RAN3-#99	R3-181517				Including pCR R3-181517 and pCR R3-181519 (unseen)	0.1.1
2018-04	RAN3-#99bis	R3-182458				Including pCR R3-182458	0.2.0
2018-05	RAN2-#101bis	R2-1806456				Including text proposal R2-1806456	0.2.1
2018-05	RAN2-#102 RAN3-#100					Approval of TR 38.874 V0.2.	0.3.0
2018-05	RAN1-#93 RAN2-#102 RAN3-#100					Including text proposals R1-1807770, R1-1807850, R2-1809010, R2-1809142, R3-183560, R3-183563, R3-183564, R3-183577	0.3.1
2018-06	RAN2-#102	R2-1809731 R3-183730				Including text proposal R2-1809099 on CP aspects of arch group 1	0.3.2
2018-08	RAN2-#AH-1807 RAN3-AH-1807	R2-1812054 R3-184692				Including text proposals R2-1810810, R2-1810811, R2-1810972, R2-1810973, R3-184225, R3-184254, R3-184278, R3-184313, R3-184347, R3-184369	0.4.0
2018-10	RAN1-#94 RAN2-#103 RAN3-#101	R2-1814069 R3-185518				Including text proposals R2-1813023, R1-1813152, R2-1813454, R3-184693, R3-185152, R3-185153, R3-185301, R3-185312	0.5.0
2018-11	RAN1-#94bis RAN2-#103bis RAN3-#101bis					Including text proposals R2-1814371, R2-1814878, R2-1815656, R2-1816061, R2-1816062, R3-186208, R3-186259, R3-186260, R3-186263, R1-1812078	0.6.0
2018-11	RAN2-#103bis					Including text proposal R2-1815660	0.6.1
2018-11	RAN2-#103bis	R3-187091 R2-1818568				Including text proposal R2-1815349	0.6.2
2018-11	RAN1-#95 RAN2-#104 RAN3-#102	R2-1819125				Including text proposals R1-1811490, R2-1816873, R2-1818742, R2-1818762, R2-1818763, R2-!818765, R2-1818790, R3-187183, R3-187184, R3-187186, R3-187256, R3-187257, R3-187272, R2-1816874	0.7.0
2018-12	RAN#82	RP-182329				Submitted to RAN#82 for approval	1.0.0
2018-12	RAN#82					Approved and raised to version 16.0.0 (MCC). TheTR is now under change control.	16.0.0