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5जी और उससे आगे के लिए एक सामान्य रिले आर्किटेक्चर

A Generic Relay Architecture for 5G & Beyond

ISO 9001:2015

दूरसंचार अभियांत्रिकी केंद्र

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ABSTRACT

This specification defines a new architecture for wireless relays in Fifth Generation (5G) and Beyond networks utilizing the existing Third Generation Partnership Project (3GPP) defined network elements and interfaces. The solution is based on 3GPP defined gNodeB (gNB) Centralized Unit (CU) and Distributed Unit (DU) split architecture. The solution consists of a relay node and a donor node. The relay node comprises of a gNB-DU serving the User Equipments (UEs) via New Radio (NR)-Uu interface. The backhaul connectivity between the relay node and the donor node is facilitated via the 5G system provided Protocol Data Unit (PDU) session. The donor node comprises of the gNB-CU with additional N6 interface with a User Plane Function (UPF) to facilitate PDU (Internet Protocol) session connectivity with the relay nodes.

HISTORY SHEET

Sl. No.	Document Number	Title	Remarks
1.	TEC 65253:2024 TSDSI STD 5002 V1.0.0	A Generic Relay Architecture for 5G & Beyond	

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V0.1.0 (SGN Internal version number)	December 2022	Initial Proposal to SGN (SWIC813)
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Abstract

This specification defines a new architecture for wireless relays in Fifth Generation (5G) and Beyond networks utilizing the existing Third Generation Partnership Project (3GPP) defined network elements and interfaces. The solution is based on 3GPP defined gNodeB (gNB) Centralized Unit (CU) and Distributed Unit (DU) split architecture. The solution consists of a relay node and a donor node. The relay node comprises of a gNB-DU serving the User Equipments (UEs) via New Radio (NR)-Uu interface. The backhaul connectivity between the relay node and the donor node is facilitated via the 5G system provided Protocol Data Unit (PDU) session. The donor node comprises of the gNB-CU with additional N6 interface with a User Plane Function (UPF) to facilitate PDU (Internet Protocol) session connectivity with the relay nodes.

Mobility of UEs and Relay nodes are handled within the proposed architecture. The architecture also supports Multi-hop configuration. Use cases such as Vehicle Mounted Relays (VMR), and Uncrewed Aerial Vehicle (UAV) based relays are supported in this architecture. The architecture can also be extended to support Multi-Radio Access Technology (Multi-RAT) relays.

1 Definitions, Abbreviations &Acronyms

1.1 Definitions

For the purposes of the present document, following terms and definitions will apply.

Term	Definition
Defined for this Draft	
Mobile-Donor BS	Modified eNB/gNB node to support wireless backhauling of relay nodes in the architecture proposed in this draft by terminating interfaces towards the core network and higher layers of the radio interface towards UEs.
Mobile-Relay Node	Relay Node which hosts the radio stack to facilitate network access to the UE in the proposed LTE relay architecture.
Mobile-Donor-eNB	Mobile Donor BS introduced as a replacement for DeNB to support wireless backhauling of relay nodes in the proposed LTE relay architecture.
Mobile-IAB Node	IAB node which hosts the radio stack to facilitate network access to the UE in the proposed IAB architecture.
Mobile-IAB Donor	Mobile Donor BS comprising gNB-CU along with a dedicated UPF to support wireless backhauling of Mobile-IAB nodes in the proposed IAB architecture.
SAT-IAB-MT	The Sat-IAB-MT functionality corresponds to the IAB-UE functionality where the MT stack is a satellite-UE stack.
SAT-M-IAB-Node	Satellite-Mobile-IAB Node hosts the radio stack to facilitate network access to the UEs through satellite in the proposed IAB architecture. It can be deployed as a stationary or mobile node or mounted on airborne vehicles.
Used from 3GPP Specifications	
BH RLC channel	An RLC channel between two nodes, which is used to transport backhaul packets. [5]
Child node	IAB-DU's and IAB-donor-DU's next hop neighbor node; the child node is also an IAB-node. [5]
Downstream	Direction toward child node or UE in IAB-topology. [5]
gNB	Node providing NR user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC. [5]
gNB-CU	Logical node hosting RRC, SDAP and PDCP protocols of the gNB or RRC and PDCP protocols of the en-gNB that controls the operation of one or more gNB-DUs. The gNB-CU terminates the F1 interface connected with the gNB-DU. [6]

gNB-DU	Logical node hosting RLC, MAC and PHY layers of the gNB or en-gNB, and its operation is partly controlled by gNB-CU. One gNB-DU supports one or multiple cells. One cell is supported by only one gNB-DU. The gNB-DU terminates the F1 interface connected with the gNB-CU. [6]
IAB-donor	gNB that provides network access to UEs via a network of backhaul and access links. [5]
IAB-donor-CU	gNB-CU of an IAB-donor, terminating the F1 interface towards IAB-nodes and IAB-donor-DU. [6]
IAB-donor-DU	gNB-DU of an IAB-donor, hosting the IAB BAP sublayer (as adapted from 3GPP TS 38.340[1]), providing wireless backhaul to IAB-nodes. [6]
IAB-DU	gNB-DU functionality supported by the IAB-node to terminate the NR access interface to UEs and next-hop IAB-nodes, and to terminate the F1 protocol to the gNB-CU functionality, as defined in 3GPP TS 38.401[2], on the IAB-donor. [5]
IAB-MT	IAB-node function that terminates the Uu interface to the parent node using the procedures and behaviors specified for UEs unless stated otherwise. IAB-MT function used in 38-series of 3GPP Specifications corresponds to IAB-UE function defined in 3GPP TS 23.501[3]. [5]
IAB-node	RAN node that supports NR access links to UEs and NR backhaul links to parent nodes and child nodes. The IAB-node does not support backhauling via LTE. [5]
Multi-hop backhauling	Using a chain of NR backhaul links between an IAB-node and an IAB-donor. [5]
NG-C	Control plane interface between NG-RAN and 5GC. [5]
NG-U	User plane interface between NG-RAN and 5GC. [5]
NR backhaul link	NR link used for backhauling between an IAB-node and an IAB-donor, and between IAB-nodes in case of a multi-hop backhauling. [5]
Parent node	IAB-MT's next hop neighbor node; the parent node can be IAB-node or IAB-donor-DU. [5]

1.2 Abbreviations and Acronyms

Abbreviation/Acronym	Expansion
3GPP	3rd Generation Partnership Project
5G	5th Generation
5GC	5th Generation Core Network
AMF	Access and Mobility Function
BAP	Backhaul Adaptation Protocol
BS	Base Station
CN	Core Network
CP	Control Plane
DeNB	Donor eNodeB
DN	Data Network
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
F1AP	F1 Application Protocol
IAB	Integrated Access and Backhaul
IAB-MT	IAB Mobile Termination
gNB	Next Generation NodeB
gNB-CU	gNB Centralized Unit
gNB-CU-CP	gNB-CU Control Plane
gNB-CU-UP	gNB-CU User Plane
gNB-DU	gNB Distributed Unit
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service

GTP	GPRS Tunneling Protocol
IP	Internet Protocol
IP-CAN	IP-Connectivity Access Network
LTE	Long Term Evolution
MAC	Medium Access Control
MME	Mobility Management Entity
mmWave	Millimeter Wave
M-DBS	Mobile-Donor Base Station
M-DeNB	Mobile-Donor-eNB
M-IAB-donor	Mobile-IAB Donor
M-IAB-node	Mobile-IAB Node
M-RN	Mobile-Relay Node
N3IWF	Non-3GPP InterWorking Function
NAS	Non-Access Stratum
NavIC	Navigation with Indian Constellation
NG-RAN	Next Generation Radio Access Network
NR	New Radio
NTN	Non-Terrestrial Networks
OAM	Operations, Administration and Maintenance
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDU	Protocol Data Unit
P-GW	PDN Gateway
PHY	Physical Layer
PTP	Precision Time Protocol
QoS	Quality of Service
RAN	Radio Access Network

RAT	Radio Access Technology
RLC	Radio Link Control
RLF	Radio Link Failure
RN	Relay Node
RRC	Radio Resource Control
RRM	Radio Resource Management
S1AP	S1 Application Protocol
SAT-IAB-MT	Satellite-IAB-Mobile Termination
SAT-M-IAB-Node	Satellite-Mobile-IAB Node
SCTP	Stream Control Transmission Protocol
SDAP	Service Data Adaptation Protocol
S-GW	Serving Gateway
TNL	Transport Network Layer
UAV	Uncrewed Aerial Vehicle
UAS	Uncrewed Aerial System
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications Systems
UPF	User Plane Function
UP	User Plane
UTM	Uncrewed Aerial System Traffic Management
VMR	Vehicle Mounted Relay
WLAN	Wireless Local Area Network
X2AP	X2 Application Protocol

2 Introduction

Network densification in Fifth Generation (5G) wireless networks and beyond is a key enabler for high spectral efficiency and capacity improvements which are required to support massive mobile traffic volumes. With a substantial increase in the density of Base Stations (BSs), ultra dense networks pose high operation and capital costs for network operators as each BS needs to connect to the Core Network (CN) through a wired fiber connection. Wireless backhauling using relays is a promising solution that can help to quickly deploy ultra dense networks in a cost-effective manner without the accompanying extension of the transport network. Currently, India has very low fiber penetration to base stations which makes wireless backhaul crucial to ensure that a large percentage of the population gets access to 5G connectivity in the foreseeable future.

Relaying in cellular networks has been discussed a lot as the use of relaying has shown to be a promising solution for extending the coverage of wireless networks and boosting the network capacity. Recognizing the importance of wireless backhauling using relays, 3rd Generation Partnership Project (3GPP) introduced specifications for base stations with wireless backhauling capabilities for Long Term Evolution (LTE)/LTE-A. Further to this, 3GPP has standardized a solution for multi-hop relaying support over 5G New Radio (NR) in Release 16 called Integrated Access and Backhaul (IAB). Despite the consensus about IAB's ability to reduce costs, designing an efficient and high-performance IAB network which can cater to a wide range of deployment scenarios and use cases is still a challenge. The limitations of the 3GPP LTE relay/5G IAB solutions established the need for starting a work item (NIP248) on "Relay/IAB support in LTE/5G networks", which was approved in the SGN TP Meeting held in December of 2020.

3 Scope

This document describes the architectures, protocols and other aspects related to wireless backhauling using relays, based on the scope below:

- Study the use cases and limitations of existing relay architectures
- Define design goals for a generic architecture to address limitations/support new use cases
- Standardize a potential architecture taking care of the design goals

4 Relay functionality in existing 3GPP networks

4.1 LTE relay architecture

This section covers details of the 3GPP LTE relay architecture which enables wireless relaying in Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). E-UTRAN architecture is briefly discussed to provide a perspective on how the LTE relay architecture has evolved. The architecture for supporting LTE relay nodes, its components and functionalities, as defined by 3GPP Specifications are discussed further.

E-UTRAN architecture

Figure 1 provides an overview of the E-UTRAN architecture and the associated functional entities. The E-UTRAN network consists of multiple BS nodes referred to as E-UTRAN NodeBs (eNodeB/eNB) connected to the Evolved Packet Core (EPC) via S1 interface. EPC's functional component Mobile Management Entity (MME) is connected via S1-MME interface and Serving Gateway (S-GW) is connected via S1-U interface with the eNB. eNBs can be interconnected through the X2 interface.

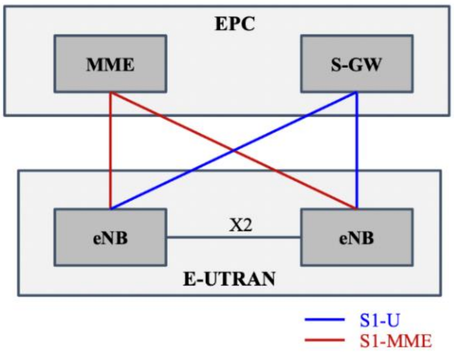

Figure 1. E-UTRAN architecture (Courtesy: 3GPP TS 36.401 [2])

LTE relay architecture

Figure 2 provides an overview of the relay architecture in the LTE network. In order to support relaying in E-UTRAN, a new node called Donor eNB (DeNB) is introduced to provide wireless backhaul connectivity to the Relay Nodes (RN). The RN connects to DeNB via a modified version of the E-UTRA radio interface referred to as the Un interface. The RN supports eNB functionality to terminate the radio protocols of the E-UTRA radio interface towards User Equipments (UEs) and the S1 and X2 interfaces towards the DeNB. In addition to the eNB functionality, the RN also supports a subset of the UE functionality (physical layer, layer-2, Radio Resource Control (RRC), and Non-Access Stratum (NAS)) in order to wirelessly connect to the DeNB over the Un interface. The DeNB is a modified eNB that embeds and provides S1 and X2 proxy functionalities between an RN and other nodes in the network such as MME, S-GW and eNBs. The DeNB appears as an MME (for S1-MME), an eNB (for X2) and an S-GW (for S1-U) to the RN. The DeNB also handles S-GW and P-GW functions needed for the RN operation and terminates the S11 interface towards the MME which is serving the RN.

There is an S1 interface between each RN and its DeNB, and there is one S1 interface between the DeNB and each MME in the MME pool. There is an X2 interface relation between each RN and its DeNB, while the DeNB may also have X2 interface relations to neighbouring eNBs. The S1 and X2 interface control/user plane packets are mapped to radio bearers over the Un interface.

The DeNB processes and forwards all S1 messages between the RN and the MMEs for all UE-dedicated procedures. For non-UE-dedicated S1-Application Protocol (S1-AP) procedures, messages are terminated at the DeNB and handled locally between the RN and the DeNB or between the DeNB and the MME(s). The DeNB processes and forwards all X2 messages between the RN and other eNBs for all UE-dedicated procedures. All non-UE-dedicated X2-Application Protocol (X2-AP) procedures are terminated at the DeNB, and handled locally between the RN and the DeNB, and between the DeNB and other eNBs. The S1-AP/X2-AP messages are encapsulated by Stream Control Transmission Protocol/Internet Protocol (SCTP/IP). While the RN connects to the DeNB via the Un interface using the same radio protocols and procedures as a UE connecting to an eNB, the RRC and Packet Data Convergence Protocol (PDCP) layers support some additional relay-specific functionalities on the RN.

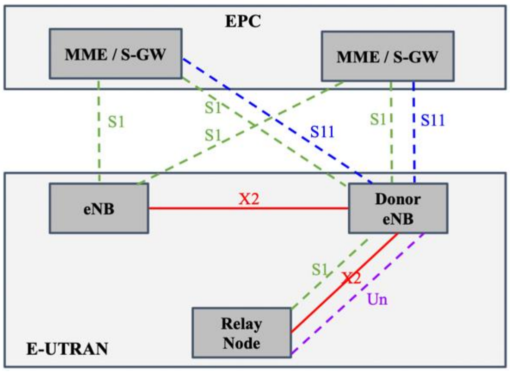

Figure 2. E-UTRAN architecture supporting RNs (Courtesy: 3GPP TS 36.300 [4])

The S1-U protocol stack for supporting RNs uses GPRS Tunneling Protocol (GTP) to transfer user data from the DeNB to RN. There is a GTP tunnel per UE bearer from the S-GW of the UE towards the DeNB which is then switched to another GTP tunnel at the DeNB towards the RN (one-to-one mapping). The X2-U protocol stack for supporting RNs has a GTP forwarding tunnel associated with each UE Evolved Packet System (EPS) bearer subject to forwarding, spanning from the other eNB to the DeNB, which is switched to another GTP tunnel in the DeNB, towards the RN (one-to-one mapping). The Control Plane (CP) and User Plane (UP) protocol stacks of S1/X2/Un interfaces for E-UTRAN with relay nodes are discussed in detail in 3GPP TS 36.300 [4].

4.2 IAB architecture in 5G networks

This section covers details of 5G supported IAB architecture [5] which enables wireless relaying in Next Generation Radio Access Network (NG-RAN). First, NG-RAN architecture [6] is briefly discussed to provide a perspective on how IAB architecture has evolved. Next, the architecture for IAB, its components and functionalities, as defined by 3GPP Specifications, are discussed.

NG-RAN architecture

Figure 3 provides an overview of the functional entities of the existing NG-RAN architecture in the 5G network. The NG-RAN consists of multiple Next Generation NodeBs (gNBs) connected to the 5G Core via the NG Interface. Xn-C interface allows inter-gNB connectivity. A gNodeB may be composed of two units, the gNB Centralized Unit (gNB-CU) and gNB Distributed Unit (gNB-DU) which are connected to each other over the F1 interface [8][9]. There can be multiple gNB-DUs connected to a single gNB-CU in a gNodeB. While the gNB-DU comprises the lower layers (Radio Link Control (RLC), Medium Access Control (MAC), Physical Layer (PHY)), the remaining protocol entities reside in the gNB-CU. A gNB-CU may further consist of a control plane component called gNB-CU-CP and a user plane component called gNB-CU-UP.

A gNB may consist of one gNB-CU-CP managing multiple gNB-CU-UPs and multiple gNB-DUs. The gNB-CU-CP hosts the RRC protocol and the control plane part of PDCP to provide control plane termination towards a UE. The gNB-CU-CP terminates the E1 interface connected with the gNB-CU-UP and the F1-C interface connected with the gNB-DU. A gNB-CU-UP hosts the user plane part of the PDCP protocol and the Service Data Adaptation Protocol (SDAP). The gNB-CU-UP terminates the F1-U interface connected with the gNB-DU. NG-C interface from gNB-CU-CP provides control plane connectivity to Access & Mobility Management Function (AMF) and NG-U interface from gNB-CU-UP provides data plane connectivity to User Plane Function (UPF) in the core network.

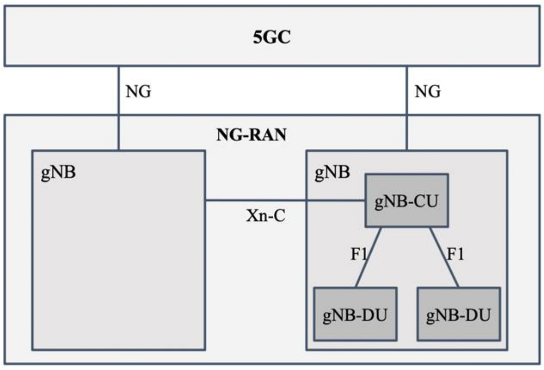

Figure 3. 5G NG-RAN architecture (Courtesy: 3GPP TS 38.401 [6])

On the gNB-CU-CP, for the control plane communications towards AMF, SCTP is used on top of the IP layer. The application layer signalling protocol is referred to as NG Application Protocol (NGAP). SCTP along with NGAP provides guaranteed delivery of signalling Protocol Data Units (PDU) towards the AMF, while SCTP along with F1AP is used to relay PDCP-C/RRC messages between the gNB-DU and gNB-CU-CP. On the gNB-CU-UP, for user plane communications towards UPF, GTP-U is used on top of User Datagram Protocol (UDP)/IP to carry the user plane PDUs. GTP-U over UDP/IP is also used to relay PDCP-U/SDAP messages between the gNB-DU and gNB-CU-UP.

IAB architecture

The IAB architecture employs an extension of the gNB functionality which is split into gNB-CU and gNB-DU [6]. The relaying node, referred to as 'IAB-Node', supports access and backhauling via NR. It is a modified gNB-DU with radio interfaces to support both access and backhaul over NR. A modified gNB called 'IAB-Donor' which is a combination of gNB-CU and gNB-DU, is introduced with additional capabilities to manage multiple IAB-nodes. IAB-donor acts as a terminating node for NR backhauling on the network side. Backhauling can occur either via a single hop or via multiple hops. All IAB-nodes that are connected to an IAB-donor via one or multiple hops form a directed acyclic graph (DAG) topology [5] with the IAB-donor as its root. The IAB-donor performs centralized resource and route management within the IAB topology. Figure 4 provides an overview of the functional entities in the existing 5G IAB architecture.

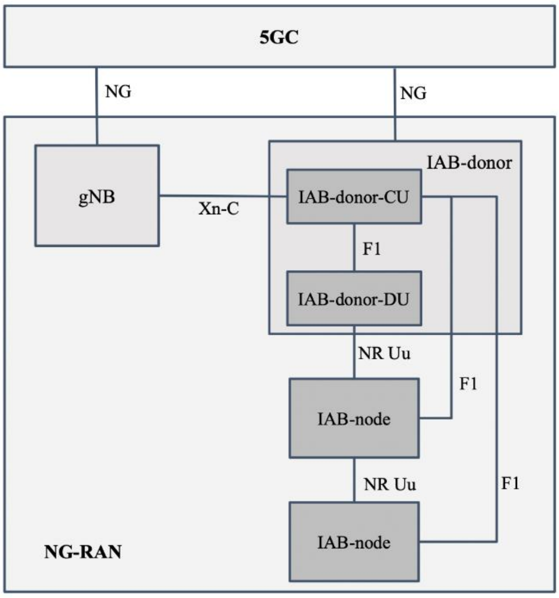

Figure 4. Existing 5G IAB architecture (Courtesy: 3GPP TS 38.401 [6])

An IAB-node consists of two functions, namely, IAB-Distributed Unit (IAB-DU) and IAB-Mobile Termination (IAB-MT). IAB-DU function of the IAB-node supports wireless backhauling towards core network by terminating the NR Uu access interface towards UEs or a neighbour IAB-node, and also terminates the F1 interface with the IAB-donor-CU. IAB-MT function of the IAB-node supports a subset of the UE functionalities of the NR Uu interface in order to connect to the IAB-DU on a neighbour IAB-node or IAB-donor-DU, to connect to the IAB-donor-CU, and to the core network. An IAB-node referred to as parent node, is the neighbour of the IAB-MT function on an IAB-node. A child node is the neighbour node of the IAB-DU function on an IAB-node or the IAB-donor-DU.

The F1-C/F1-U traffic between an IAB-node's IAB-DU function and IAB-donor-CU are backhauled via the IAB-donor-DU and the optional intermediate hop IAB-node(s). The F1 interface uses an IP transport layer between IAB-DU and IAB-donor-CU, comprising UDP and GTP-U on top of IP for the user plane and SCTP on top of IP for the control plane. The IAB-MT of each IAB-node sustains NAS connectivity to the 5G core. Signalling between the IAB-MT on an IAB-node and the CP on the IAB-donor-CU uses RRC protocol. It may further sustain a PDU-session via the NGC to support its own traffic requirements for Operations, Administration and Maintenance (OAM). Backhaul Adaptation Protocol (BAP) has been introduced to enable efficient IP data forwarding across the interconnected IAB-nodes and IAB-donor. This IAB-specific BAP layer is transparent to UEs. On the wireless backhaul, the IP layer is carried over the BAP sublayer which allows efficient multi-hop forwarding to route packets from IAB-donor to the target IAB-node and vice versa. The IP traffic that can be forwarded over the BAP includes F1-traffic as well as non-F1 traffic such as OAM of the IAB nodes. The control plane and user plane protocol stacks for IAB are discussed in detail in 3GPP TS 38.300 [5].

4.3 Use cases considered by existing relay solutions

In this section, various use cases that have been considered for LTE Relay/IAB by the 3GPP specifications are discussed briefly [7][10][11][12][13][14][15].

Achieve cell densification with enhanced signal quality

In urban areas user density is quite high, which makes it necessary to ensure enhanced network capacity with wide coverage and provide increased data rate to users. This can be achieved by overlaying mmWave 5G small cells over a macro cell. The limited coverage of 5G mmWave access creates a high demand for denser deployments outdoors and thereby, increases the need for backhauling. In such dense networks, IAB can be an economically viable alternative to achieve the same over a shorter time period. Reducing reliance on wired backhaul for new small cells can help operators provide faster and flexible rollout of 5G networks with reduced deployment cost.

Rural connectivity

While rural areas are characterized by low user density, ubiquitous coverage, it becomes crucial considering the distribution of users over a wide area. Relay/IAB nodes can provide an efficient mechanism to extend coverage without an increase in the number of BS nodes, thereby decreasing the deployment costs significantly. This is also important for accelerating network deployment in regions with challenging topography, such as mountainous areas and deserts, where deploying a large number of BS nodes with conventional fixed backhaul connectivity is not feasible.

Remediate isolated coverage gaps

Isolated coverage holes can arise when signals from nearby BS nodes can hardly reach a certain area due to significant blocking, for e.g., due to buildings around. In 5G Networks, radio signals in high frequency bands propagate straight with very little diffraction leading to coverage holes. In

order to resolve such coverage gaps, IAB/Relay nodes can help in provisioning a new cell with wireless backhaul instead of leasing a fiber connection.

Enhance coverage indoors

Due to high penetration loss in indoor areas, signal from an outdoor base station reaches the indoor users with low strength. Relay/IAB nodes can help improve indoor capacity to users in small coverage areas (e.g. deep indoor, or in buildings far from the BS node). To alleviate this, a Relay/IAB node needs to be installed in an appropriate location so that it is exposed both to the indoors and outdoors to efficiently support wireless backhaul without the need for any cable provisioning throughout the building. For instance, an IAB node installed on top of a building and exposed to outdoor IAB-donor for backhaul can provide high speed radio connectivity within the premises.

Range extension in linear structures

IAB can help reduce capital expenditure by extending coverage along linear structures like streets and highways with multi-hop backhauling. By deploying multiple relays with wireless backhaul to a single donor BS which has fiber connectivity to the core network, coverage can be achieved along the entire stretch.

On-demand deployment

A provisional enhancement in terms of coverage or capacity might be required in certain scenarios like a large-scale event in stadium-like venues or a public safety event. If the Relay/IAB nodes can be mobile, it is possible to rapidly deploy a dynamic network, particularly for emergency and disaster relief situations. This can prove to be a cost-effective solution for seamless realization of rapidly deployable ad-hoc networks without the need for a conventional wired backhaul solution.

4.4 Limitations of existing relay solutions

The E-UTRAN architecture for supporting LTE relays and the 5G IAB architecture proposed in 3GPP specifications, do not follow similar design principles and have several shortcomings which are explained in this section.

Need for a special donor node

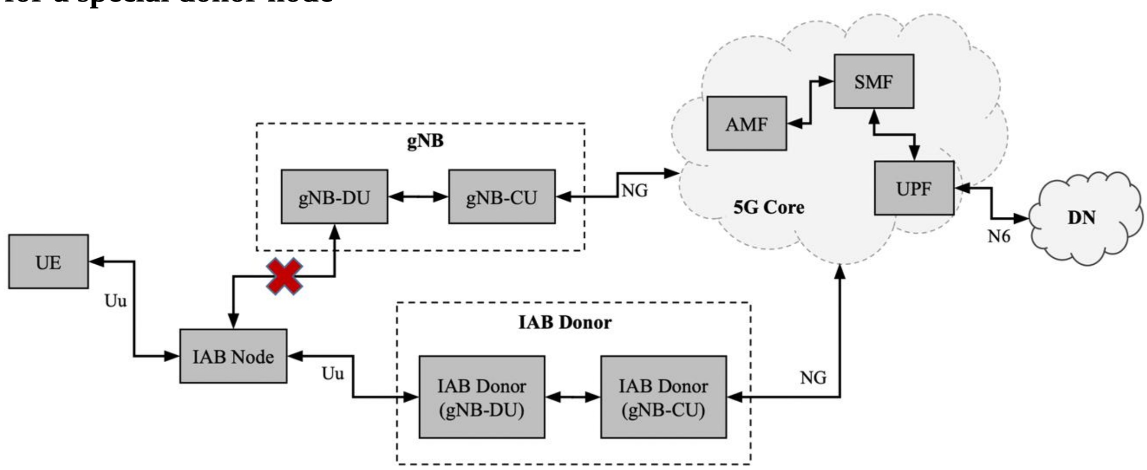

Figure 5. Need for special donor node in IAB architecture

In addition to the network nodes that constitute the standard E-UTRAN/5G architecture, a donor BS node with special capabilities is required to support relays. The DeNB node is introduced in E-UTRAN specifically to support wireless backhauling for RNs. In 5G IAB architecture, an IAB-donor node is required to support wireless backhauling for the IAB-nodes (as shown in Figure 5).

Complexity in protocol stack

In LTE relay architecture, the DeNB is a bulky modification of the standard eNB with protocol stacks of the CN also integrated into it. The protocol stack for the Un interface between RN and DeNB should support the transfer of S1 and X2 messages, which makes it challenging to implement.

Similarly, in 5G IAB architecture, an IAB-Donor has a special gNB-DU function and a special gNB-CU function requiring significant modifications to the protocol stacks of the CU/DU of a standard gNB. Implementation of an additional layer 2 protocol (BAP) in the stack is necessary to support routing between the IAB-nodes and IAB-donor. Multiple enhancements in RRC Layer would be necessary to provide BAP addresses to IAB-nodes and to distinguish between an IAB-node's IAB-MT and an actual UE. Special mechanisms would have to be supported to create a Data Channel to carry IAB data and for configuration of Backhaul RLC (BH RLC) Channel to carry the IAB data.

Deployment constraints

At least one donor node must be deployed in the RAN beforehand as the relay nodes can only associate with the special donor node, which makes the deployment of such networks economically inefficient. In the 5G IAB architecture, an IAB-node cannot connect to a standard gNB-DU even though it has the IAB-MT function (i.e. UE Stack for Uu interface). The deployment of LTE-RNs/IAB-nodes needs careful network planning as these nodes can only be deployed in the vicinity of the respective donor nodes. This does not serve the purpose of extending network coverage and deploying 5G cells flexibly wherever needed. As a result, the feasibility of dual or multi-connectivity for IAB-nodes is less as the density of IAB-donors would be far less than that of gNBs within an area. LTE RNs also require a separate MME/S-GW than that for UEs, which is an extra burden on the deployment side.

No support for Multi-hop in E-UTRAN

E-UTRAN relay architecture does not provide support for establishing a multi-hop relay network.

No support for mobile relays

E-UTRAN relay architecture only supports relays that are stationary. Though 3GPP investigated several possible architectures for mobile relays in a study item [16], these architectures required significant modification of multiple protocols. Similarly, the IAB architecture only supports stationary IAB-nodes and they cannot move seamlessly across different parent nodes (IAB-donors or IAB-nodes) while retaining contexts of downstream IAB-MTs and UEs. For instance, an IAB-node cannot move to a new IAB-donor which has better signal strength compared to the current IAB-donor that it is attached to. Though an IAB-node can migrate to a different parent node under the same IAB-donor CU, this mobility is limited to backhaul Radio Link Failure (RLF) recovery scenarios.

No support for Multi-RAT

3GPP specifications defined LTE relay/5G IAB architectures do not support the co-existence of multiple RATs as it is not possible to use different RATs on access and backhaul for an LTE-RN/IAB-node. For instance, it is not possible for an LTE-RN/IAB-node to use 5G NR as backhaul

while providing LTE access to UEs. Multi-RAT convergence would be vital for Beyond-5G networks wherein a UE should be able to use any RAT for access including Non-3GPP access such as Wireless Local Area Network (WLAN), independent of the RAT used for backhaul.

Despite being a part of the standards and having several advantages, relays in LTE cellular networks did not gain much commercial interest and have seen very limited deployment. The 3GPP IAB architecture has some shortcomings highlighted above that may hinder its wide commercial deployments.

5 Additional Use Cases and Design Goals for the proposed relay architecture

The aim is to define a novel, generic architecture to support relay functionality in both 3GPP LTE and 5G networks while addressing the limitations listed above. The intent is also to support numerous deployment scenarios including Vehicle Mounted Relay (VMR) and multi-RAT coexistence, which are some key use cases not supported by the 3GPP specifications currently.

Vehicle Mounted Relays

When relay nodes do not require fixed connectivity with the core network, additional flexibility can be expected as relays can become mobile and can facilitate a host of deployment opportunities. In urban environments, the high possibility of the presence of many vehicles around, makes VMRs a very lucrative option to extend network coverage and support enhanced capacity. Vehicles that are moving at low/pedestrian speed or temporarily stationary can be used to carry BS nodes acting as relays, for providing coverage and connectivity to neighbouring UEs outside the vehicle. During outdoor sports/racing/pedestrian events, vehicles equipped with relays could conveniently move along with users or devices that are outside the vehicle and provide service to them. VMRs can also help improve the user experience for onboard passengers in moving vehicles, especially vehicles meant for public transportation like buses and trains. Group mobility in case of UEs connected to a VMR, prevents enormous signalling overhead that may arise due to concurrent handovers of in-vehicle UEs. Only a relay node is required to perform handovers whereas UEs retain their connections to the VMR node. As an extension of VMRs, utilizing UAVs can help build a cost-effective and scalable solution to achieve significant performance improvements in wireless networks. Deploying UAVs as hovering relay nodes for IAB scenarios in 5G networks can be very beneficial in certain deployment scenarios such as emergency and disaster relief operations.

Multi-RAT

Deployment of 5G NR along with other Radio Access Technologies (RATs) would help operators to achieve better spectral efficiency and facilitate wider coverage at lower costs. Considering multi-RAT coexistence, IAB Radio Access Network (RAN) can be deployed in areas with partial or no core connectivity by utilizing other RATs (e.g., LTE or WLAN) as overlay networks. Using NR backhaul to allow WLAN access based UEs to connect to 5G CN is another important use case, as WLAN is likely to be a widely used access technology. Both network and users would benefit from faster mobility, enhanced service continuity, and augmented capacity when relays can maintain simultaneous connections to multiple cells belonging to different RATs. Such a capability in IAB may give rise to newer deployment scenarios.

Listed below are the key design goals identified for the proposed relay architecture.

- The architecture shall have provisions to enable smooth transition and flexible integration from/to the legacy deployments, requiring minimal changes in the existing network elements and functionalities. Reusing existing interfaces can allow a standard LTE/5G network to be converted to a multihop relay network on-demand. The relaying functionality should be transparent to legacy or standard UEs.
- Relays shall be designed as plug-and-play devices, so that a self-organizing and self-optimizing topology involving relays may be formed as soon as they become operational. Support for topology adaptation and multi-connectivity capabilities is required to autonomously add or remove relays to the network topology, recover from backhaul link overload and failure and reconfigure backhaul under local congestion in the event of varying traffic conditions.
- The proposed architecture shall have the flexibility to use different radio access technologies like LTE, 5G NR, and non-3GPP access such as WLAN, across two interfaces of the relays. The relay nodes shall be able to maintain simultaneous connections to multiple cells belonging to different RATs.
- The architecture shall support mobility of relays. Relays shall support inter-cell and inter-RAT handover to another BS (eNB, gNB, or WLAN Access Point) or to another relay.
- The architecture shall support mobility of UEs associated with a relay. A UE associated with a relay may move to another relay or BS(eNB/gNB/WLAN Access Point).
- The architecture shall support Multi-hop Relays.
- The architecture shall have support to enforce Quality of Service (QoS) in access and backhaul to ensure that each flow/bearer fulfils its QoS requirements for UEs and relays in the network.
- The Relay shall be a layer 3 node which can demodulate and decode the incoming signal and re-modulate and re-encode before retransmitting the signal. It shall be like a conventional base station that manages radio resources among UEs.
- The architecture shall support in-band backhauling as deploying in-band relaying results in no extra equipment requirement and no additional spectrum costs.

6 Proposed architecture to support relay functionality in LTE, 5G & beyond 5G networks

We propose a recursive architecture which can support on-demand multi-hop relay functionality with minimal changes in the existing network elements and interfaces. The architecture does not define any new interface and reuses the existing interfaces. The proposed architecture considers splitting of the BS (eNB/gNB) functionality into two logical units, namely, radio unit and core network unit (as shown in **Figure 6**). Even if these units are not co-located, when connected via an IP based interface they can still provide BS functionality to a UE. The proposed architecture places these units in two separate nodes that shall be connected over an IP connection provided by the respective LTE/5G network itself (as shown in **Figure 7**).

The stack at the radio unit typically contains the lower layers of the interface towards UEs and is proposed to be placed in the new Relay Node. The core network unit contains the stack for interfaces towards the core network along with the higher layers of the radio interface towards UEs and is proposed to be placed in the new Donor Base Station. To maintain consistency with the 3GPP LTE Relay/5G IAB architectures, we have retained similar naming conventions in our proposed architecture. In the LTE Relay architecture, the new relay node is called Mobile-Relay Node (M-RN) and the new Donor BS is called Mobile-Donor-eNB (M-DeNB). In the 5G IAB architecture the new relay node is called Mobile-IAB Node (M-IAB-node) and the new Donor BS is called Mobile-IAB Donor (M-IAB-donor). Relays are plug-and-play devices and the donor BS nodes are simplified nodes as compared to conventional base stations in the cellular network. The M-RN, M-IAB-node and M-IAB-donor are simplified in the proposed architecture in comparison to the 3GPP specifications defined nodes. The idea of using "IP connectivity enabled by the LTE/5G network to connect other network elements which are part of the same network" can be generalized to solve other problems as well.

Following sections provide further details of the architecture and relaying functionalities for LTE and 5G cellular networks [17][18].

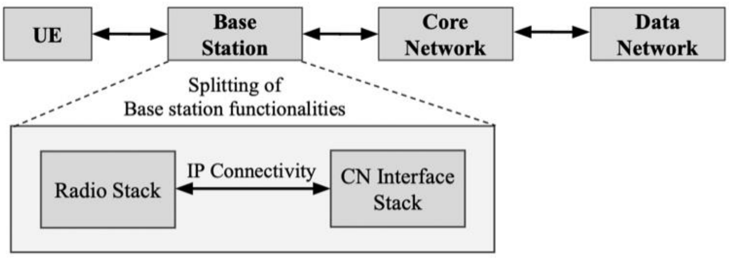

Figure 6. Splitting of the base station (eNB/gNB) functionality into two logical units: radio unit and core unit

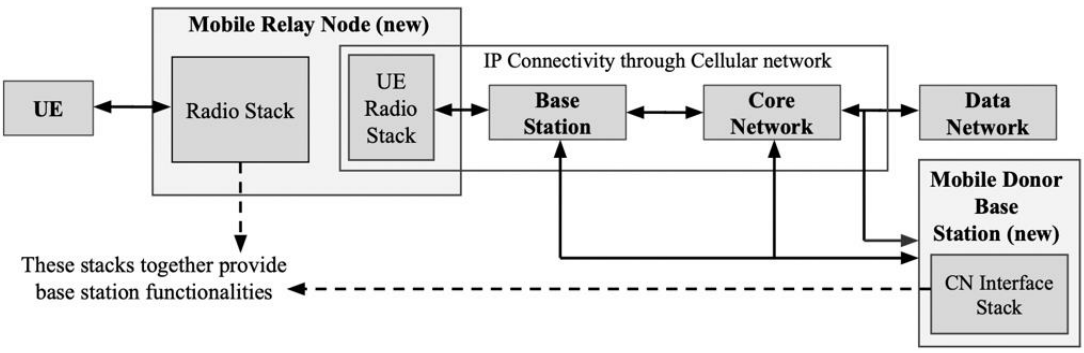

Figure 7. Conceptual view of the proposed architecture

6.1 Relaying in LTE network

Relaying in the LTE network shall be facilitated by introducing two network nodes: Mobile-Relay Node between UEs and eNB, and Mobile-Donor-eNB which shall be located close to the EPC. The eNB functionality is considered to be split and distributed among these two nodes (M-RN and M-DeNB). Although these two logical units (radio interface and core network interface) of eNB functionality are not co-located, they shall be connected via IP connectivity of the LTE network itself. Further architectural details along with network nodes, protocol stacks, interfaces, signalling and dataflow are explained in the following subsections.

6.1.1 Architecture

An abstract view of a conventional LTE network and the proposed architecture is shown in **Figure 8**. In conventional LTE networks, IP connectivity is established between UE and PDN through eNB

and EPC (S-GW + P-GW). An eNB functionality can be visualized as a combination of two logical units, one containing the radio stack (PHY, MAC, RLC and PDCP layer) and the other containing the core network interface (data and control) along with RRC/RRM as shown in the **Figure 8**.

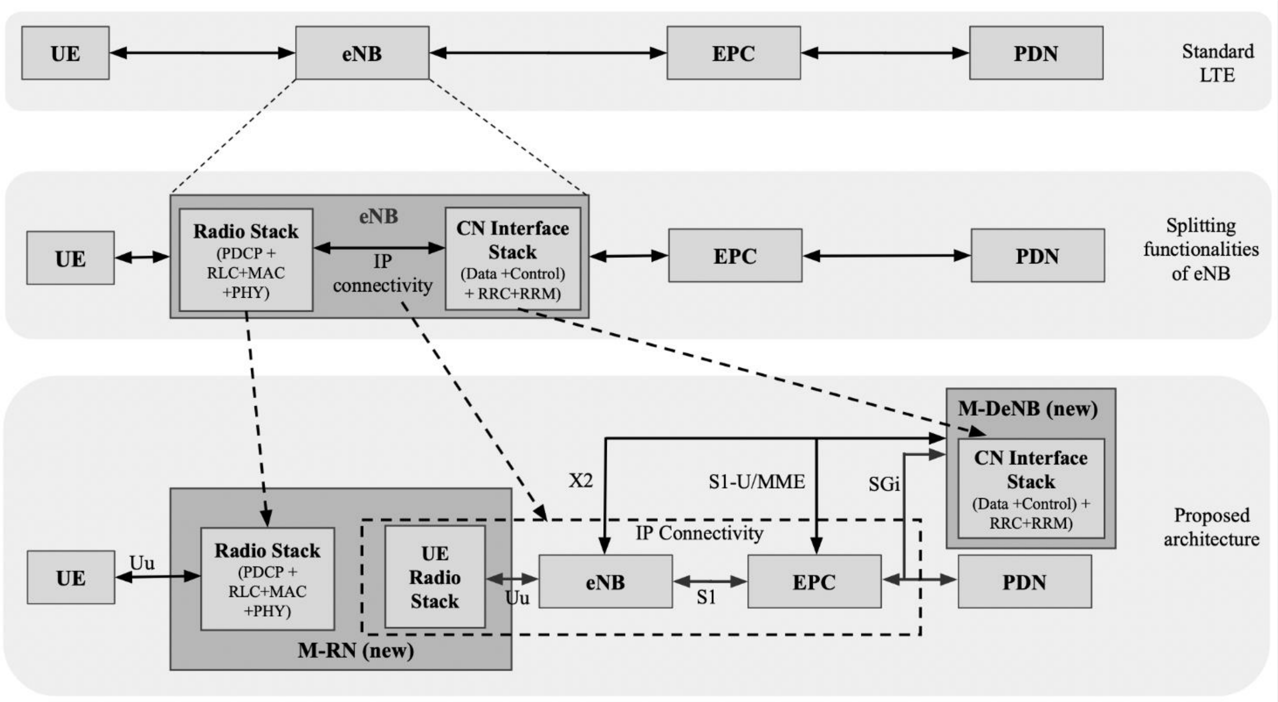

Figure 8. Abstract view of the proposed relay architecture for LTE network

In the proposed architecture, the radio stack is placed at the Mobile-Relay Node and the Core Network interface stack is placed at Mobile-Donor-eNB and these two units together act as an eNodeB. Existing standard interface (Uu interface) shall be re-used by M-RN to connect with UE . Similarly, M-DeNB shall also reuse standard interfaces to connect with EPC, (S1 interface) and other eNBs (X2 interface). Whereas, a new Un interface is required between DeNB and RN in LTE relay architecture as detailed in Section 4.1 of the current document.

6.1.2 Network Functions (or Nodes)

Figure 9 shows standard network elements and interfaces for 3GPP LTE architecture (without employing any relay) that facilitates IP connectivity in the LTE network. In the proposed architecture (as shown in **Figure 10**), a Mobile-Relay Node behaves as a UE for the standard LTE network but as an eNB for UEs and for other Relays which are connecting to it over the radio Interface.

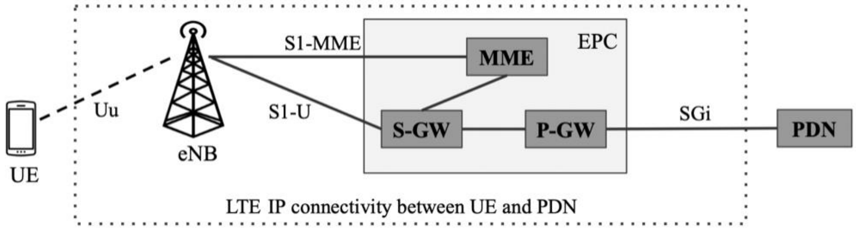

Figure 9. 3GPP LTE architecture with network elements and their interfaces.

A Mobile-Relay Node shall connect to M-DeNB over the LTE network using IP connectivity just as a UE connects to a network entity. UE shall connect to M-RN as it connects to an eNB using standard interfaces. One M-DeNB shall be able to manage multiple relay nodes (up to 256) just like one eNB supporting multiple cells/radio units. It shall enable connectivity to the core network for

UEs connecting via M-RNs. RRC connection for a UE connected to the M-RN is managed by the M-DeNB as the M-DeNB together with an M-RN acts as the eNB for the UE.

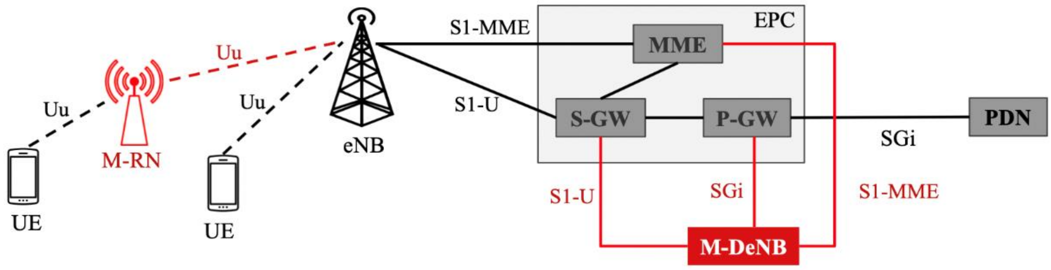

Figure 10. An illustration of the proposed architecture with network elements and their interfaces. New elements (M-RN and M-DeNB) are presented in red color. Note that the proposed architecture reuses the existing standard interfaces. UE uses Uu interface only and M-DeNB uses S1-U, SGi and S1-MME interfaces.

All other network nodes are standard LTE network nodes. Connectivity between eNB and the EPC functions (MME, S-GW and P-GW) shall remain the same. There is no need for a specialized Donor Node (e.g., DeNB) in the network as required in the relay based 3GPP LTE network.

6.1.3 Protocol stacks & interfaces

Protocol stacks for M-RN and M-DeNB are shown in **Figure 11**. A M-RN shall contain two interfaces, one for the UE side which shall contain eNB radio stack (PHY, MAC, RLC, and PDCP) and other for eNB side which shall contain UE radio stack including UE NAS and RRC. It shall connect to UEs via eNB radio stack and on the other side it shall connect to eNB via UE radio stack over Uu interface.

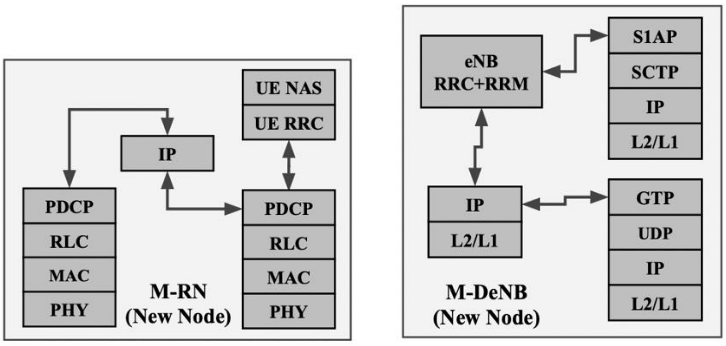

Figure 11. Protocol stack for Mobile-Relay node (left) and Mobile-Donor-eNB (right)

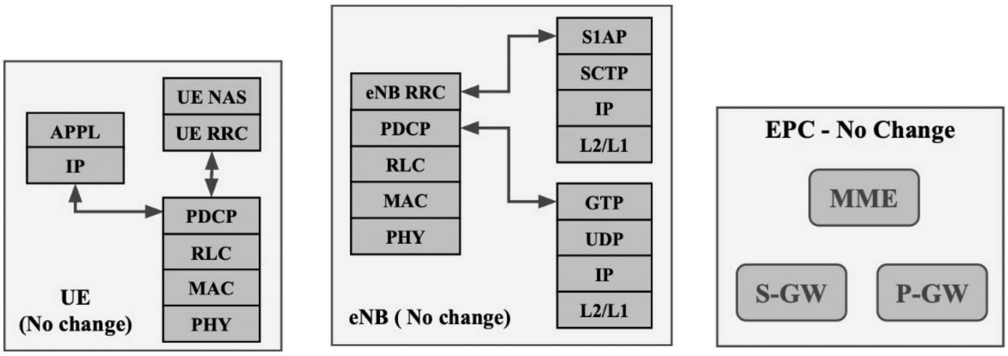

Figure 12. No change in the protocol stacks/functional entities for UE (left), eNB (middle) and EPC (right)

The new node M-DeNB located near to EPC which shall connect to MME, P-GW and S-GW over the standard interfaces S1-MME, SGi and S1-U respectively. Protocol stack at M-DeNB consists of

data and control plane layers in addition to eNB RRC and RRM. The M-DeNB acts as any other eNB for EPC and acts as an application server to the P-GW. M-DeNB shall connect to other eNBs on the X2 interface and act as any other eNB for eNBs. There are no changes required for the protocol stacks/functions of UE, eNB and EPC as shown in **Figure 12** to support the proposed architecture.

6.1.4 Signalling & Data flow

Data and control path for the mobile-relay node and UE are illustrated in **Figures 13 and 14** respectively. Initiation of the mobile-relay node is executed by establishing RRC connection between the mobile-relay node and MME through standard initial connection procedure by considering the mobile-relay node as a UE. Next, the IP-CAN bearer is established between the M-RN and M-DeNB through eNB, S-GW and P-GW.

Further, UEs which are in the vicinity of a mobile-relay node shall make a radio connection with the mobile-relay node as if it is an eNB. The RRC+NAS messages from such UEs (e.g. RRC Connection Request/Attach Request) shall be sent to the M-DeNB by M-RN over IP connectivity between M-RN and M-DeNB (IP connectivity provided by the LTE network). The M-DeNB and M-RN together act as an eNB for such UEs and forward the control (UE NAS) messages to the MME as an eNB via a UE associated signalling message over S1 interface.

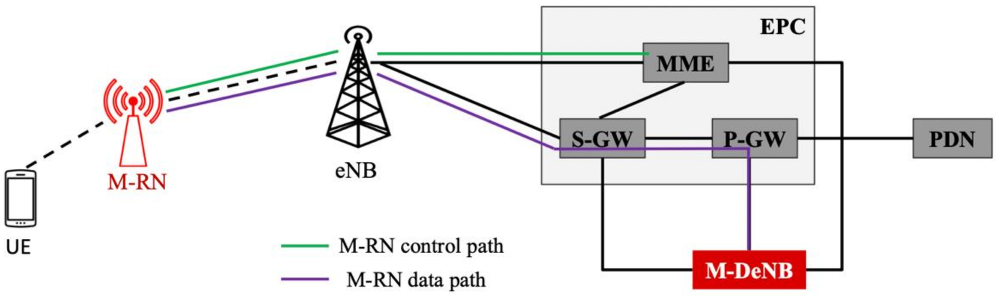

Figure 13. Data and control path for the relay node (RN)

The data path for such UEs are also established via the M-DeNB to S-GW, P-GW and data network. It means that there would be a loop in data paths for such UEs. The S-GW/P-GW that are connected to M-DeNB over S1-U/SGi interface can be located in the mobile edge to reduce the loop overhead.

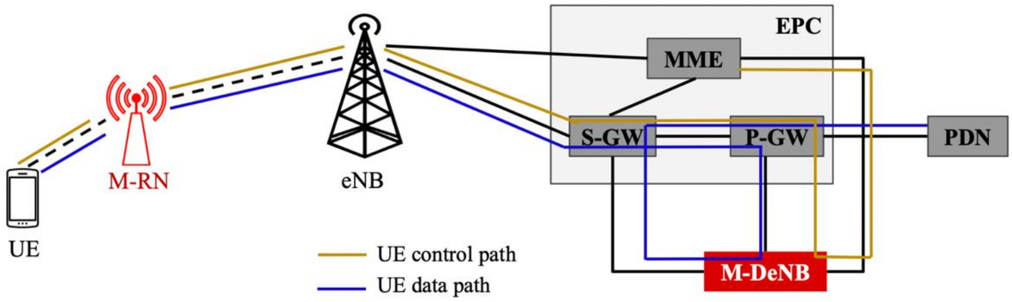

Figure 14. Data and control path for the UE

6.1.4.1 Control signalling flow procedure in the proposed architecture

M-RN and M-DeNB together constitute an eNB (logically) though they are physically separated from each other. UEs as well as other LTE network elements can view them as an eNB and interact using standard LTE interfaces. Hence, control signalling for UE is the same as in the LTE architecture. Detailed steps for control signalling flow for UE through the proposed mobile-relay node are as follows (also shown in **Figures 15 and 16**):

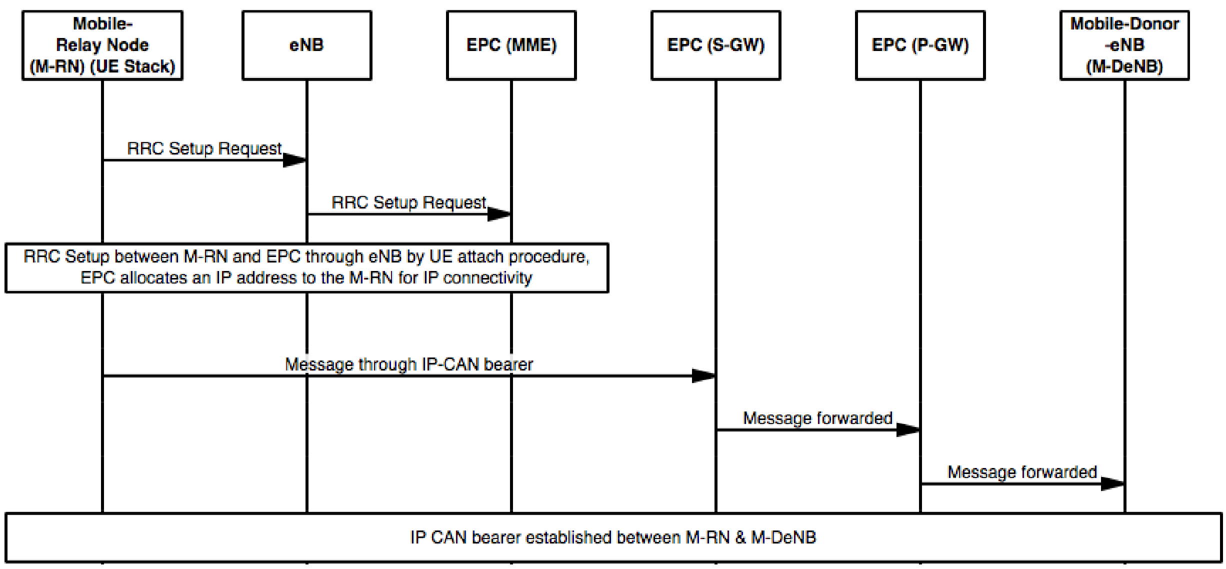

Figure 15. M-RN setup

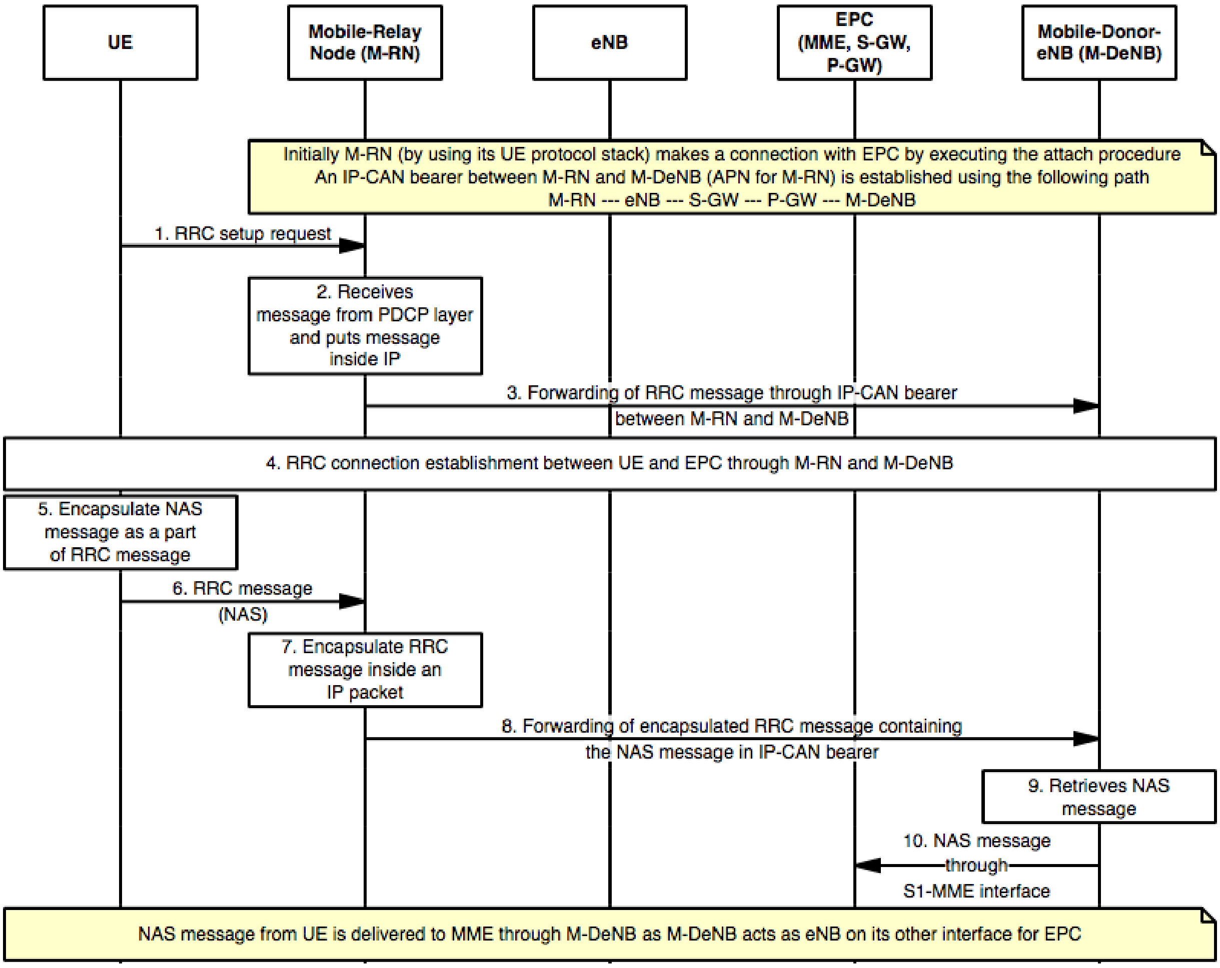

Figure 16. Control signalling flow between UE and EPC through M-RN and M-DeNB

Note: *The M-RN setup involves following steps as shown in* ***Figure 15****. The mobile-relay node, acting as UE, establishes a radio connection with the neighboring eNB over the Uu interface. This facilitates the M-RN connection with the EPC (MME) through a standard UE attach procedure and EPC allocates an IP address to the mobile-relay node for IP connectivity to the DN. As a result, there shall be a IP-CAN bearer available between the mobile-relay node and P-GW.*

Further, P-GW enables connectivity to the M-DeNB through the SGi interface. This establishes the IP-CAN bearer between M-RN and M-DeNB and M-DeNB acts as an eNB on its other interface towards EPC.

Steps for control signalling flow between UE and EPC through M-RN and M-DeNB are as follows (**Figure 16**):

1. UE has to make an RRC connection directly with M-DeNB as RRC is situated at M-DeNB. Hence UE sends RRC connection message to M-RN for execution of the same. It is facilitated using the eNB radio stack available at M-RN on the UE side.

2. M-RN shall carry the RRC connection message from UE. Next, M-RN shall encapsulate this message in an IP packet using its IP address.

3. M-RN shall forward this encapsulated RRC connection message to the M-DeNB through the IP-CAN bearer established between M-RN and M-DeNB (M-RN→eNB→S-GW→P-GW→M-DeNB).
4. RRC connection is established between UE and M-DeNB using IP connectivity between M-RN and M-DeNB.
5. With this, UE is ready to communicate with the EPC (LTE network). Further on, UE's NAS messages for the EPC shall be encapsulated as a part of the RRC message.
6. UE shall send this encapsulated NAS message to the M-RN.
7. M-RN shall encapsulate this received message in an IP packet using its own IP address.
8. M-RN shall forward the encapsulated RRC message containing the NAS message to M-DeNB using the IP-CAN bearer between M-RN and M-DeNB (M-RN→eNB→S-GW→P-GW→M-DeNB).
9. M-DeNB determines the control packet and retrieves the NAS message (as eNB's RRC is located at the M-DeNB).
10. M-DeNB shall send this NAS message to EPC (MME) using the standard interface S1-MME.

6.1.4.2 Data flow procedure in the proposed architecture

Detailed steps for UE data flow through the proposed mobile-relay node are as follows (also shown in the **Figure 17**):

Note: *Initiation of the Mobile-Relay Node shall be executed as discussed in the previous section. Hence, there shall be a IP-CAN bearer available between the mobile-relay node and M-DeNB and M-DeNB acts as an eNB on its other interface towards EPC. Further RRC connection between UE and M-DeNB is also established as detailed in the previous section.*

1. As UE is ready to send data to the PDN, it shall send data to M-RN using the radio bearer which is already established between them.
2. M-RN shall encapsulate the UE data packet in an IP packet by using its own IP address, as it functions as a data plane node.
3. M-RN shall forward the encapsulated UE data to M-DeNB using the IP-CAN bearer between M-RN and M-DeNB.

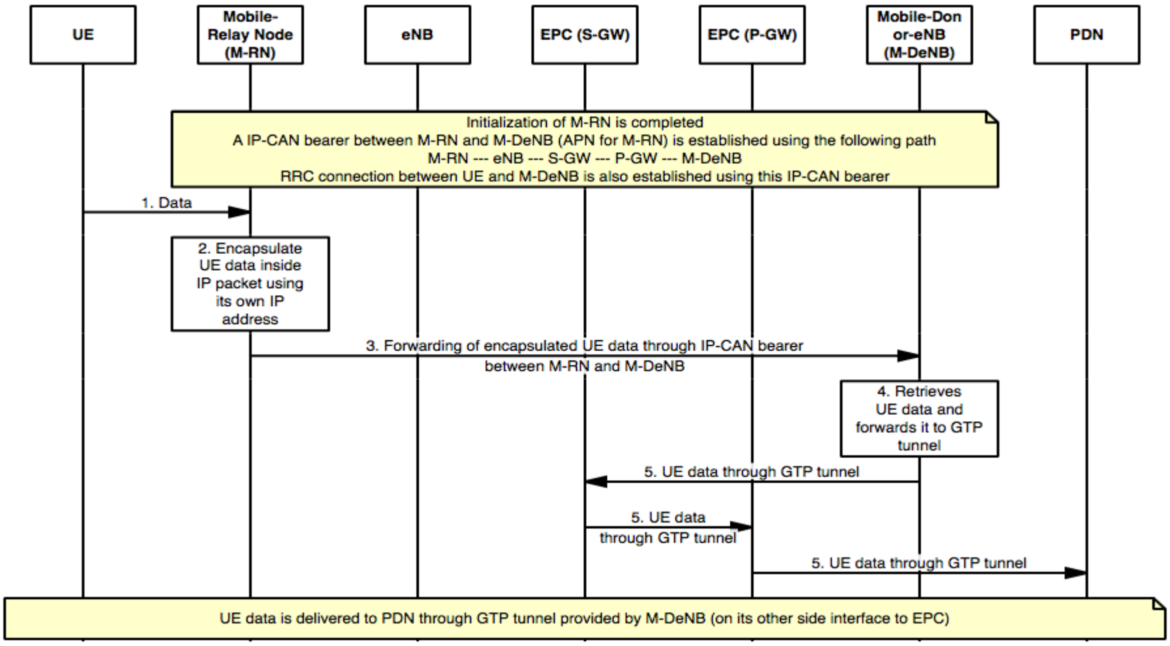

Figure 17. Data flow between UE and EPC through M-RN and M-DeNB

4. M-DeNB shall determine the data packet and retrieve UE data. It shall forward the UE's data into the GTP tunnel.
5. This GTP tunnel is established for the UE from the S1-U interface side of M-DeNB. This tunnel shall carry data from M-DeNB to S-GW, then S-GW to P-GW and finally shall take from P-GW to the PDN.

6.2 Relaying in 5G network

The proposed architecture shall support IAB in 5G networks as described in this section. Similar to the LTE solution discussed above, multihop relaying is facilitated by splitting the gNB-CU and gNB-DU across a Mobile Relay Node and Mobile-Donor BS node which are interfaced over the IP connection provided by the 5G network itself. Further architectural details along with network nodes, protocol stacks, interfaces, signalling and dataflow are explained in the following subsections.

6.2.1 Architecture

The overall concept and architecture is similar to the LTE multi hop relay architecture explained in the previous sections.

An abstract view of the proposed architecture and its evolution from the standard 5G architecture is shown in **Figure 18**. The gNB-DU unit (radio interface) in the Mobile-IAB-node (M-IAB-node) and the gNB-CU unit (core network interface) in the Mobile-IAB-donor (M-IAB-donor) together provide gNB functionality for UEs. Though this looks similar to the CU-DU split deployment of a gNB, the novelty in this approach is that the 5G network itself enables the IP connectivity between gNB-DU in the M-IAB-node and gNB-CU in the M-IAB-donor for the F1 logical interface between them, instead of a standalone IP connection in the former case.

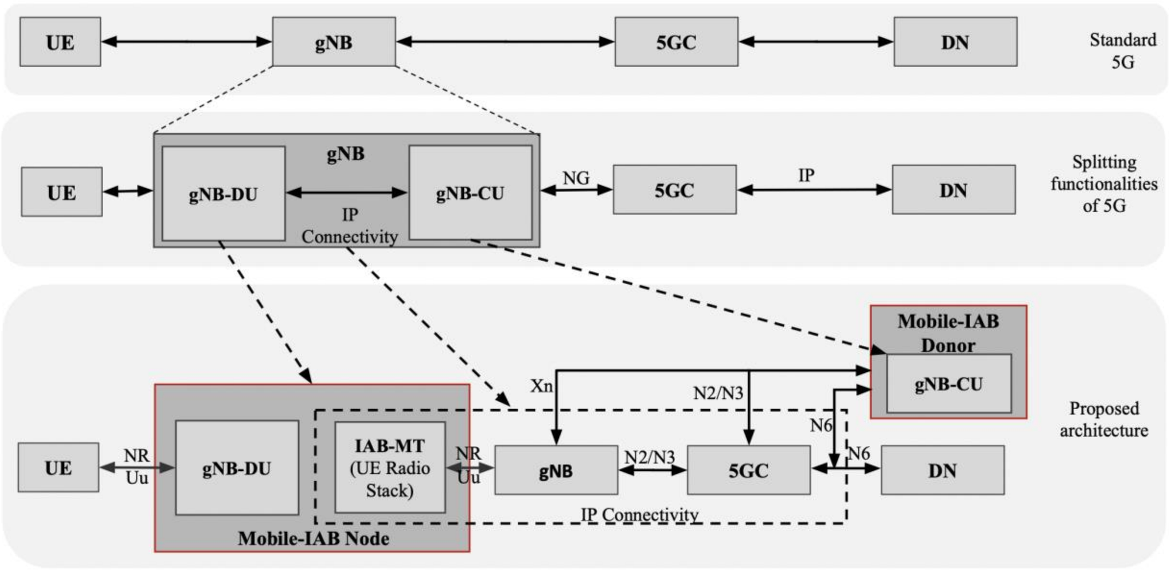

Figure 18. Proposed IAB architecture

The architecture reuses the existing standard interfaces that are economical and easier to develop and maintain. The standard interfaces also facilitate installing M-IAB-nodes anywhere without requiring additional interface modules at available cell sites, as they can connect to any gNB. No changes are required in the other existing network elements. With a simpler design, the impact on the RAN and 5G Core (5GC) is minimized. Also, there is very minimal impact on the existing solutions for OAM and network service provisioning, as the 5GC is untouched.

6.2.2 Network Functions (or Nodes)

Mobile-IAB Node is the relay node in the proposed architecture (as shown in **Figure 19**) and is a standard gNB-DU that also has an additional Uu interface radio stack to support UE functionalities. The Mobile-IAB Donor is the mobile donor BS node, and it is moved to the edge cloud as shown in **Figure 19**. It hosts a standard gNB-CU. Along with the M-IAB-donor, a dedicated UPF is also deployed in the edge cloud to exchange radio messages with the M-IAB-nodes. The M-IAB-node's gNB-DU and M-IAB-donor's gNB-CU provide gNB functionalities to prospective UEs in conjunction. The M-IAB-donor’s gNB-CU acts as a server that is connected to the UPF in the edge cloud over the N6 interface. This UPF forwards RLC and lower layers packets from gNB-DU of the M-IAB-nodes to the gNB-CU of the M-IAB-donor over the F1 interface. The M-IAB-node is responsible for forwarding/receiving control plane/user plane packets of UE to/from the 5GC.

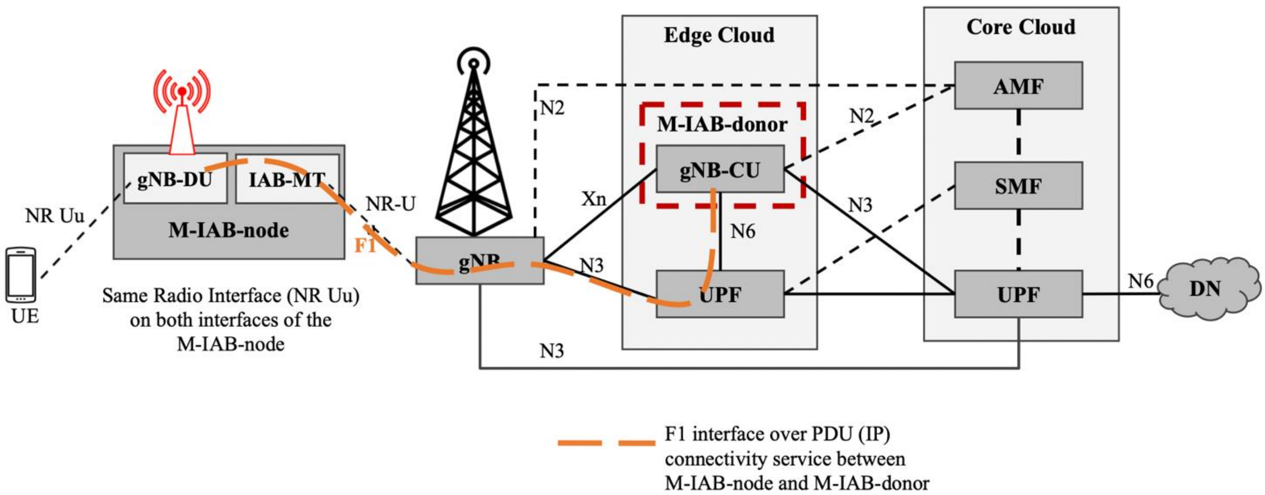

Figure 19. A detailed block diagram of the proposed IAB architecture with network elements and their interfaces. Note that the proposed architecture reuses existing standard interfaces.

The edge cloud is in the proximity of the RAN, to ensure that control plane/user plane delays between the IAB-MT and M-IAB-donor are affordable. While a single M-IAB-donor with the gNB-CU would suffice at the edge cloud for all M-IAB-nodes within the network, multiple M-IAB-donor gNB-CUs can also be deployed for load balancing and network robustness. If multiple M-IAB-donor gNB-CUs are available, the OAM server can select the best one for an M-IAB-node based on criteria like load and quality of backhaul links.

6.2.3 Protocol stacks & interfaces

The protocol stacks for the proposed IAB architecture are shown in **Figure 20**. The M-IAB-donor comprises a standard gNB-CU without any changes. It terminates the F1 interface with the gNB-DU of an M-IAB-node and provides the higher layer (RRC/SDAP + PDCP) functionality for a gNB's Uu radio stack. It also supports the core network interface stack consisting of NGAP/SCTP and GTP/UDP over IP for the N2 and N3 interfaces respectively. The M-IAB-node has a standard gNB-DU (IAB-DU) comprising the lower layers (PHY, MAC, RLC) of the gNB's Uu radio stack, which it shall use to connect to UEs. It also has a UE radio stack (IAB-MT) for the uplink path. The IAB-MT has the complete UE stack instead of the partial UE stack as in the 3GPP IAB architecture. This simplifies many UE-related procedures for an IAB-MT. The additional processing in an M-IAB-node in the proposed architecture due to an extra layer on the IAB-MT (PDCP + SDAP vs. BAP), would not be very significant. There are no changes required for the protocol stacks of UE, gNB and 5GC as shown in **Figure 21**, to support the proposed architecture.

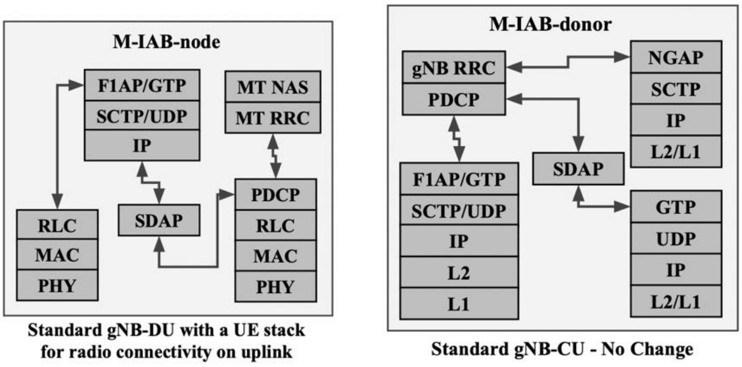

Figure 20. Protocol stack for M-IAB-Node and M-IAB-Donor

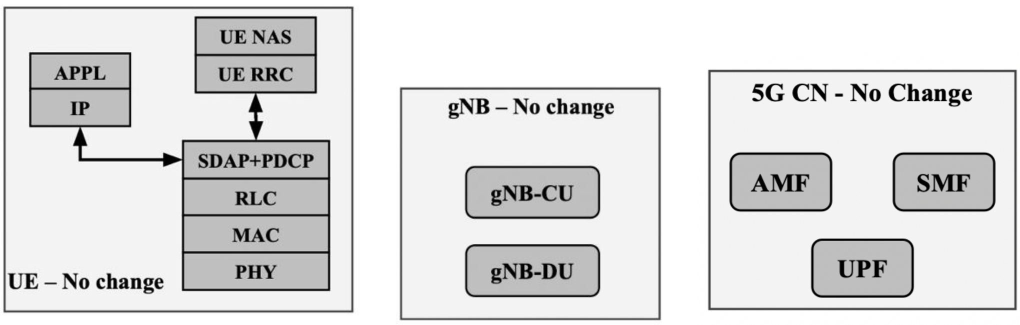

Figure 21. Protocol stack for UE, gNB and 5G CN

6.2.4 Signalling & Data flow

Data and control path for M-IAB-node and UE are illustrated in **Figures 22 and 23** respectively. The IAB-MT makes a connection to a gNB over the NR Uu interface and establishes a signalling connection with the 5GC's AMF. After registration, the IAB-MT shall be able to reach the M-IAB-donor's gNB-CU over the 5G IP network. The user plane path for IAB-MT terminates at the M-

IAB-donor's gNB-CU irrespective of its hop level. The IP address of the endpoint (M-IAB-donor) at IAB-MT is obtained from the OAM server during the initial setup procedure.

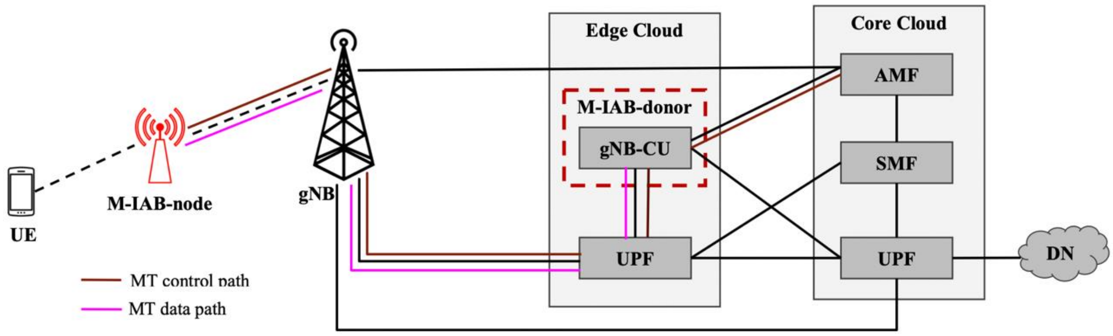

Figure 22. Data and control path for M-IAB-node's IAB-MT

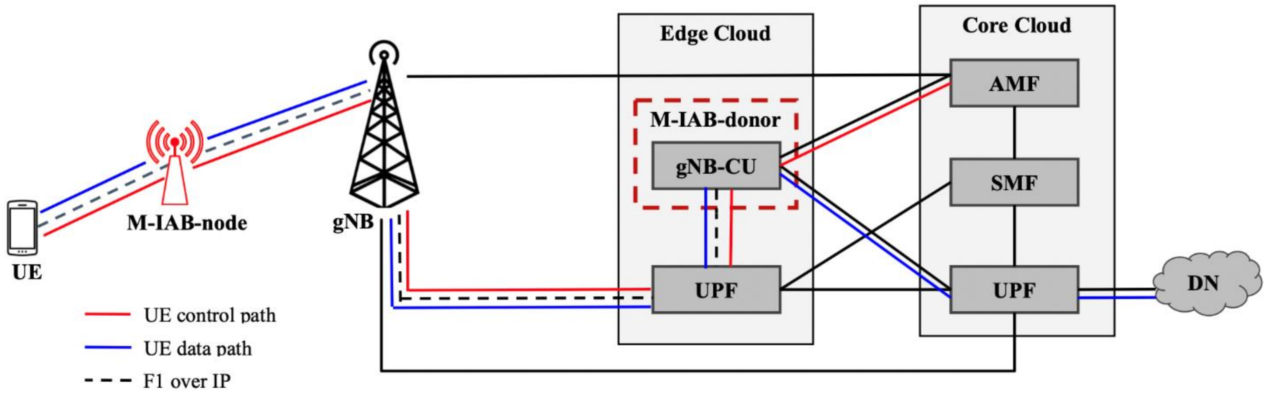

Figure 23. Data and control path for UE

The M-IAB-node is responsible for forwarding/receiving control plane/user plane packets of UE to/from the 5GC. The control plane signalling of a UE as well as user plane data are sent via the U-plane of the M-IAB-node's IAB-MT. These packets are exchanged with the M-IAB-donor's gNB-CU over the F1 logical interface. The M-IAB-donor then sends across the UE's signalling/data packets to the AMF/UPF respectively. In the end, the path followed by UE packets is: M-IAB-node→gNB→UPF→M-IAB-donor's gNB-CU→5GC (AMF/UPF).

6.2.4.1 Signalling procedure for integration of M-IAB-node with M-IAB-donor

This procedure (**Figure 24**) details initial path establishment and F1 setup procedure between M-IAB-node and M-IAB-donor.

1. M-IAB-node's IAB-MT setup procedure via gNB is executed. It is similar to that of UE initial access procedure as detailed in clause 8.1 of 3GPP TS 38.401, i.e., performing RRC connection setup procedure with a gNB along with registration and authentication with the core network.

Note: *M-IAB-node incorporates the gNB-DU functionality and hence is to be treated as a gNB-DU by the rest of the network*

2. The establishment of one or more PDU sessions for IAB-MT (which is a UE from the gNB perspective) and IP address/prefix allocation for the IAB-MT takes place, as detailed in 'UE Requested PDU Session Establishment' procedure - clause 4.3.2.2 of 3GPP TS 23.502. These PDU sessions are to be used by M-IAB-node to connect to M-IAB-donor via the 5G network.

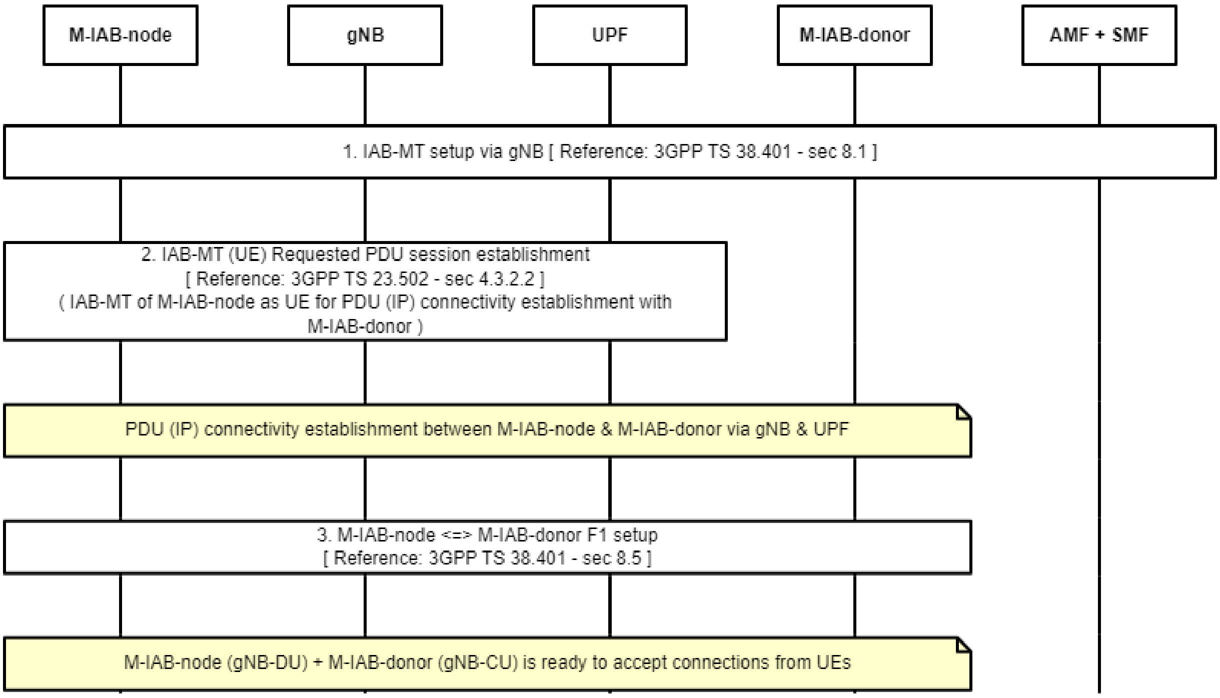

Figure 24. M-IAB-node integration with M-IAB-donor

Note: *Through these PDU session(s), PDU (IP) connectivity is established between M-IAB-node and M-IAB-donor via gNB and UPF using the IP address/prefix allocated by the 5G core in step 2 above.*

3. M-IAB-node (gNB-DU) initiates the Transport Network Layer (TNL) establishment and F1 setup with the M-IAB-donor (gNB-CU) using the allocated IP/prefix address via the PDU sessions, which is the same as the F1 setup procedure detailed in clause 8.5 of 3GPP TS 38.401. The gNB-DU of M-IAB-node is configured via Operation and Maintenance (OAM) also. The PDU sessions can be used by M-IAB-node to reach out to OAM entities also just as it uses them to reach out to the M-IAB-donor.

Note: *Once the F1 interface between M-IAB-node (gNB-DU) and M-IAB-donor (gNB-CU) is established, M-IAB-node along with M-IAB-donor is ready to accept connections from UEs.*

6.2.4.2 Signalling procedure of UE connectivity to 5G network via M-IAB-node

Since the M-IAB-node and the M-IAB-donor work in conjunction to provide the complete gNB functionality to UEs connecting to the M-IAB-node over its radio (Uu) interface, the signalling flow for a UE connecting to 5G network via M-IAB-node is exactly the same as that of a UE connecting to any other gNB (or a gNB-DU and gNB-CU pair).

Refer to the procedure ‘Initial UE Access’ - clause 8.1 of 3GPP TS 38.401 and also the ‘UE Requested PDU Session Establishment’ procedure detailed in clause 4.3.2.2 of 3GPP TS 23.502.

6.3 Multi-hop relaying

In this chapter, we provide details on how the proposed solution shall support multi-hop relays in 5G network.

We consider the example of 2 relay nodes to explain multi-hop connectivity as shown in figure below. UE connects to the core network via two relay nodes M-IAB-node named R2 and a second M-IAB-node named R1. R1 and R2 support the same M-IAB-node protocol stack which entails gNB-DU (to support UEs) and IAB-MT (for uplink path to the CN) stacks as explained in section 6.2.3. M-IAB-donor provides gNB-CU connectivity to the UEs connected via M-IAB-nodes R2 and R1.

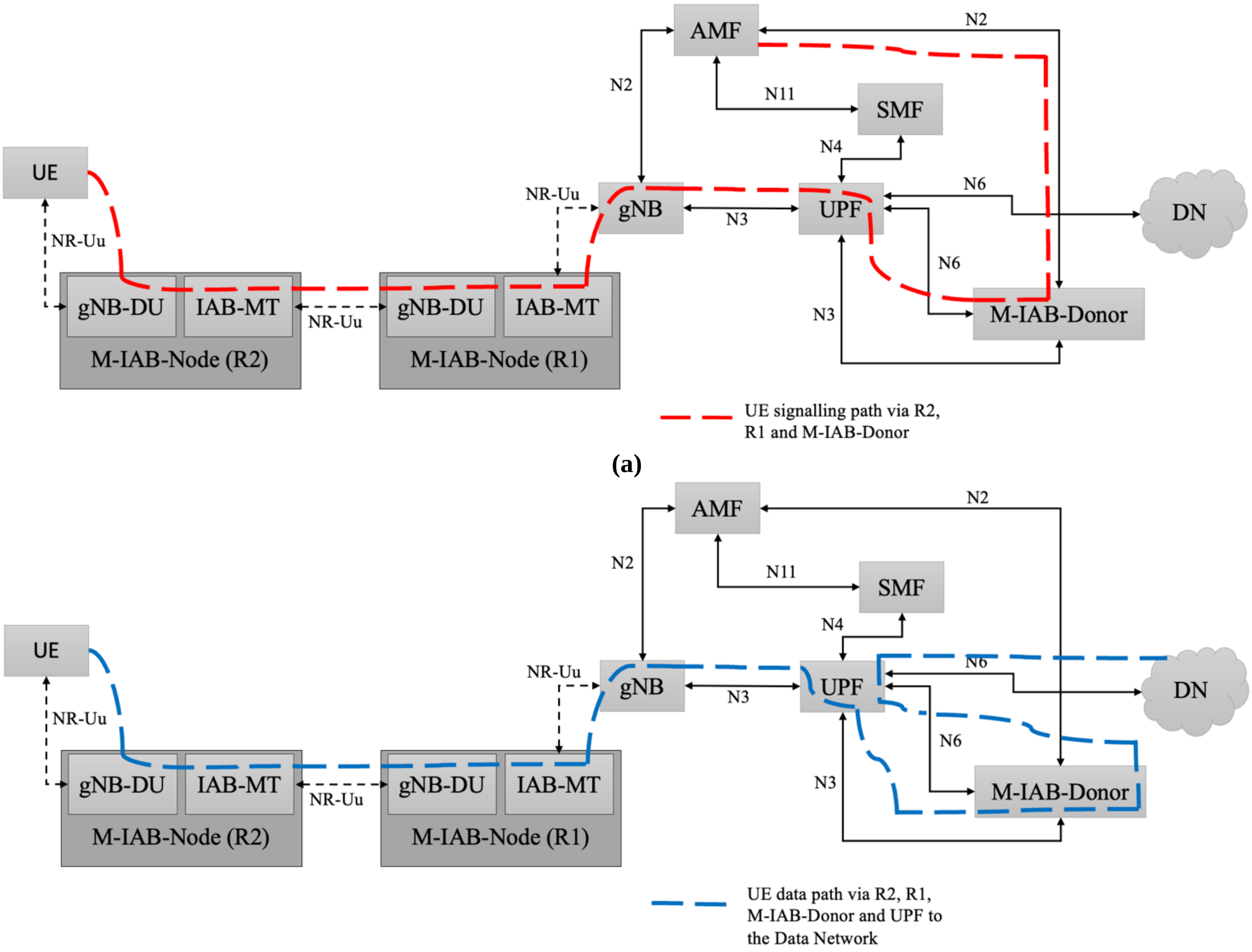

Figure 25. Multi-hop relaying in 5G Network

IAB-MT of R1 establishes PDU (IP) connectivity with M-IAB-donor via gNB and UPF, which helps establish F1 logical path between gNB-DU of R1 and gNB-CU of M-IAB-donor. This is covered in detail in section 6.2.4. Similarly, R2 also establishes a data path to facilitate F1 connectivity with M-IAB-donor via R1, gNB and UPF. The communication between R2 and M-IAB-donor is facilitated through encapsulation within the F1 path established between R1 and M-IAB-donor via gNB & UPF.

UE connects to gNB-DU of R2 and its signalling information is forwarded via the F1 path established between R2 and M-IAB-donor (via R1, gNB & UPF) which will terminate at AMF. **Figure 25**. (a) shows the signalling flow and (b) shows data path of UE in the multi-hop relay scenario.

Detailed signalling and data flow

To understand signalling and data flow we consider a multi-hop system as shown in **Figure 26**. The system comprises of two M-IAB-nodes (R1 and R2) and UE seeks to connect to the CN via these relay nodes.

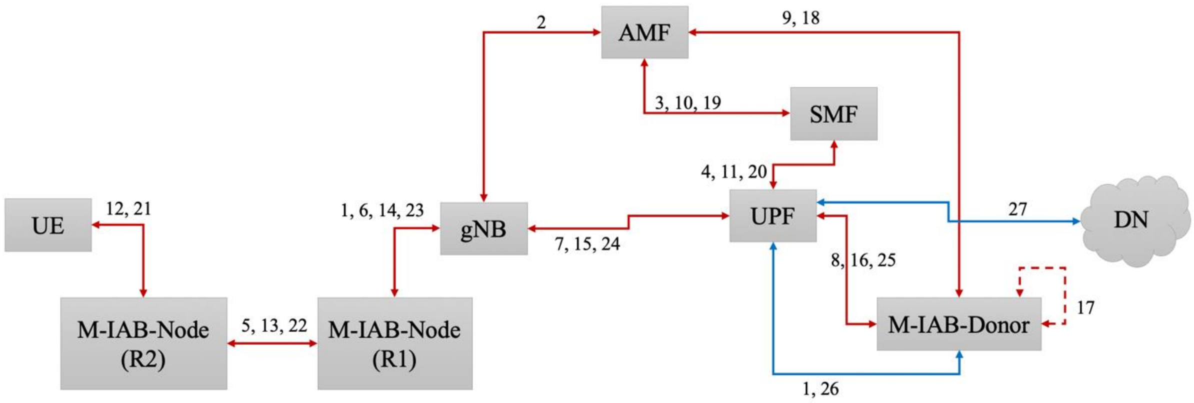

Figure 26. An illustration of UEs signalling and data flow

<u>Signalling flow:</u>

1) M-IAB-node R1 is instantiated and it starts acting as a UE using its IAB-MT stack. It connects to the gNB through a UE-RRC Connection (1).

2) R1 sends NAS Messages (as part of the Registration procedure) to the AMF via gNB (2). The NAS messages sent by R1 are meant to designate the M-IAB-donor as its gNB-CU (or donor node).

3) AMF facilitates data path setup with the help of SMF for R1 to M-IAB-donor via UPF (3,4). As a consequence, an IP address is allocated to R1 by the CN. Once R1 has established a data path with M-IAB-donor, it starts behaving as a gNB-DU using its gNB-DU functionality.

4) An M-IAB-node R2, while acting as a UE (IAB-MT), connects to R1 (M-IAB-node/gNB-DU) through a radio link (5). The NAS messages from R2, encapsulated within an RRC and lower layers (PDCP etc.), is sent to the M-IAB-donor via the data path already established for R1 (6, 7, 8). M-IAB-donor acts as the gNB-CU for R2, both for R2's IAB-MT and the UEs connected to R2 via Uu interface as well. The NAS messages sent by R2 (IAB-MT) designates M-IAB-donor as its gNB-CU. NAS messages from IAB-MT of R2 is sent via F1 interface of R1 (gNB-DU) further encapsulated inside IP packets generated by R1 (IAB-MT) towards the M-IAB-donor (via intermediate gNB and UPF).

5) M-IAB-donor decapsulates the F1 interface messages using IP, SCTP and F1AP after handling it at lower layers. The gNB-CU of M-IAB-donor also handles the packet at PCDP and RRC layers and forwards the NAS messages received from R2 to AMF using N2 interface (via NGAP/SCTP/IP)(9).

6) AMF forwards R2's request for a data path to SMF, SMF setups the data path with UPF to M-IAB-donor (10, 11). The data path is also established via M-IAB-donor (gNB-CU) and R1 (gNB-DU) (though not shown in the figure) connecting the IAB-MT of R2 to R1 via one or more PDU-Sessions. As part of this process, one or more IP addresses are also allocated to the IAB-MT of R2 by the core network. These IP addresses, allocated to IAB-MT of R2, enable F1 interface connectivity of the gNB-DU of R2 to M-IAB-donor. At the conclusion of this step, gNB-DU of R1 and gNB-CU of M-IAB-donor together starts playing the role of gNB for IAB-MT of R2. M-IAB-donor is playing a dual role for R2, it is acting as the gNB for IAB-MT of R2, as well as gNB-CU for the gNB-DU of R2.

7) The UE connects to R2 (gNB-DU) through a radio link (UE-RRC Connection) (12). UE sends NAS messages to AMF through R2, R1, gNB, UPF and M-IAB-donor (12, 13, 14, 15, 16, 17).

   a) Since the M-IAB-donor acts as the gNB-CU for R1 also, M-IAB-donor needs to decapsulate (de-tunnel) twice to retrieve the UE packet. M-IAB-donor itself can decapsulate (de-tunnel) in a loop (17) or route the packet twice through UPF back to M-IAB-donor.

   b) Once M-IAB-donor decapsulates SCTP/F1AP and PDCP packet of R2, it handles it at the RRC layer.

8) The NAS packet inside the RRC message is handled through NGAP/SCTP stack and forwarded to AMF over N2 interface (18).

Data flow:

9) AMF facilitates data path establishment for the UE, through SMF (19). SMF setups a data path for the UE to an external data network via the UPF (20). An IP address is also allocated to the UE for data transfer to the external data network.

10) Once the UE has established a data path with an external data network, it starts transmitting data (21). The UE sends data towards external data network using its IP address towards R2 over the PDU session established for the UE towards R2.

11) R2 forwards the UE data to R1 over the data path established for R2 towards M-IAB-donor (22). The data message from UE is sent over F1, encapsulated inside SDAP, PDCP and IP packet generated by R2 (IAB-MT) towards R1. R1 inserts the UE data packet in its F1 interface via GTP-U, UDP and IP layers, and further radio interface of SDAP, PDCP and underlying layers (of IAB-MT stack) and sends it towards gNB (23). The gNB, sends it towards UPF (24). UPF then forwards the IP data packet to M-IAB-donor (25).

As explained in signalling flow, the UEs data packet is handled twice at the M-IAB-donor decapsulating R1's outer headers first (R1's GTP-U, UDP, IP, SDAP & PDCP layers) and then R2's headers (R2's GTP-U, UDP, IP, SDAP & PDCP layers) (17). Once the UE data packet destined for UPF is decapsulated through F1 (GTP-U, UDP, IP) and Radio interface (PDCP, SDAP) layers, it is forwarded to UPF over N3 interface (using GTP/UDP/IP) (26) by the M-IAB-donor, which takes it to an external data network (DN) (27).

6.4 Mobility of UEs

We consider two scenarios to discuss how mobility of UEs work in the proposed relay architecture:

Scenario 1: Initially, the UE is in the vicinity of M-IAB-node and connected to the 5G network via M-IAB-node. Due to the mobility of UE, it is out of M-IAB-node's coverage and receives better signal strength from another neighboring gNB. Hence, UE shall be handed over from M-IAB-node to gNB.

Scenario 2: Initially, the UE is in the vicinity of a M-IAB-node (say M-IAB-node1) and connected to the 5G network via that M-IAB-node. Due to the mobility of UE, it is out of M-IAB-node1's coverage and receives better signal strength from another M-IAB-node (say M-IAB-node2). Hence, UE shall be handed over from M-IAB-node1 to M-IAB-node2.

6.4.1 Scenario 1: UE handover from M-IAB-node to another gNB

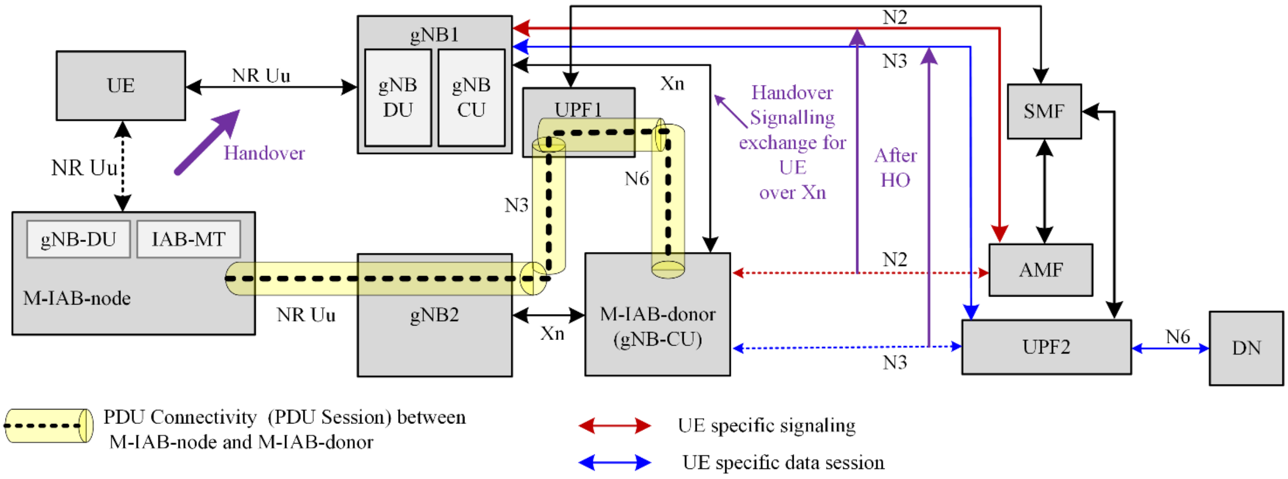

Figure 27. Working of the proposed solution for mobility of a UE between M-IAB-node and gNB1

Working of the proposed solution to support efficient mobility of a UE from an M-IAB-node to a macro base station (gNB) is described here. For the connected UE, the M-IAB-node provides the gNB-DU functionality and the M-IAB-donor provides the gNB-CU functionality. Once the UE moves away from the M-IAB-node, the UE gets handed over to a nearby gNB.

The M-IAB-node is connected to its corresponding M-IAB-donor through PDU (IP) connectivity service facilitated by the 5G network. PDU (IP) connectivity between the M-IAB-node (IAB-MT) and the M-IAB-donor (gNB-CU) is supported via gNB2 and UPF1 (as shown in **Figure 27)**. For this scenario, initially the UE is in the proximity of M-IAB-node and connects to the M-IAB-node (gNB-DU) + M-IAB-donor (gNB-CU) in the same way as a UE conventionally connects to a gNB (gNB-DU + gNB-CU) [Reference: 'UE Initial Access' procedure - clause 8.1 of 3GPP TS 38.401].

When UE moves away from the M-IAB-node, signal strength received at the UE from the M-IAB-node reduces. UE detects better signal strength from a neighboring gNB (say gNB1) and a handover of UE from M-IAB-node (gNB-DU) + M-IAB-donor (gNB-CU) to gNB1 is triggered. It is a conventional inter-gNB handover. The UE is handed over from M-IAB-node + M-IAB-donor to gNB1 through the Xn interface (between the M-IAB-donor and gNB1) following the procedure described in 3GPP TS 23.502 - clause 4.9.1.2.2.

In **Figure 27**, it is shown that the UEs connected to the M-IAB-node can have PDU sessions established with the DN via UPF2. Depending on the DNN that a UE wants to connect to, PDU sessions for the UEs can also be established through other UPFs (even including UPF1) via the M-IAB-node's gNB-DU and gNB-CU of the M-IAB-donor. *Additional UPFs have not been shown in the figure for the sake of simplicity.*

6.4.1.1 Signalling procedure for UE handover from M-IAB-node to another gNB

The following signalling flow (**Figure 28**) details the UE handover procedure between M-IAB-node and another gNB, gNB1. It is an "Xn based inter-NG-RAN handover without User Plane function re-allocation" as detailed in 3GPP TS 23.502 - clause 4.9.1.2.2.

Note: *M-IAB-node is integrated with M-IAB-donor via gNB2 and UPF1, integration procedure is detailed in Section 6.2.4.1.*

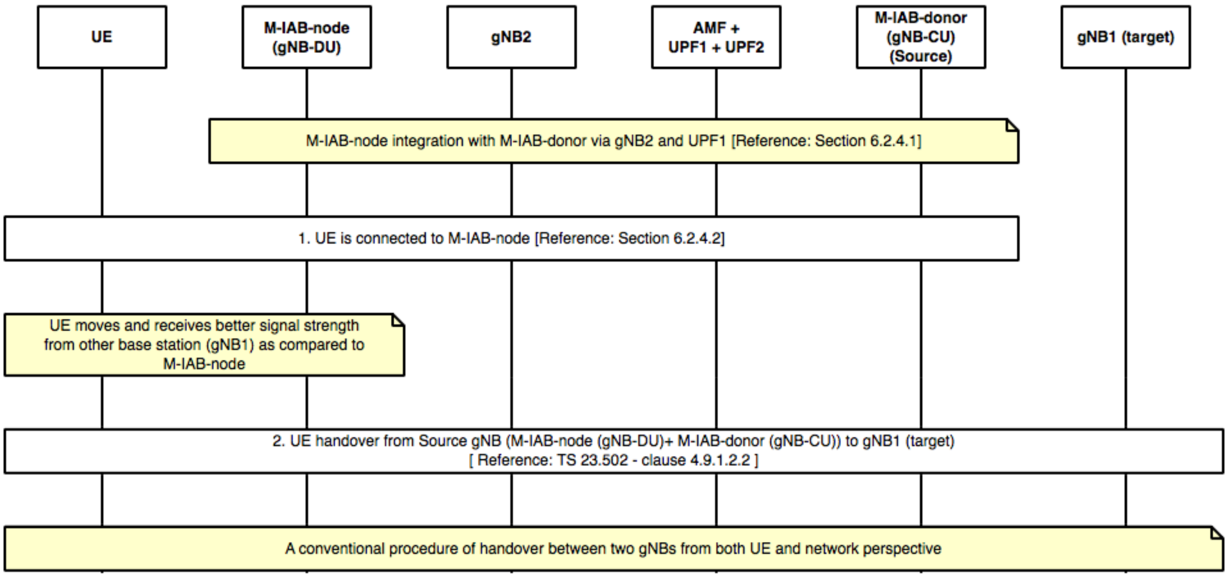

Figure 28. Signalling procedure for UE handover from M-IAB-node to another gNB

1. UE is connected to the 5G network through the M-IAB-node as detailed in Section 6.2.4.2.

Note: *When the UE moves away from M-IAB-node, UE receives better signal strength from a neighboring gNB (gNB1 in this case) as compared to M-IAB-node.*

2. UE is handed over to gNB1 by following the standard handover procedure between two gNBs as detailed in 3GPP TS 23.502 - clause 4.9.1.2.2. In this handover procedure, source gNB consists of gNB-DU (at M-IAB-node) and gNB-CU (at M-IAB-donor), whereas target gNB is gNB1.

Note: *It is a conventional inter-gNB handover from the perspective of the UE and the network.*

6.4.2 Scenario 2: Mobility of UE between M-IAB-nodes

Working of the proposed solution, in the case of the handover of a UE or group of UEs from one M-IAB-node to another, is shown in **Figure 29**.

Initially a stationary UE or group of UEs are in the proximity of M-IAB-node1 and due to mobility, UE(s) start receiving better signal strength from another M-IAB-node (say M-IAB-node2). M-IAB-node1 and M-IAB-node2 are connected to the same M-IAB-donor through PDU (IP) connectivity facilitated by the 5G network. Here M-IAB-node1 is connected to gNB1 as a UE and M-IAB-node2 is connected to gNB2 as a UE.

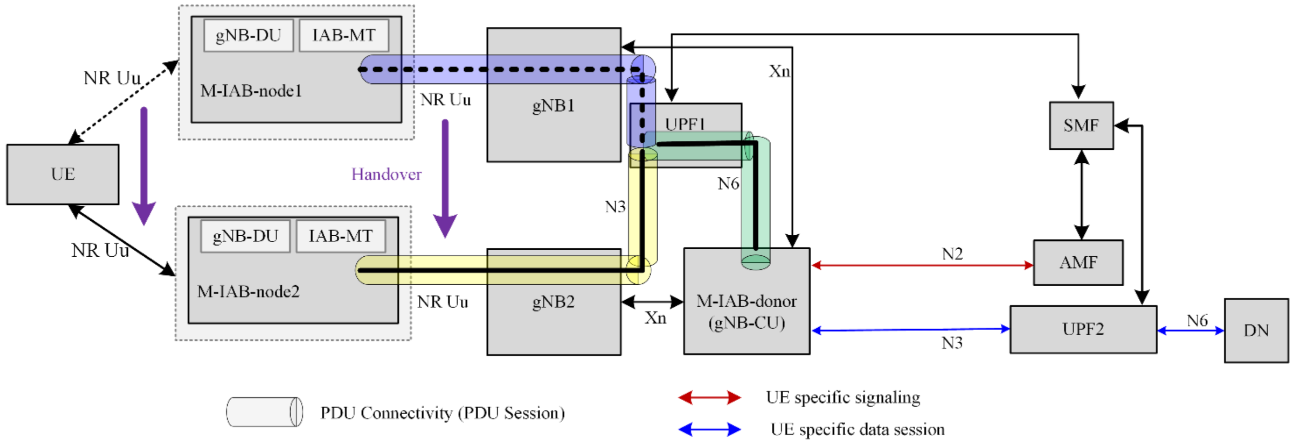

Figure 29. Working of the proposed solution for mobility of a UE between M-IAB-nodes

Note: *Both the M-IAB-nodes can also be connected to the same gNB. Since M-IAB-donor is the same for both M-IAB-nodes, it does not matter if the M-IAB-nodes are connected to the 5G network via the same gNB or different gNBs. Irrespective of the gNB(s) being used for connectivity of M-IAB-node to the rest of the network and especially the M-IAB-donor, the inter M-IAB-node handover procedure remains the same.*

Initially, UE is connected to the 5G network via M-IAB-node1. When UE moves away from M-IAB-node1 and receives better signal strength from M-IAB-node2 (as compared to M-IAB-node1), UE is handed over from M-IAB-node1 to M-IAB-node2.

This handover of the UE from M-IAB-node1 (source) to M-IAB-node2 (target) is an intra-gNB-CU and inter-gNB-DU handover in a scenario of UE mobility between two gNB-DUs within the same gNB-CU [Reference: 3GPP TS 38.401 - clause 8.2.1.2]. After the handover, UE is connected to the 5G network via M-IAB-node2.

6.4.2.1 Signalling procedure for UE mobility between different M-IAB-nodes

The following signalling flow (**Figure 30**) details UE handover procedure between two M-IAB-nodes. Here, both M-IAB-nodes are connected to the same gNB-CU (M-IAB-donor). If both M-IAB-nodes are connected to different M-IAB-donors (gNB-CUs), the procedure will be the same as conventional inter-gNB handover as detailed in 3GPP TS 23.502 - clause 4.9.1.2.2.

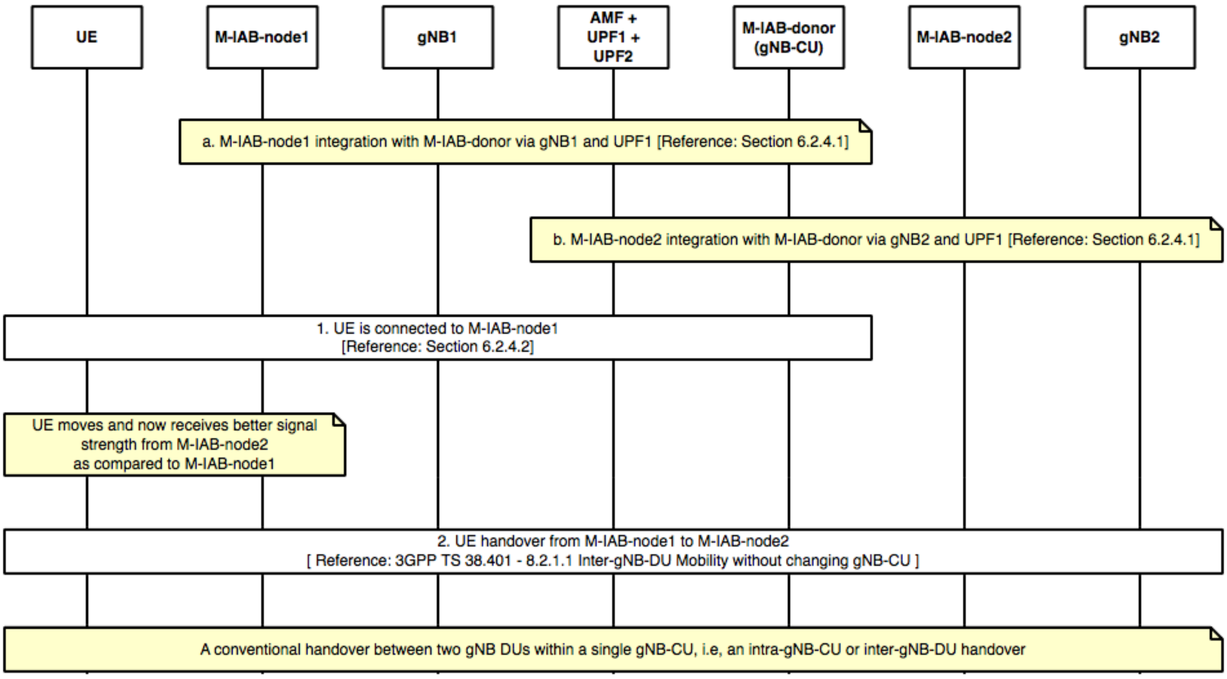

Figure 30. Signalling procedure for UE handover from M-IAB-node1 to M-IAB-node2

***Note a**: M-IAB-node1 is integrated with M-IAB-donor (via gNB1 & UPF1) as detailed in Section 6.2.4.1.*

***Note b**: M-IAB-node2 is integrated with the same M-IAB-donor (via gNB2 & UPF1) as detailed in Section 6.2.4.1.*

1. UE is initially connected to the 5G network through M-IAB-node1 as detailed in Section 6.2.4.2. For UE, its gNB-DU is placed at M-IAB-node1 and gNB-CU is placed at M-IAB-donor.

***Note**: UE moves away from the M-IAB-node1 and UE detects better signal strength from M-IAB-node2 as compared to M-IAB-node1.*

2. UE is handed over to M-IAB-node2 by following the standard inter-gNB-DU handover procedure without any change in the gNB-CU as detailed in 3GPP TS 38.401 - clause 8.2.1.2. In this handover procedure, source gNB-DU belongs to M-IAB-node1 and target gNB-DU belongs to M-IAB-node2.

***Note**: It is a conventional handover between two gNB DUs connected to the same gNB-CU, i.e, an intra-gNB-CU or inter-gNB-DU handover.*

6.5 Mobility of Relay nodes

This section details the mobility of Relay Nodes with respect to the proposed architecture in the 5G network (shown in **Figure 31**).

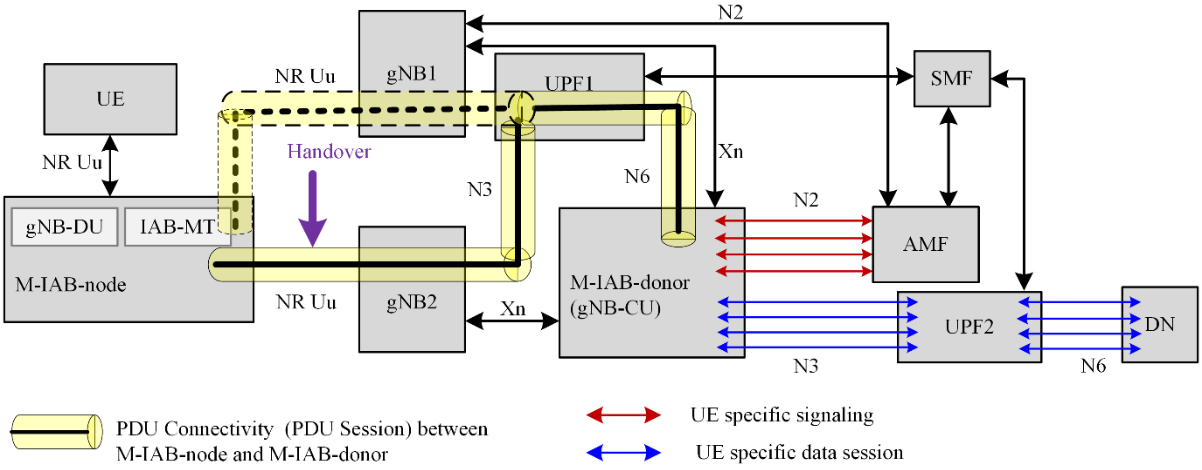

Figure 31. Working of the proposed solution for mobility of M-IAB-node between gNBs

Initially IAB-MT of M-IAB-node is connected to gNB1 over the radio (Uu) interface and its PDU session(s) with M-IAB-donor are established via gNB1 and the UPF1 as shown in Figure 29. When the M-IAB-node moves and gets closer to gNB2, it is handed over to gNB2 by gNB1. This is similar to a conventional UE handover between gNB1 and gNB2 [Reference: Clause 4.9.1.2.2 of 3GPP TS 23.502], considering the IAB-MT function of M-IAB-node as a UE. After the handover of the M-IAB-node (IAB-MT) is complete, the corresponding IAB-MT's PDU (IP) connectivity service is re-established via gNB2 & UPF1 in order to reach M-IAB-donor. As the M-IAB-donor is placed beyond the UPF, M-IAB-node's mobility does not impact its PDU (IP) connectivity with the M-IAB-donor and M-IAB-node always remains connected to the same IAB-donor for the gNB-CU functionality.

Note *that in the proposed solution, the scenario of mobility of M-IAB-node between different M-IAB-donors doesn't occur. Since M-IAB-donor (gNB-CU) nodes are placed beyond the UPF with IP connectivity between M-IAB-node and M-IAB-donor facilitated by the 5G network itself (via PDU Sessions), they (M-IAB-donors) are always reachable by an M-IAB-node despite M-IAB-node's mobility. Once the F1 interface between M-IAB-node and M-IAB-donor is established over the PDU sessions, the F1 interface between them always remains available even though the M-IAB-node itself may be moving through the 5G network.*

6.6 Applicability to beyond 5G

This section covers some use cases on how the proposed architecture can support relay functionality in future mobile networks, i.e., in beyond 5G networks.

6.6.1 Hybrid relay architecture considering multiple RATs for future networks

For future networks, coexistence of multiple Radio Access Technology (RAT) types, including existing RATs (such as 5G-NR, LTE, WLAN) and new evolving RATs (such as Tera HZ access and satellite access) is essential to handle huge traffic volumes with diversified services and use cases. Hence, solutions for future ready relay-based architecture also have to aid such coexistence of different types of RATs. The proposed relay solution supports this feature where access and backhaul links can belong to different RATs. In addition, existing 3GPP specifications defined interfaces can be used and there is no need for additional interfaces. In the proposed solution, UE shall have the flexibility to use any RAT relay node to connect with its donor node using any other RAT for backhaul connectivity.

To understand multi-RAT relays, few RAT interoperability scenarios based on availability and type of RATs can be considered as shown in **Figure 32**. UE connects to the relay node (via the RAT1 access point) over the RAT1 radio interface (**Figure 32 (a)**), and the relay node is connected to its donor node (RAT1 donor) via RAT2 based backhaul connectivity. Here, the relay node entails a RAT1 radio access protocol stack towards the UE and a RAT2 MT stack towards the backhaul access and core network, which facilitates IP connectivity with the RAT1 donor. For example, UE can connect to a relay node over LTE radio interface, if the relay node possesses an LTE radio protocol stack towards the UE. Similarly, the relay node should have a 5G-NR protocol stack towards gNB to establish IP connectivity with its donor using the 5G network for backhaul. Initially, IP connectivity service is established between the MT stack of the relay node (acting as a UE for the RAT2 backhaul access network) and the RAT1 donor, UE then connects to the RAT1 donor through the relay node (via RAT2 access network and RAT2 core network). Further, RAT1 donor extends UE connectivity to the data network through RAT1 compatible core network. If the same core is compatible with both RAT1 and RAT2, the RAT1 donor provides connectivity to the data network through the same core as shown in **Figure 32 (b)**. An example of this scenario could be the 5G core which supports RAT types like WLAN, LTE and 5G NR In the case of a WLAN access network, an InterWorking Function (IWF) can act as a donor node for a WLAN access point.

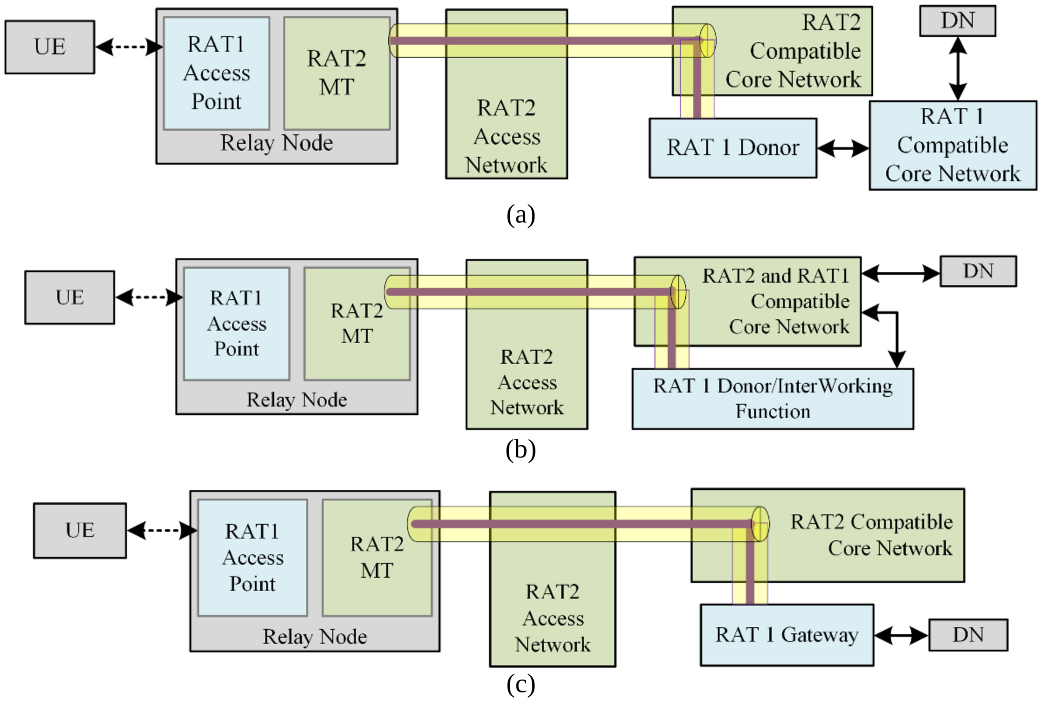

Figure 32. Multi-RAT scenario option when different RATs are used for access and backhauling

For some types of RATs, such as WLAN, a gateway can facilitate direct connectivity to the data network without the need for any core network (shown in **Figure 32 (c)**). However, UE connects to the RAT1 gateway through the RAT2 backhaul link in this scenario as well.

Note: *Gateway node is similar to a Broadband Network Gateway (BNG) which aggregates data traffic in broadband access networks [19]. These broadband access networks are based on WLAN or other fixed access technologies.*

Hybrid Multi-RAT architecture

Multi-RAT scenarios discussed above can be logically extended to a hybrid multi-RAT architecture in which UEs, relay nodes, access network, backhaul network, core network, and donors can support different radio access technologies (shown in **Figure 33**). For example, UE can have radio interfaces for single or multiple RATs. Note that there can be additional RATs; only three RAT1, RAT2 and RAT3 are shown in the figure for representation purposes. Similarly, all other components in the proposed solution can be compliant with single or multiple RATs. UE can connect to a relay node over the radio interface of any RAT (let's assume RAT2), and a relay node can connect to the donor/gateway (RAT2) through backhaul connectivity of any other available RAT (let's assume RAT3). Further, donor (RAT2) can provide connectivity to the data network through a core compliant with its RAT (RAT2). If it is a gateway (based on the type of RAT) it can provide direct connectivity to the data network.

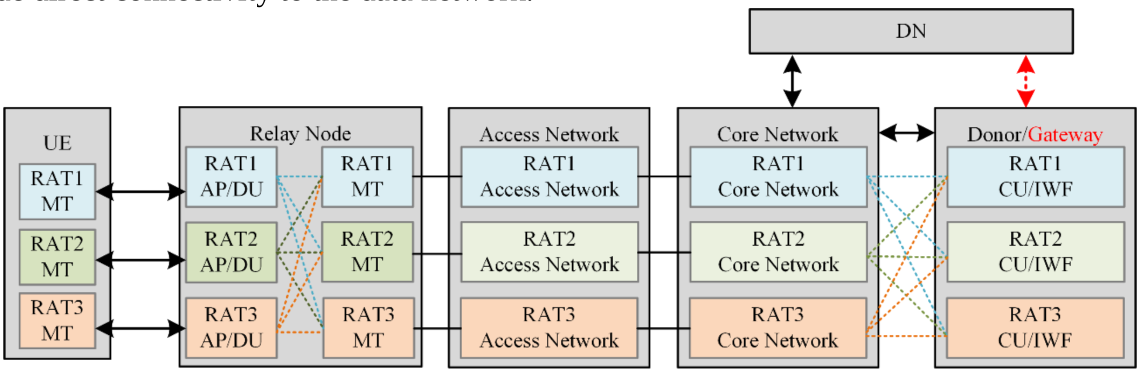

Figure 33. Hybrid Multi-RAT scenario option when combination of RATs can be used for access and backhauling

The proposed relay solution supports hybrid relay architecture for multi-RAT scenarios which can be implemented/deployed based on available RAT infrastructure.

6.6.2 Integration of NTN based relay nodes using proposed solution

In remote and hilly areas due to certain geographical limitations, it is difficult to deploy terrestrial base stations, hence coverage through satellite communication becomes important. Non-Terrestrial Networks (NTN), i.e. satellite access networks can provide connectivity for such locations. NTN can be integrated with relay nodes to provide ubiquitous coverage and also guarantee service availability to the end-users. Therefore, NTN based relays are beneficial for beyond 5G networks.

The integration of NTN based relay in the proposed solution is illustrated in **Figure 34**. UE connects to the relay node, i.e. Sat-M-IAB Node over the NR Uu radio interface. Sat-M-IAB Node consists of a standard gNB-DU with an additional Uu interface radio stack to support Satellite-UE functionality. Sat-M-IAB Node connects with M-IAB-donor using PDU (IP) connectivity service established through satellite access and 5G core. M-IAB-donor hosts a standard gNB-CU. The gNB-DU in Sat-M-IAB Node and gNB-CU in the M-IAB-donor together provide gNB functionality to the UEs. In this approach, 5GS enables IP connectivity via NTN (satellite access network) to establish the F1 logical interface between gNB-DU of Sat-M-IAB Node and gNB-CU of M-IAB-donor.

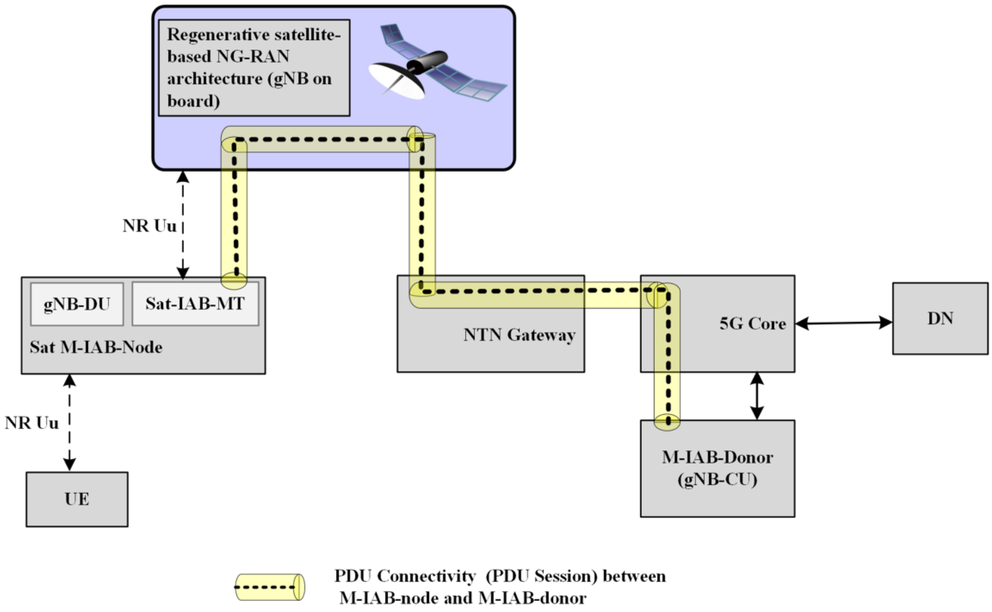

Figure 34. Block diagram of the integration of NTN based relays in the proposed solution

NTN (satellite access network) connectivity to the 5GC is provided via the NTN Gateway. Various types of satellite-based NG-RAN architectures are defined in [1] such as transparent satellite-based and regenerative satellite-based NG-RAN architectures. For the sake of simplicity, we assume that satellite implement regenerative (gNB on board) payload. However, any of the satellite-based NG-RAN architecture as defined in [1] can be integrated with our proposed NTN based relay solution. The main advantage is that UEs need not be a satellite-UE, they are connected to the satellites via a relay node.

In our proposed NTN based relay solution, Sat-IAB-MT will experience intra-satellite or inter-satellite handover that occur between satellite beams or between two different satellites and are different from the conventional handovers as seen in case of terrestrial BSs. The mobility of UEs in the proposed NTN based relay solution will work in the similar way as detailed in Section 6.4. Moreover, Sat-M-IAB Nodes can be deployed as a stationary node or moving nodes on ground and can also act as an aerial node (e.g. UAV) that will enable connection of standard UEs with the 5GC through satellite access. Satellite access link provides backhaul connectivity to the Sat-M-IAB nodes, hence no other additional infrastructure and interface modules are required.

6.7 Duplexing Constraints

There can be “In-band” or “out-of-band” backhauling for relay nodes (M-IAB-nodes) with respect to access link. In case of out-of-band back-hauling for relay node, M-IAB-node can simultaneously transmit and receive (to/from UE or gNB) as different carrier frequencies are used for transmitting and receiving to/from destination/source nodes (for access and backhaul).

For in-band backhauling of relay nodes, same or partially overlapped carrier frequencies shall be used for communicating with child and parent nodes (UE on the one side and gNB on the other side in this proposed solution). Hence, there shall be half duplexing constraints in case of in-band backhauling (for relays) to avoid self-interference between transmitting and receiving RF modules at M-IAB-nodes.

Note: *The proposed relay solution can support both FDD/TDD mechanisms.*

6.8 Timing Alignment

In wireless transmission scenarios, there is always a time offset (denoted as T_{TA}) between associated uplink and downlink frames (say Uplink frame i and Downlink frame i) due to drift and delays induced in transmission (as shown in **Figure 35**) [22]. This offset value is provided to UE by its serving gNB as timing advance offset for uplink frame alignment. In the proposed solution, timing advance procedure as defined in [23] is supported by IAB-MT (as UE) and the gNB-DU of an M-IAB-Node.

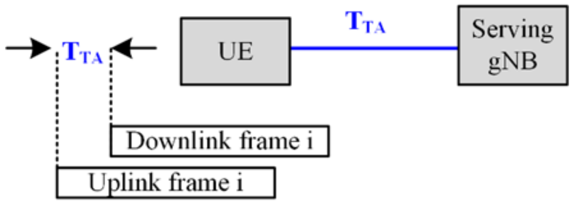

Figure 35: Timing advance offset for a UE connected to a gNB

In addition, gNB-DUs need to be time synchronized with other network nodes. Techniques such as Navigation with Indian Constellation (NavIC), Global Navigation Satellite System (GNSS), or Precision Time Protocol (PTP), can be used to achieve time-domain synchronization across IAB-nodes for their operation.

6.9 Spectrum Aspects

This section covers spectrum allocation/coordination aspects in case of deploying proposed relay solution. As detailed in previous sections, gNB-DU (at M-IAB node) and gNB-CU (at M-IAB-donor) together serve as a gNB for connected UEs (to M-IAB-donor through M-IAB node). M-IAB node is connected with UEs as gNB-DU on one side and is connected to other gNB (say gNB1) as a UE. Say spectrum S1 is used by M-IAB node (as gNB-DU) at Uu interface (UE side), and spectrum S2 is used by M-IAB node (IAB-MT) at Uu interface (gNB side). Resource allocation for spectrum S1 is governed by gNB-CU which is placed at M-IAB-donor and resource allocation for spectrum S2 is governed by gNB1. Spectrums S1 and S2 can be allocated based on out-of-band or in-band backhauling scenarios with respect to access links.

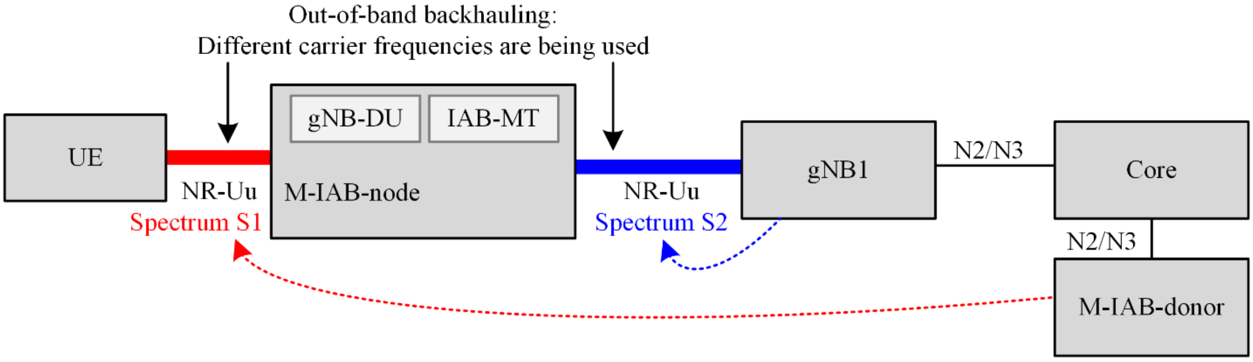

Figure 36. Out-of-band relay node

In case of out-of-band backhauling for relay node (as shown in **Figure 36**), S1 and S2 have different carrier frequencies and resource allocation can be done in same way as it is performed in case of any two neighbouring gNBs.

Figure 37 shows in-band backhauling for relay node in which S1 and S2 use same or partially overlapped carrier frequencies and there can be interference in transmitting and receiving at the same time. Hence resource coordination is required between gNB1 and M-IAB-donor through Xn interface to avoid such interference. Resource coordination between gNBs is a conventional mechanism which is performed between gNBs during Xn setup procedure (section 8.4.1, 3GPP TS 38.423 V17.4.0 (2023-03) [20]).

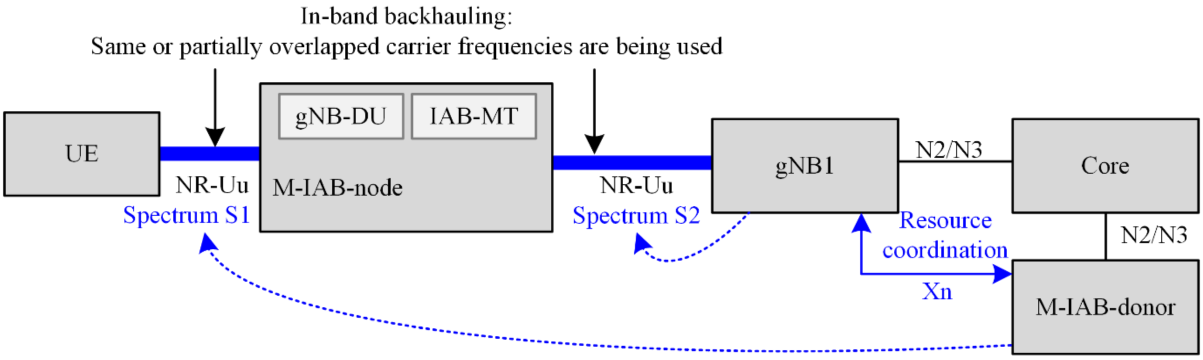

Figure 37. In-band relay node

In the proposed solution, no exceptional mechanism is required for spectrum management between gNB1 (which is providing backhaul for F1 connectivity) and gNB/M-IAB-donor (which is providing connectivity to UE through M-IAB-node). As these are conventional gNBs for each other and use of PDU session for F1 connectivity (for M-IAB-node) is transparent to the gNB1. Hence conventional resource allocation mechanisms are applicable for the proposed relay solution.

7 Applications

In this chapter, we cover a few applications of the proposed relay architecture.

7.1 Vehicle-mounted relays

This section details how VMRs can effectively be supported by the proposed architecture. We consider two scenarios related to UE connectivity and handover when an M-IAB-node is mounted on a vehicle acting as a VMR.

Scenario 1: Handover of UEs moving with the VMR

Working of the proposed solution to support VMR mobility wherein the UEs within the vehicle are connected to the VMR (M-IAB-node) and are moving along with it, is shown in **Figure 38**.

Multiple UEs within the vehicle are connected to VMR, which in turn is connected to gNB1 as a UE. For all these UEs within the VMR vehicle, M-IAB-donor provides the gNB-CU functionality. Both the signalling and the data of a UE are sent by the VMR over the F1 interface to M-IAB-donor (gNB-CU). As mentioned earlier, initially IAB-MT of VMR is connected to gNB1 over the radio (Uu) interface and its PDU session(s) to M-IAB-donor are established via gNB1 and the UPF1.

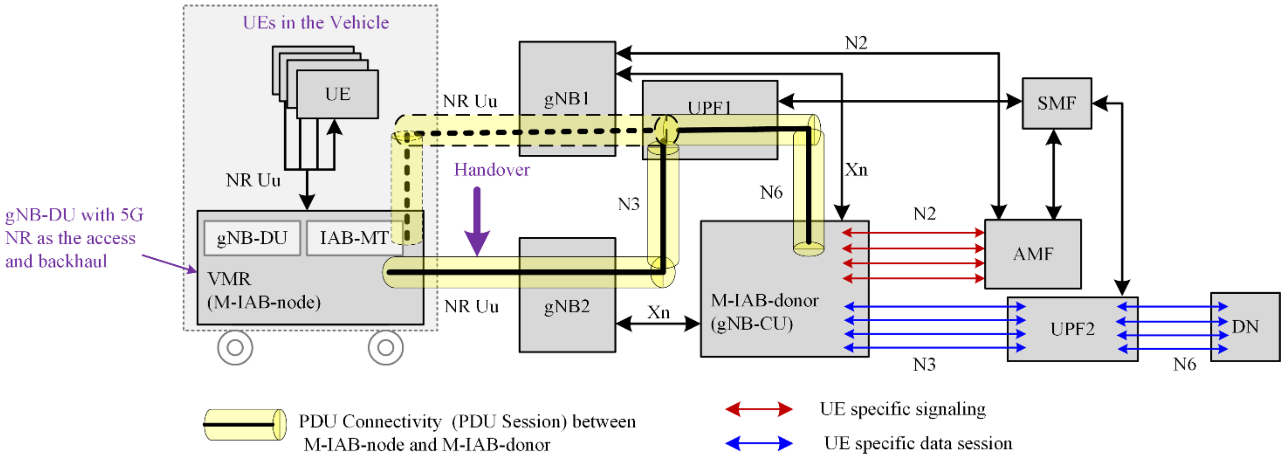

Figure 38 . Handover of UEs moving with the VMR

When the VMR moves and gets closer to gNB2, it is handed over to gNB2 by gNB1. This is similar to a conventional UE handover between gNB1 and gNB2 [Reference: Clause 4.9.1.2.2 of 3GPP TS 23.502] and is also detailed in Section 6.5, considering the IAB-MT function of VMR as a UE.

When the UEs within the VMR move along with it, it essentially is a no mobility scenario for the UEs as they remain connected to the same gNB-DU (VMR) and the same gNB-CU (M-IAB-donor) despite the mobility of the VMR. Therefore, there is no additional handover signalling for these UEs.

Scenario 2: Handover for stationary UEs connected to VMR

Working of the proposed solution for the scenario involving a UE or group of UEs outside the VMR, wherein the UEs are initially connected to the VMR (M-IAB-node) and then handed over to another gNB, is shown in **Figure 39**.

In this scenario, initially a stationary UE or group of UEs are in the proximity of the VMR for a brief period of time, let's say when the vehicle (mounted with VMR) is waiting at a traffic signal. The stationary UE gets connected to the VMR due to good signal strength. This UE connected to the VMR is served by the gNB-DU in the VMR and the gNB-CU in the M-IAB-donor. Once the VMR moves far away, the UE gets handed over to a nearby gNB.

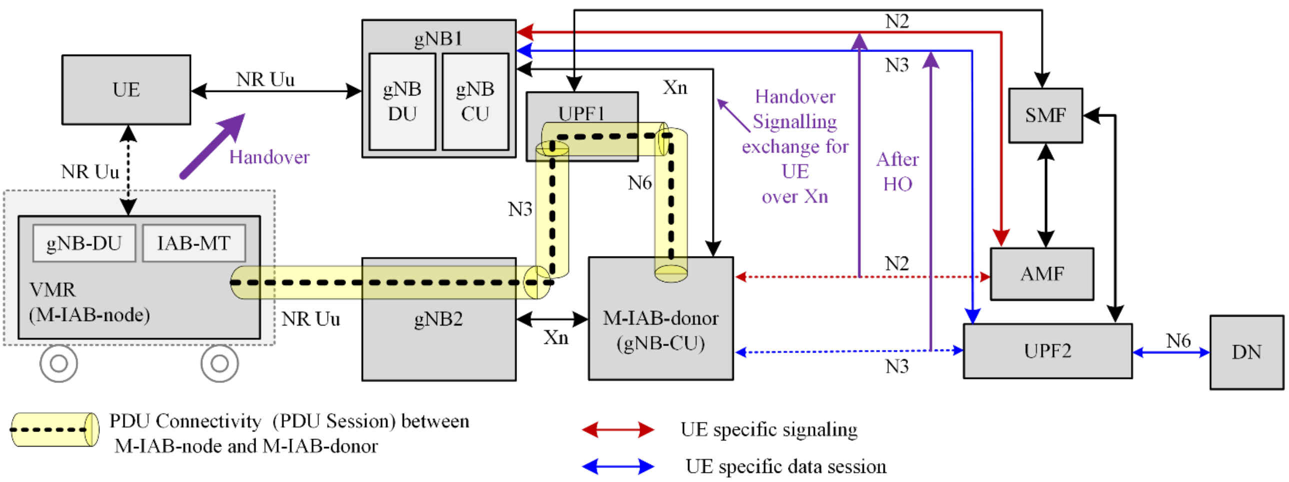

Figure 39. Handover of stationary UEs connected to VMR

For this scenario, initially, stationary UE is in the proximity of the VMR and connects to VMR (M-IAB-node) + M-IAB-donor in the same way as a UE conventionally connects to a gNB. When the

VMR moves away from the UE, signal strength received at the UE from the VMR is reduced. UE detects better signal strength from a neighboring gNB (say gNB1). Hence there is a handover of UE from VMR (M-IAB-node) + M-IAB-donor to gNB1**,** which is a conventional inter-gNB handover (as detailed in Section 6.4.2). The UE is handed over from M-IAB-donor to gNB-CU of gNB1 through the Xn interface. Note that this handover does not add any additional signalling due to the deployment of the VMR and it is a conventional UE handover between gNBs.

7.2 Multi-RAT relays

The general concept of deploying multi-RAT scenarios in the proposed solution is discussed above in Section 6.6.1. Different radio access technologies such as WLAN (Wi-Fi) and 5G-NR can be flexibly utilized for access and backhaul links of the proposed architecture to support multi-RAT relays. Here we present an applicable use case of utilizing WLAN (Wi-Fi) as the access network for UEs while 5G-NR provides backhaul link to support the multi-RAT relay node (shown in **Figure 40**).

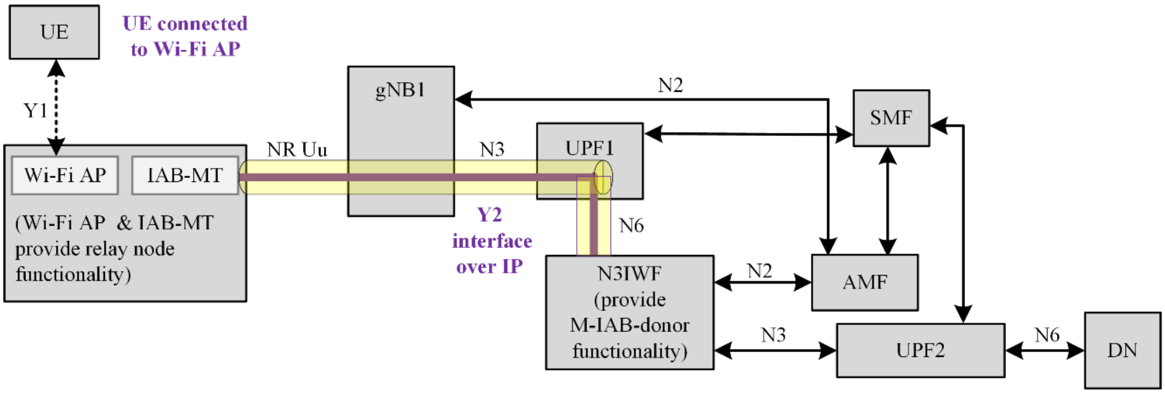

Figure 40. WLAN (Wi-Fi) as access with 5G-NR backhaul based Multi-RAT relay architecture with Non-3GPP InterWorking Function as M-IAB-donor

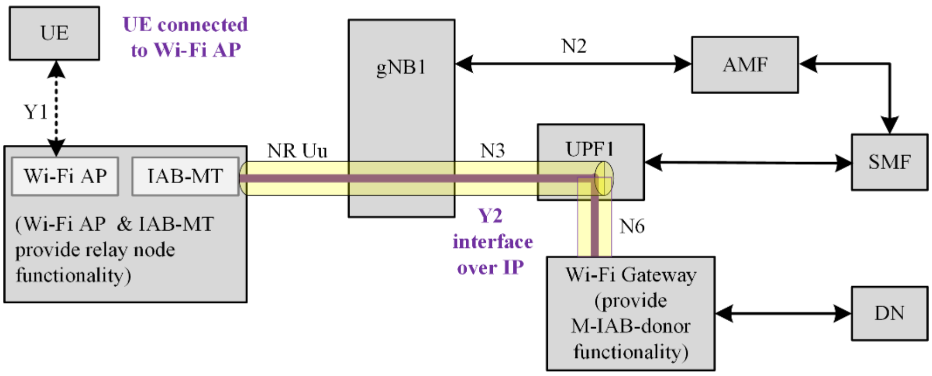

Figure 41. WLAN (Wi-Fi) as access with 5G-NR backhaul based Multi-RAT relay architecture using Wi-Fi gateway for connectivity with data network

Wireless Access Point (Wi-Fi AP) works as a relay node providing wireless connectivity to UEs to reach the 5G core via Non-3GPP InterWorking Function (N3IWF). UEs connect to the relay node (Wi-Fi AP) and further to the data network via N3IWF+UPF2 by using connectivity between the relay node (IAB-MT) and N3IWF. IAB-MT of the relay node uses 5G-NR as a backhaul and connects to N3IWF via the 5G network (gNB1+UPF1). An PDU (IP) connectivity service originating from Wi-Fi AP (IAB-MT) and terminating at N3IWF encapsulates the UE traffic for all UEs connected to the Relay node. This PDU connectivity service facilitates Y2 interface connectivity between Wi-Fi AP and N3IWF.

In another kind of implementation, there can be a WLAN (Wi-Fi) gateway in place of a Non-3GPP InterWorking Function (N3IWF) which can provide direct connectivity to the data network (shown in **Figure 41**). UE is connected to the data network through the following path: Relay node ⇒ gNB1 ⇒ UPF1 ⇒ WLAN (Wi-Fi) gateway. Here the 5G network only provides backhaul connectivity, and the WLAN (Wi-Fi) gateway provides direct connectivity to the data network.

7.3 UAV

Overview on Uncrewed Aerial System

Uncrewed Aerial System (UAS) comprises of the Uncrewed Aerial Vehicle (UAV) or drone and the UAV controller, which can be managed by an operator. The UAV can be controlled using the UAV controller which supports maneuvering of the UAV's flight path. 5G system enables communication between UAV and the UAV controller, which is specified in 3GPP TS 22.125 [21]. This communication covers Command and Control (C2) between the UAV and the UAV controller, along with uplink/downlink data between the UAV and the data network.

Uncrewed Aerial System Traffic Management (UTM) is used to provide support services like UAS identification & tracking, authorization and storing of UAS operations related data. **Figure 42**.

provides an overview of UAS support in the 3GPP ecosystem, where UAVs are connected over cellular connectivity. The UAV controller can be managing the UAV either via direct connectivity or via cellular connectivity placed in a data center.

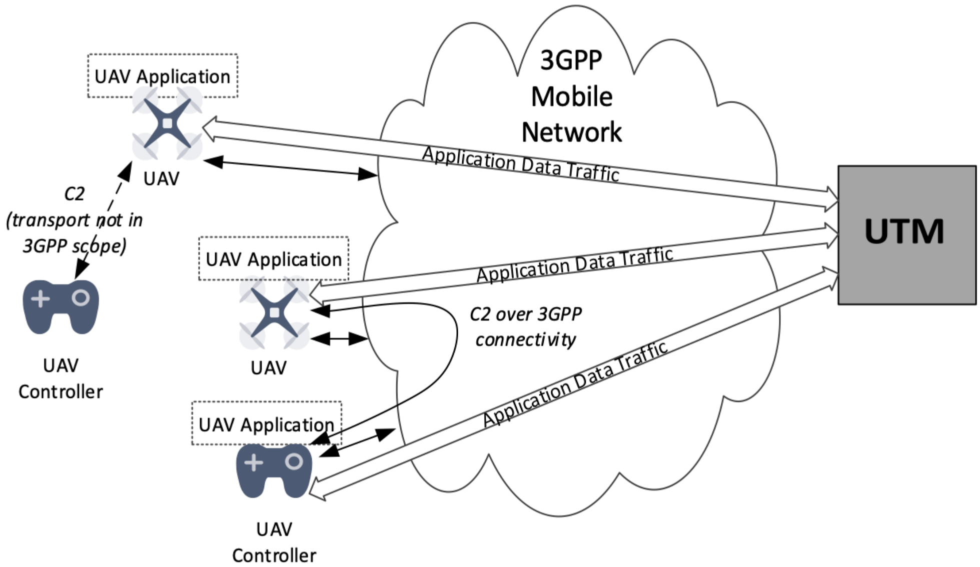

Figure 42. UAS model in 3GPP ecosystem [Courtesy: 3GPP TS 22.125]

UAV applicability in the proposed architecture

Several industry verticals recognize the utilities of UAVs and are deploying them to support innumerable use cases. Here, we consider UAVs as relay in the proposed solution which will be especially helpful to extend network coverage temporarily. Such scenarios could be sporting events, mass gatherings or providing coverage to archaeological sites. This section covers details of how a UAV can be supported and utilized by the proposed relay architecture.

UAVs can be hovering over a particular area providing network coverage, or they could be moving similar to a vehicle mounted relay and providing coverage. Here we discuss about the first option and the VMR scenario is discussed in section 7.4.

UAV hovering over a certain area and providing coverage

M-IAB-node is mounted on the UAV and is hovering over a particular area providing coverage. As shown in **Figure 43**, UEs are connected to the gNB-DU (over the Uu interface) of the M-IAB-node on the UAV. gNB-DU of M-IAB-node has F1 connectivity established with gNB-CU of M-IAB-donor using the PDU connectivity service, via gNB and UPF1. For the UEs connected to UAV, M-IAB-node & M-IAB-donor together provide gNB functionality. UE signalling and data path is tunnelled through the F1 path (PDU connectivity service) setup between the M-IAB-node and M-IAB-donor.

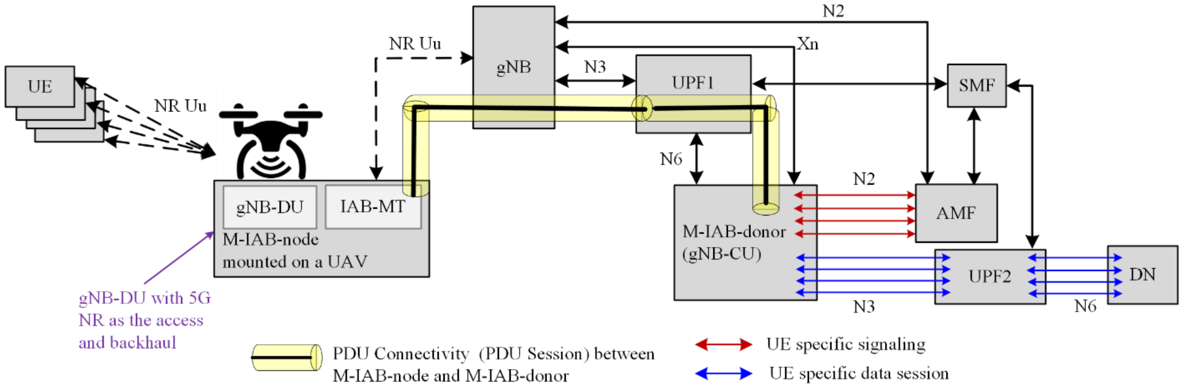

Figure 43. Working of the proposed solution for UEs connected to a UAV

Handover of UE between UAVs hovering over a certain area

UAVs are hovering and providing coverage over a certain area, but users may have to be handed over to another UAV mounted relay, either due to excessive load or if the UAV runs out of battery. In both the cases, UEs have to be handed over to another UAV mounted with a relay node. **Figure 44**. shows how such handovers are addressed in the proposed solution.

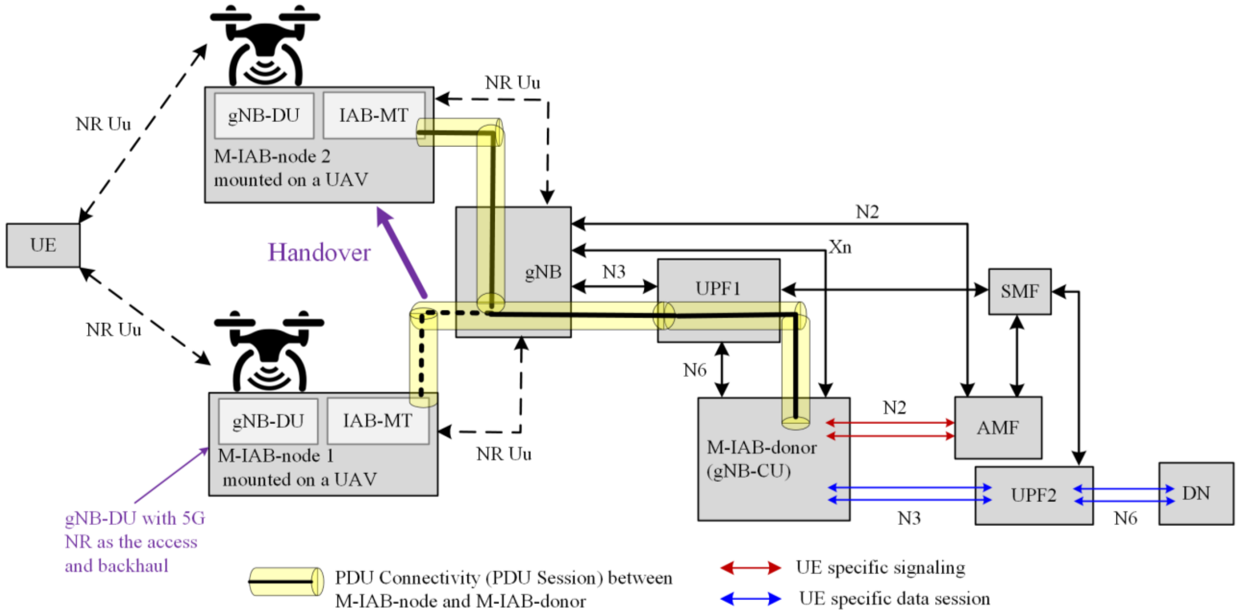

Figure 44. UEs handover between UAVs mounted with relay nodes

UE is initially connected to M-IAB-node 1, it's data session is setup through F1 path established between M-IAB-node 1 and M-IAB-donor. When UE gets handed over to M-IAB-node 2 its data path is established through the M-IAB-node 2, which is very similar to the UE handover scenario explained in section 6.4.2. Note that this handover does not add any additional signalling due to the deployment of the UAVs and it is a conventional UE handover between gNBs.

7.4 Other Applications/Use cases

Here, we shall provide details on how existing IAB/Relay applications/use cases can be supported by the proposed architecture.

Wireless backhauling using relays in cellular networks has proven to be suitable for extending coverage area and enhancing network capacity with minimal deployment costs. 3GPP has introduced the concept of IAB to support relaying in 5G network. Various scenarios/use cases are described in Section 4.3 that illustrates the advantages of using a 5G IAB solution.

Even though architecturally our proposed relay solution is different from the 5G IAB solution, it offers similar functionalities, i.e., UE connectivity with the relay node uses the same gNB-DU function along with the donor function interfacing with the core network. The proposed relay solution supports gNB-DU function in the M-IAB-node and gNB-CU function in the M-IAB-donor similar to the respective IAB-node and IAB-donor functions in the 5G IAB solution. Therefore, all use cases detailed in Section 4.3 can also be supported by the proposed relay solution, few of them are discussed below in the context of the proposed solution.

- M-IAB-node (mounted on a UAV) can be used to fill up coverage gaps in certain areas that occur due to blocking of signal because of the surrounding environment such as to interior parts of archaeological/mining sites or to villages covered by dense forests/in a valley/next to a hill. UAVs (M-IAB-node onboard) are also a good choice to provide emergency coverage in the event of natural disasters like earthquake, landslides and tsunamis where the terrestrial network could be damage.
- M-IAB-node can easily be deployed as a plug-and-play radio node to extend coverage in densely populated areas.
- M-IAB-nodes can flexibly be deployed to provide better radio connectivity to the users inside a building as compared to a conventional BS.
- M-IAB-node can also be implemented as VMR to provide efficient coverage to the users inside a moving vehicle.

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