5G ALLSTAR

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Preliminary document of 5G-ALLSTAR architecture, API and interface specifications

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Abstract

This deliverable has been created as part of the work in the project Work Package (WP)

Keywords

Network architecture ; Multi-connectivity ; System design ; Key component ; Key enabling technology ; Proof-of-Concept system

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Executive Summary

This deliverable reports the preliminary design of 5G-ALLSTAR system architecture for enabling the spectrum sharing and multi-connectivity functionalities in the 5G cellular and satellite access networks. It also includes a preliminary design of the intercontinental operability between European and Korean systems. The work and results provided in this document will be a guideline for other tasks and work-packages of the 5G-ALLSTAR project.

The deliverable is structured as follow:

- In Chapter 2 we report the use case requirements, the network key functionalities and the preliminary 5G-ALLSTAR system architecture.
- In Chapter 3 we report the preliminary design of the 5G and satellite access network architecture including the main functional modules that will be developed within the project.
- Chapter 4 presents a set of different multi-connectivity architectures and interfaces reporting the selected multi-connectivity architecture for the 5G-ALLSTAR system. The selected multi-connectivity architecture will be able to foster the development of the particular 5G-ALLSTAR use cases and key functionalities.
- Chapter 5 presents the key components for 5G and satellite access networks with the preliminary overview of the radio resource management and traffic scheduling functions that will be investigated in the project mainly referred to the activities that will be performed in WP3 and WP4 respectively.
- Chapter 6 reports the intercontinental operability functionalities to foster the communication between European and Korean system from architecture and interfaces perspective.
- Chapter 7 provides some conclusions on the reported activities for this document.

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List of Abbreviations

3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
5G-ALLSTAR	5G AgiLe and fLexible integration of SaTellite And cellulaR
5GC	5G Core
ABS	Almost Blank Sub-frame
ADC	Analog-to-Digital Converter
AMF	Access and Mobility Management Function
AN	Access Network
AP	Access Point
AT3SF	Access Traffic Steering, Switching and Splitting Function
ATSSS	Access Traffic Steering, Switching and Splitting
BBU	Base Band Unit
BPF	Band Pass Filter
BS	Base Station
CA	Carrier Aggregation
CC	Component Carrier
CMC	Connection Mobility Control
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing
CRC	Cyclic Redundancy Check
C-RAN	Cloud (or Centralized)-Radio Access Network
cRRM	Centralized RRM
CoMP	Coordinated Multi-Point
CSI-RS	Channel State Information Reference Signal
CU	Central Unit
DAC	Digital-to-Analog Converter
DRA	Dynamic Resource Allocation
D-RAN	Distributed Radio Access Network
DC	Dual Connectivity
DMRS	Demodulation Reference Signal
dRRM	Distributed RRM
DL	Downlink
DN	Data Network
DRB	Data Radio Bearer
DU	Distributed Unit
eMBB	Enhanced Mobile BroadBand
eNB	E-UTRAN NodeB
en-gNB	5G NR BS connected to 4G EPC
EIRP	Effective Isotropic Radiated Power
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FACS	Flexible Access Common Spectrum
FDD	Frequency Division Duplexing
GEO	Geostationary Orbit / Geostationary Orbit Satellite

gNB	Next generation NodeB
GS	Ground Segment
HEO	Highly Eccentric Orbit / Highly Eccentric Orbit Satellite
HST	High-Speed Train
IAB	Integrated Access and Backhaul
ICI	Inter-Carrier Interference
IoT	Internet of Things
ISL	Inter-Satellite Link
LB	Load Balancing
LDPC	Low-Density Parity-Check
LEO	Low Earth Orbit / Low Earth Orbit Satellite
LNA	Low Noise Amplifier
LNB	Low Noise Block
LTE	Long Term Evolution
MAC	Medium Access Control
MA-gNB	Multi-Access gNB
MC	Multi-connectivity
MCG	Master Cell Group
MEO	Medium Earth Orbit / Medium Earth Orbit Satellite
MHN	Mobile Hotspot Network
mmWave	Millimeter Wave
mMTC	Massive Machine Type Communication
MN	Master Node
MN system	Moving Network System
MR-DC	Multi-RAT Dual Connectivity
MT	Mobile Termination
NFV	Network Function Virtualization
ng-eNB	node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC
NG-RAN	Next Generation Radio Access Network
NR	New Radio
NSA	Non Stand Alone
NTN	Non-Terrestrial Network
OBP	On-Board Processing
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
PCC	Primary Component Carrier
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PoC	Proof-of-Concept
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PS	Packet Scheduling

PT-RS	Phase Tracking Reference Signal
QCI	Quality Channel Indicators
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RAT	Radio Access Technology
RAC	Radio Admission Control
RAN	Radio Access Network
RBC	Radio Bearer Control
RF	Radio Frequency
RLC	Radio Link Control
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
Rxx	(3GPP) Release xx
SA	Stand Alone
SAN	Satellite Access Network
SCC	Secondary Component Carrier
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCG	Secondary Cell Group

SDAP	Service Data Adaptation Protocol
SDN	Software-Defined Networking
SN	Secondary Node
SRB	Signalling Radio Bearer
SRI	Satellite Radio Interface
SSPA	Solid State Power Amplifier
SSS	Steering, Switching and Splitting
TA	Timing Advance
TDD	Time Division Duplexing
TE	Terminal Equipment
TP	Transmission Point
TR	Technical Report
TS	Technical Specification
TWTA	Travelling Wave Tube Amplifier
UE	User Equipment
UHD	Ultra High Definition
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communication
UT	User Terminal
V2X	Vehicle-to-Everything
V-UE	Vehicle UE
WP	Work Package

1 Introduction

This deliverable (D2.2) summarizes the activities performed within WP2 "*Scenarios for Multiple access in 5G*" concerning the preliminary design of the 5G-ALLSTAR architecture, and of the API and interfaces specifications.

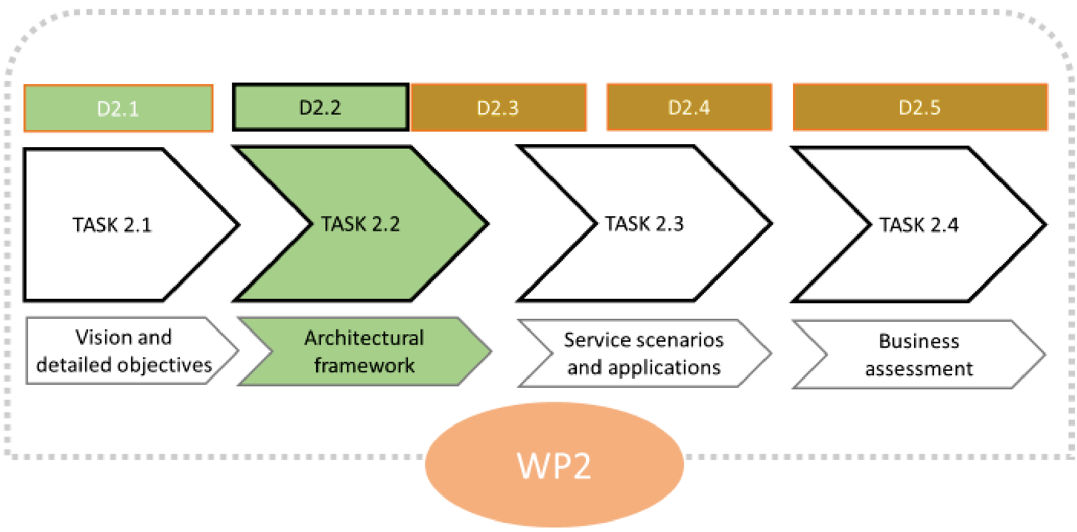

Figure 1-1: WP2 vision.

The WP2 structure is outlined in Figure 1-1 and is divided into four main tasks and five deliverables. This document undertakes the output of Task 2.2 and mainly concerns the design of the 5G-ALLSTAR system architecture including both (i) the 5G network functionalities already included in the 3rd Generation Partnership Project (3GPP) documents and (ii) the advanced functionalities that will be investigated and developed in the 5G-ALLSTAR project. D2.2 includes also a preliminary overview of the intercontinental operability between the European and Korean systemd and the architecture and the key functionalities for creating the flexible integration between 5G cellular radio and satellite access network (AN)s.

2 Overall Architecture of 5G-ALLSTAR System

The chapter provides a wide overview of the 5G-ALLSTAR project by including use case requirements (see section 2.1), the key functionalities of the network aimed at satisfying the project's requirements (see section 2.2), the key consideration for software defined networking (see section 2.3) and the system architectures (see 2.4) designed taking into account the main requirements and functionalities of the project.

2.1 Use Case Requirements

In order to cope with the new wireless services and applications across industry verticals, the development of 5G wireless technologies targets to satisfy highly ambitious goals, namely multi-Gbps data throughput, near-100% reliability, and sub-ms latency. The achievement of these goals is to be done per corresponding 5G use case, as follows:

- **Enhanced Mobile BroadBand (eMBB)** focuses on achieving very high data rate at a reasonable reliability and latency. Example use cases include web browsing, file transfer, and multimedia streaming.
- **Massive Machine Type Communication (mMTC)** mainly supports machine-to-machine communication such as sensor monitoring and asset tracking, where each machine type nodes can be typically low-cost and battery-operated.
- **Ultra-Reliable Low-Latency Communication (URLLC)** aims to support applications with very tight reliability and latency requirements. Typical examples of URLLC include Vehicle-to-Everything (V2X), remote surgery, and industrial manufacturing.

There are several KPIs identified as the essential requirements for the 5G-ALLSTAR development to be verified during the Proof-of-Concept (PoC) stage, namely user experienced data rate, user plane latency, control plane latency, reliability, and service continuity. All of these requirements are quite important to satisfy each identified use cases for the 5G-ALLSTAR project. The overall target requirements are provided in Table 2-1.

Table 2-1: Target performance requirements to be verified in the 5G-ALLSTAR project

KPI	Target performance	Demonstration of KPIs through		
		Simulation	Testbeds	Field trial
User experienced data rate	Downlink (DL): 50 Mbps Uplink (UL): 10 Mbps	○	○	○
User plane latency	< 10 ms for delay sensitive traffic	○	○	○
Control plane latency	< 20 ms	○	○	
Reliability	99.999 % success probability of transmission	○	○	
Service continuity	No service interruption (verifying zero service interruption when one of a link (e.g., cellular) fails abruptly or disappears due to mobility e.g. in rural areas)			○

The above requirements are closely related to each use case identified in D2.1 [1], as follows:

- **Multi-connectivity (MC):** MC between heterogeneous access links (e.g., between cellular and satellite links) enables a UE to simultaneously connect to the multiple base stations (BSs) built on different access technologies. MC is expected to provide improved data rate, latency, reliability, and service continuity. Hence, in the 5G-ALLSTAR project the following performance requirements needs to be satisfied in the MC use case:
  - User experienced data rate: 50 Mbps for downlink and 10 Mbps for uplink

  - User plane latency: Less than 10 ms
  - Control plane latency: Less than 20 ms
  - Reliability: 99.999% success probability
  - Service continuity: No service interruption
- **Broadband moving hotspot network:** Large throughput in-vehicle Internet connectivity can be provided with the 5G-ALLSTAR technology for transportation applications. Main target requirements are user experienced data rate, latency, and service continuity:
  - Average data rate per vehicle: 500 Mbps (downlink)
  - User experienced data rate per vehicle: 50 Mbps (downlink)
  - User plane latency: Less than 4 ms
  - Control plane latency: Less than 10 ms
  - Service continuity: No service interruption
- **Ultra-High-Definition (UHD) video streaming through interoperable networks:** This use case is for the global interoperability demonstration between European and Korean PoCs. Since the video streaming within transportation vehicles is the main application, eMBB-type service requirements are assumed:
  - User experienced data rate: 50 Mbps for downlink and 10 Mbps for uplink
  - User plane latency: Less than 10 ms (terrestrial), Less than 600 ms (satellite)
  - Service continuity: No service interruption

2.2 Key Functionalities

In order to satisfy the above use case-specific requirements, several key functionalities need to be defined. Details of access and network functionalities are summarized as follows:

- **MC:** MC use case requires to satisfy low user-perceived latency, access reliability, and service continuity. The following specific techniques are to be investigated:
  - Traffic splitting, steering, and aggregation need to be investigated to maximize global interoperability capability.
  - Intelligent routing can differently route delay-sensitive and delay-tolerant traffic so as to satisfy the user-perceived latency.
  - Satellite beam handover operation is required to maximize satellite coverage and to guarantee UE experience.
- **Broadband moving hotspot network:** The main concern of this use case is to provide very high data rate. The following specific techniques should be investigated:
  - Traffic aggregation technique (i.e., link aggregation) can maximize the bandwidth and the corresponding aggregated throughput, especially between different bands (i.e., between low frequency and millimetre-wave (mmWave) bands)
  - Mobility support for fast moving vehicle communication should be investigated. It includes fast handover and fast beam switching/steering operations.
  - Vertical handover schemes are also needed to provide mobility support between heterogeneous access links.
- **UHD video streaming through interoperable networks:** Key functionalities for this use case are related to provide Quality of Experience (QoE)/Quality of Service (QoS) guaranteeing, as follows:

- Traffic splitting, steering, and aggregation need to be investigated to maximize global interoperability capability.
- Intelligent routing can differently route delay-sensitive and delay-tolerant traffic so as to satisfy the user-perceived latency.
- Adaptive video transmission/reception technique is required to satisfy the QoS/QoE of the UHD video streaming.

2.3 Slicing, SDN and NVF

The objective of the 5G mobile network design is to provide a multi-service network, aimed at satisfying, on the same common physical infrastructure and simultaneously, the different and conflicting requirements of different services. Network Slicing is the reference paradigm to provide the needed network flexibility, [2][5][6][7]. The idea behind Network Slicing is to provide several independent virtual network instances on top to the common physical network, where each of these virtual networks (slices) is configured to satisfy particular requirements. The key technologies to enable Network Slicing are Software-Defined Networking (SDN) and Network Function Virtualization (NFV). The SDN approach allows the coordination between slices that share the same infrastructure with the centralized SDN Controller and introduces programmability and open access to the network. The NFV approach allows the virtualization of the network, reducing costs and time of deployment and adding architectural flexibility.

In the 5G-ALLSTAR project, we are interested in being compliant with the Network Slicing concepts. In the project, we consider Radio Access Network (RAN) Slicing, which is a complex task because of the scarce and limited frequency spectrum resources available and of the needs to satisfy at the same time the different service requirements. Indeed, the RAN Slicing requires dynamic resources management enabling efficient resources sharing and virtual resources isolation, with the aim of obtaining logical self-contained networks (slices) and functional requirements flexibility (each slice generally needs different control/user plane functional split).

The slice resource management is classified into two models, depending on the resource isolation level.

In the first model, named *dedicated resource* model, each slice consists of isolated resources in terms of control and user plane; each service instance has access to its own protocol stack (RRC/SDAP/PDCP/RLC/MAC) and to a percentage of dedicated physical resource blocks (PRBs). The dedicated resource model guarantees isolation among slices but lacks in resource management efficiency.

The second model, named *shared resources* model, allows slices to share control plane, Medium Access Control (MAC) scheduler and spectrum. In particular, the PRBs are managed by a common scheduler, which allocates resources to slices according to a specified policy, considering the radio network conditions and the service requirements.

The 5G-ALLSTAR project adopts the shared resources model. The project will develop algorithms for the shared spectrum management and the traffic management in multi-RAT RANs, considering the RAN resources as shared by different UEs with different service requirements.

The other key considerations in RAN Slicing are about flexible RAN virtualization and functional split, as depicted in Figure 2-1. RAN virtualization (or softwarization), allows the splitting of the RAN functions. This approach is called Cloud RAN (C-RAN) approach, and it consists of the splitting of the RAN functions between i) the Base Band Units (BBUs), hosted in the cloud and providing high-layer protocol stack functions and non-real-time technology-independent control functions, and ii) Remote Radio Heads (RRHs), hosted in the distributed sites and providing antenna equipment, radio access and technology-dependent real-time control functions. The BBUs provide the RAN functionalities and are typically connected via high capacity fronthaul network to several RRHs.

The concept of flexible functional split consists of the capability of moving the functions from the cloud to the distributed sites in a dynamic way, considering on-the-fly the fronthaul capacity, the latency and the time-critical nature of the functions, and considering the environmental conditions and the traffic load on the RAN. The 5G-ALLSTAR architecture is developed taking care of these considerations and provides a software-defined RAN (SD-RAN) composed by a C-RAN and several distributed units (DUs), with both C-RAN and DUs programmable to allow flexible functional split.

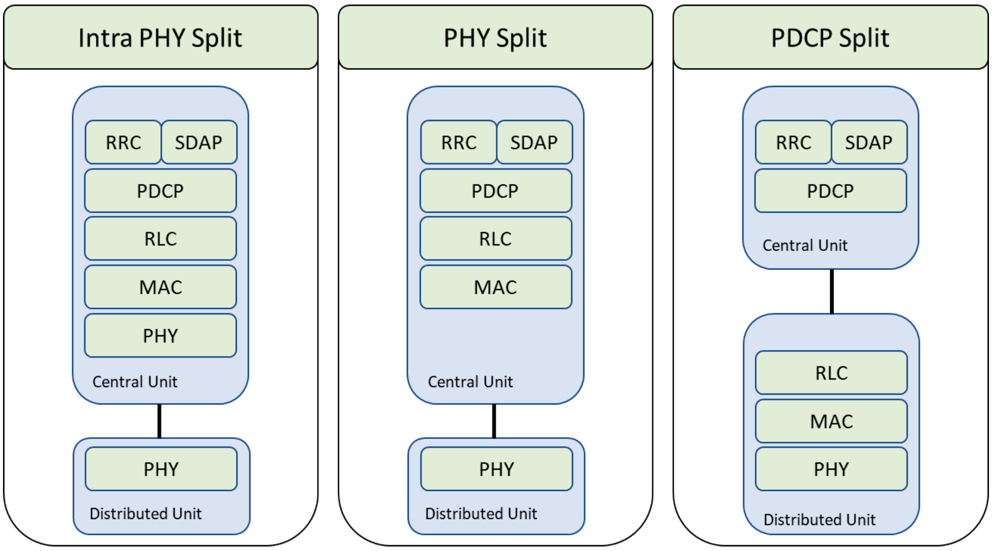

Figure 2-1: Three main functional split options.

2.4 System Architecture Overview

The 5G-ALLSTAR architecture depicted in Figure 2-2 is designed to combine the current vision of 5G architectures [2] with the 5G-ALLSTAR project needs, with particular focus on the channel and traffic flow optimizations. The network architecture in Figure 2-2 is composed by four main parts, as typically presented in 5G networks: i) Data Network (DN), ii) Core Network (CN), iii) C-RAN and iv) User Equipment (UEs).

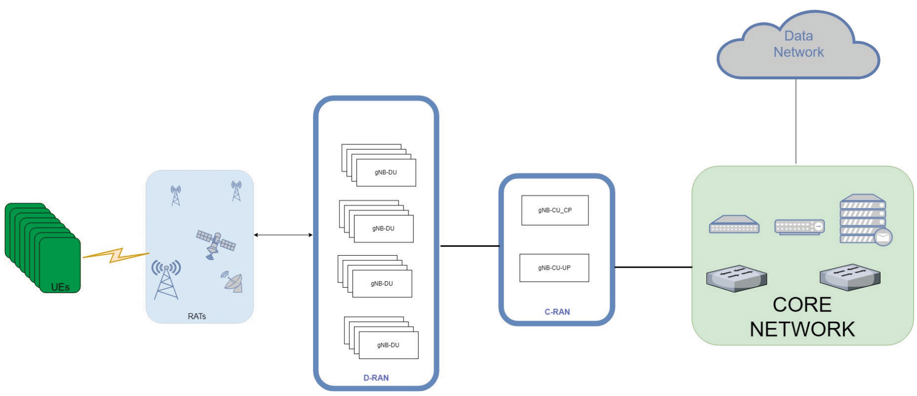

Figure 2-2: 5G-ALLSTAR architecture.

The DN (from both public and private data providers) can be considered, in general, as a data container, from which the network can get the service data (e.g., documents, movie contents, etc…); this entity enables the transmission of data between UE and data providers.

In addition to the already implemented CN functionalities, the 5G-ALLSTAR project is adding advanced QoE/QoS management functionalities.

The RAN is considered as a multi-technology software, i.e., an access network composed by interoperable radio technologies and managed and configured by using the software-defined approach.

The RAN is designed to be composed by two different parts, as suggested in [3], both of them based on the software-defined paradigm with the aim of being dynamically configured, generated/destroyed with the objective of providing network flexibility for satisfying the users' service needs. In particular, considering [4], the RAN is designed to be composed by:

- A central or cloud-based RAN (C-RAN) with coordination capabilities and technology independent functionalities. The C-RAN is implemented by using cloud-based technologies to allow resources flexibility and high computing performances. It contains
  - Control plane functionalities, e.g. Interferences Management, Radio Bearer Control, Radio Admission Control (RAC), Dynamic Resources Allocation (DRA), Measurement Configuration, T3S, etc., implemented in a single logical entity, i.e., the gNB-CU-CP (see Figure 2-2);
  - User plane functionalities, e.g., higher layers of the protocol stack, implemented in different logical entities, i.e., the gNB-CU-UPs (see Figure 2-2).
- A distributed RAN (D-RAN) with distributed and technology-dependent functionalities. The D-RAN is implemented as close as possible to the radio technologies and includes
  - Control plane functionalities, implemented in the logical entity, called gNB-DU-CP (e.g., Measurement Collection and Provision, MAC and Physical-Layer (PHY) configuration, QoE/QoS Management …);
  - User plane functionalities, implemented in the logical entity called gNB-DU-UP (e.g. lower layers of the protocol stack as for instance MAC, PHY, etc.)

  The gNB-DU-CP and the gNB-DU-UP compose the whole gNB-DU depicted in Figure 2-2.

The UE is considered to be any device which communicates by connecting to the access network (e.g., human being, Internot of Things (IoT) device, artificial intelligence-based robot, etc…).

3 Network Architectures of 5G Cellular Access and Satellite Access System

3.1 Radio Access Network Architecture

Based on the 5G-ALLSTAR general architecture depicted in Figure 2-2, the main objective of the 5G-ALLSTAR project is to implement advanced functionalities at both CN side and RAN side. The functionalities that will be developed, implemented and tested during the 5G-ALLSTAR project are:

- Advanced Radio Resource Management (RRM) functionalities for the multi-Radio Access Technology (RAT) spectrum sharing scenario, where algorithms for interference analysis and mitigation will be developed. RRM functionalities are conceived to be in the Centralized RRM (cRRM) and Distributed RRM (dRRM) blocks in Figure 3-1.
- Traffic switching, steering and splitting. In fact, in the 5G-ALLSTAR project, the traffic management will be performed taking into account the network status and the QoE requirements for each user.
    - The QoE/QoS Management, designed to be logically located in the CN, is in charge of assigning a set of personalized parameters (in addition to the QFI[8]) for each traffic flow depending on the learned UE needs and expectations. The Traffic Flow Control, managed by the RAN, performs switching, steering and splitting decisions for the traffic on the basis of the personalized paramenters and considering the actual performances of the radio access technologies. The RATs performances are directly provided by the cRRM.
    - QoE Estimation provides the estimation of the individual perceived QoS on the basis of the information provided by the user via explicit or implicit feedbacks and on the measurements provided by the dRRM.

These functionalities are placed on the reference architecture described above and are shown in Figure 3-1.

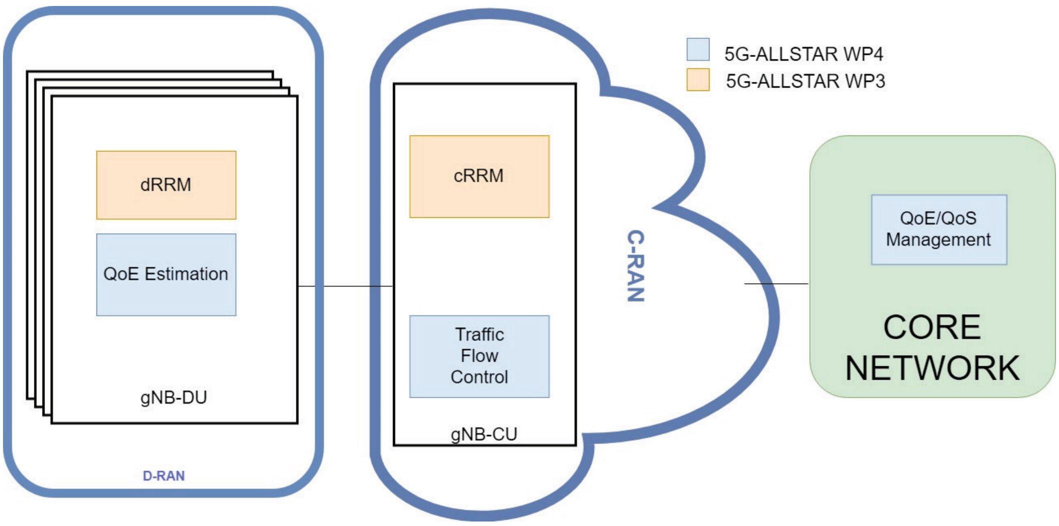

Figure 3-1: 5G-ALLSTAR functionalities.

The Traffic Flow Controller needs to be placed in the C-RAN for several reasons, for example to guarantee the fast and lossless traffic switching among different RATs, and to have complete information from RANs. The QoE Estimation is placed on the DUs (i.e., D-RAN) since the QoE estimation – for each UE – rely on a large amount of information (such as RRM measures, UE feedbacks, …) available within the D-RAN itself. Finally, we note that, on the one hand, it is fundamental to have a set of RRM functionalities in the C-RAN for the coordination of the radio resources of each technology, in order to avoid interferences and to reach the optimal performance; on the other hand, it is necessary to have a set of RRM functionalities directly placed on the different radio technologies, since, in some cases, these functionalities are technology dependent and needs to collect measurements of the radio system in real-time to perform configuration.

3.1.1 5G Cellular Access Network

3.1.1.1 General architecture of NG-RAN

The 5G RAN is the Next Generation-RAN (NG-RAN) [17]. A BS, i.e. a NG-RAN node, could be:

- a 5G BS, namely a next generation NodeB (gNB), that provides New Radio (NR) control plane and user plane services, or
- an ng-eNB, which is Long Term Evolution (LTE) AN from 3GPP Release 15 (R15) onwards that provides Evolved Universal Terrestrial Radio Access Network (E-UTRAN) services towards the UE, and is connected via NG interface to the 5G Core (5GC).

Like shown on Figure 3-2, the gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the Access and Mobility Management Function (AMF) by means of the NG-C interface and to the User Plane Function (UPF) by means of the NG-U interface.

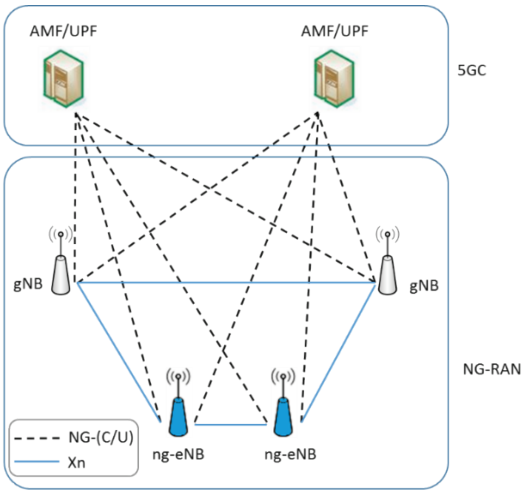

Figure 3-2: NG-RAN in relation to the 5GC.

Both the user plane and control plane architectures for NG-RAN follow the same high-level architecture scheme, as depicted in Figure 3-3 below (inherited from [28]).

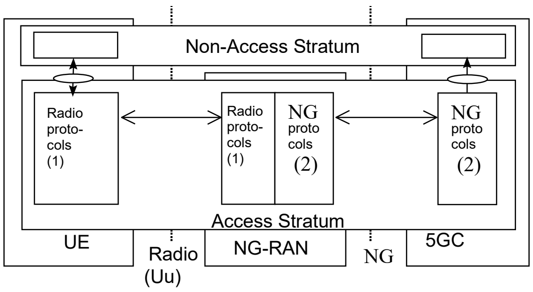

Figure 3-3: Overall NG-RAN architecture.

3.1.1.2 Deployment options

One of the characteristics of NG RAN is the ability to function in what is called "Stand-Alone" (SA) operation and "Non-Stand-Alone" (NSA) operation. In the former case, the gNB is connected to the 5GC whereas in the latter case LTE and NR are closely integrated and connect to the 4G core network called Evolved Packet Core (EPC), operating Dual Connectivity (DC) to the terminal. In a DC architecture, the radio resource are provided to the terminal simultaneously by a Master Node (MN) and a Secondary Node (SN). Both NSA and SA architecture options are specified as part of the phase-1 5G standards of 3GPP in R15. It is possible to draw different configuration options from the general architecture, each of which is a possible deployment for network operators. These configurations are depicted below.

3.1.1.2.1 NR gNB connected to the GC (option 2)

With this SA option, the gNBs are connected to the 5GC through the NG interface. The gNBs are interconnected through the Xn interface.

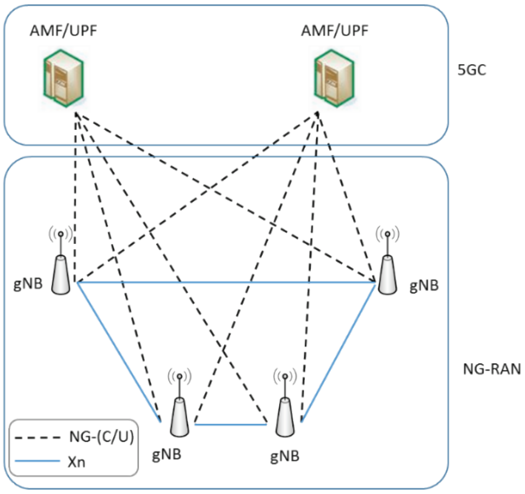

Figure 3-4: Deployment option 2.

3.1.1.2.2 Multi-RAT DC with the EPC (option 3)

With this NSA option, widely known as EN-DC (LTE-NR DC), a UE is connected to a MN eNB and to a SN en-gNB (en-gNB: 5G NR BS connected to EPC). An en-gNB, unlike a gNB, only implements part of the 5G BS functionality that is required to achieve SN functions for EN-DC. The eNB is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface. The en-gNB may also be connected to the EPC via the S1-U interface and to other en-gNBs via the X2-U interface. Note that the en-gNB may send UP to the EPC either directly or via the eNB.

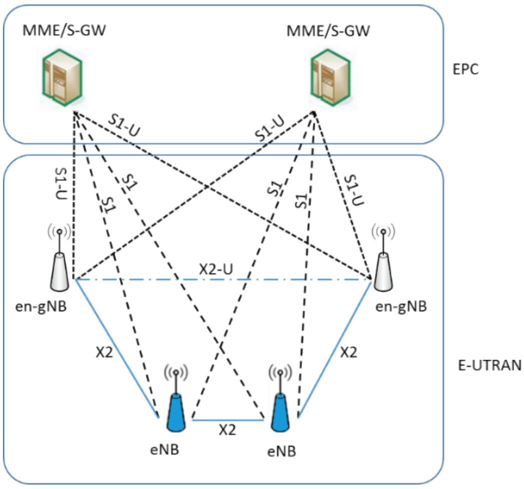

Figure 3-5: Deployment option 3.

3.1.1.2.3 Multi-RAT DC with the 5GC, NR as a master (option 4)

With this NSA option, a UE is connected to a MN gNB and to a SN ng-eNB. The gNB is connected to 5GC and the ng-eNB is connected to the gNB via the Xn interface. The ng-eNB may send UP to the 5G Core either directly or via the gNB.

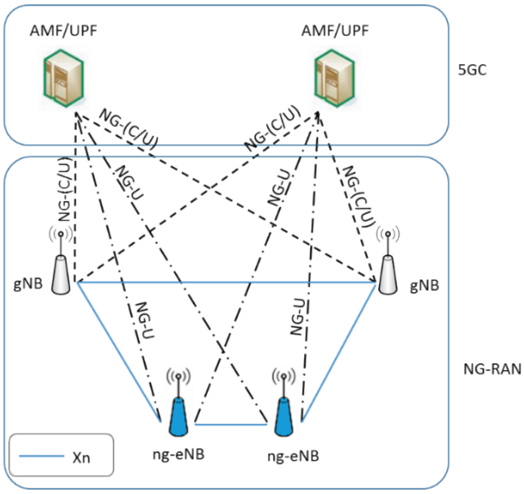

Figure 3-6: Deployment option 4.

3.1.1.2.4 LTE ng-eNB connected to the 5GC (option 5)

With this SA option, the ng-eNBs are connected to the 5G Core Network (5GC) through the NG interface. The ng-eNBs interconnect through the Xn interface. Essentially this option allows the existing LTE radio infrastructure (through an upgrade to the eNB) to connect to the new 5G Core.

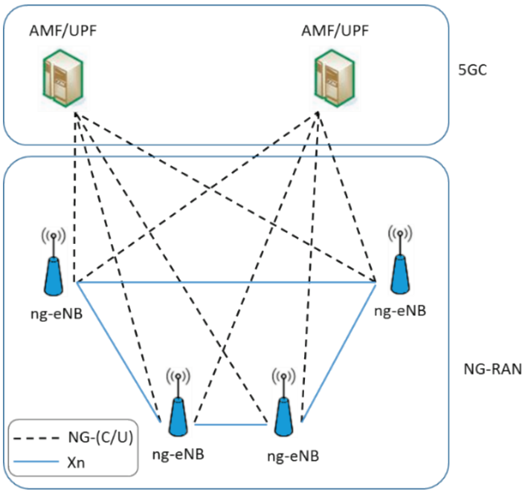

Figure 3-7: Deployment option 5.

3.1.1.2.5 Multi-RAT DC with the 5GC, E-UTRA as a master (option 7)

With this NSA option, a UE is connected to a MN ng-eNB and to a SN gNB. The ng-eNB is connected to the 5GC, and the gNB is connected to the ng-eNB via the Xn interface. The gNB may send UP to the 5GC either directly or via the ng-eNB.

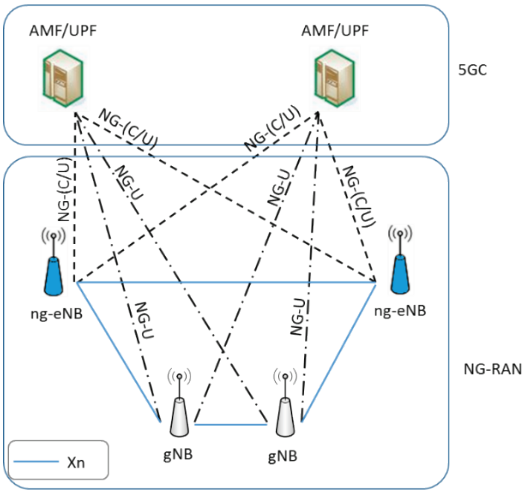

Figure 3-8: Deployment option 7.

3.1.1.3 5G NR gNB architecture

3.1.1.3.1 Lower layer split

Contrary to the 4G RAN, the 5G NR logical node, the gNB, is split between Central Units (CUs) and DUs. The benefits for such an architecture are:

- flexible hardware implementation
- coordination of performance features, load management and real-time performance optimization
- adaptation to various use cases

The split of the NR functions between CU and DUs is shown on Figure 3-9. The choice of a split between Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) was driven by the reason that the split between MN and SN in DC configuration is the same.

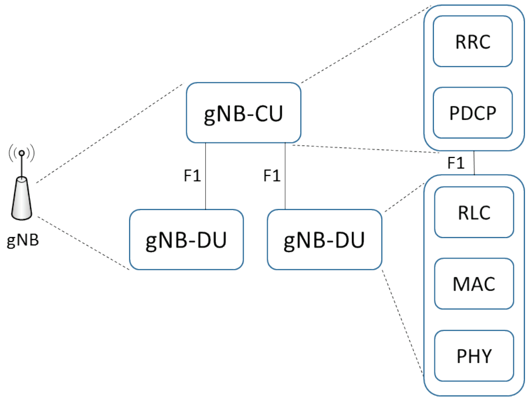

Figure 3-9: 5G NR gNB split.

3.1.1.3.2 Higher layer split

Figure 3-10 (inspired by [28]) shows how a split gNB is inserted into the NG RAN architecture. in NG-RAN a set of gNBs is connected to the 5G Core Network (5GC) through the NG interface, and they can be interconnected through the Xn interface. A gNB may then consist of a gNB-CU and one or more gNB-DU(s), and the interface between gNB-CU and gNB-DU is called F1. The NG and Xn-C interfaces for a gNB terminate in the gNB-CU. The maximum number of gNB-DUs connected to a gNB-CU is only limited by implementation choice. In the 3GPP standard, one gNB-DU connects only to one gNB-CU, but implementations that allow multiple gNB-CUs to connect to a single gNB-DU, e.g., for added resiliency, are not precluded. One gNB-DU may support one or more cells. The internal structure of the gNB is not visible to the core network and other RAN nodes, so the gNB-CU and connected gNB-DUs are only visible to other gNBs and the 5GC as a gNB.

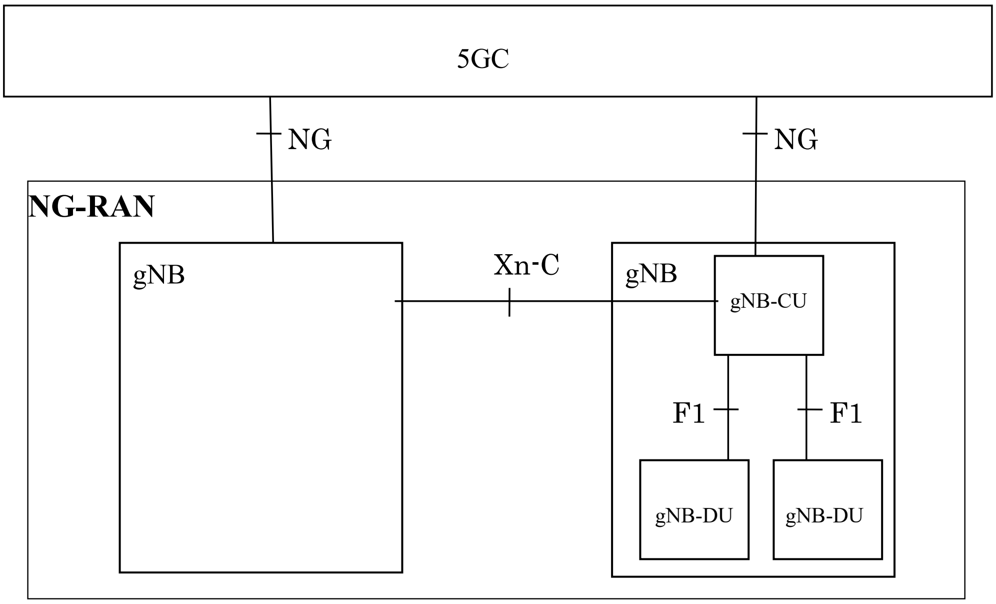

Figure 3-10: 5G NR higher layer split.

3.1.1.4 C-RAN

A radio BS can be functionally split into:

- a BBU, also known as digital unit, that generates and processes a digitized baseband signal, and
- a RRH, also known as Remote Radio Unit (RRU), that creates the analog transmisson Radio Frequency (RF) signal from the baseband signal and sources it to the antenna.

In a traditional RAN architecture, each cell site must have its own dedicated BBU and RRH, together with the associated cooling and routing functionalities, see Figure 3-11 (top), as described from [12][16][17]. The very rapid growth in the number of BSs would cause major capex (capital expenditure) and opex (operating expense) issues, which could significantly limit the number and locations of BSs that could be deployed. Without rapid and massive deployment, 5G high frequency BSs will be unable to meet the extraordinary increase in demand for data volume, diversity of services and associated performance expectations.

In order to solve this issue, the most significant technological trend is to adopt a C-RAN architecture, that moves the baseband processing (BBU) to a centralized location, see Figure 3-11 (bottom). The separation of BBU and RRU nevertheless creates the need for a fronthaul transport network that must be high-speed, low-latency and accurately synchronized.

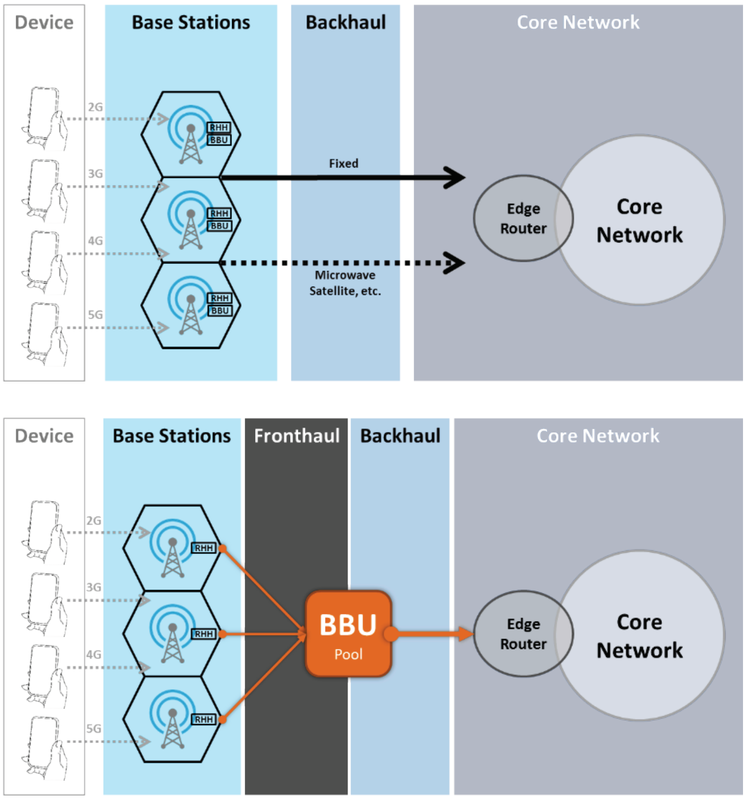

Figure 3-11: From [12]. Top: overview of a mobile network. Bottom: C-RAN architecture.

3.1.1.5 5G Antennas

Base Station antennas are part of the Access Network. The evolution of antennas is driven by three different aspects [13]:

- Spectrum;
- Densification;
- Efficiency.

The impact of these challenges on the antennas is illustrated in Figure 3-12: (i) multiband antennas contain arrays covering more and more wide frequency bands as standardization evolves; (ii) multibeam antennas allow to assign the same time-frequency resources to different users, therefore increasing densification; (iii) array antennas enable MIMO, with which a data stream can be broken into several layers transmitted simultaneously over independent paths between the BS antenna and the user.

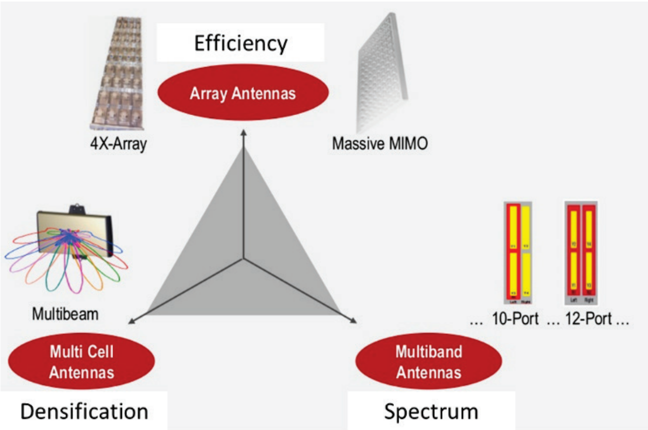

Figure 3-12: From [13]. Magic triangle for antennas.

3.1.2 Satellite Access Network

5G networks will entails both 3GPP and non-3GPP access technologies which are required to be interoperable. Access technologies can be either terrestrial or non-terrestrial. How MC will be handled in 5G-ALLSTAR is discussed in section 4.

Satellite access is one of the Non-Terrestrial Network (NTN) technologies that will be key enabler for 5G system as it will increase coverage and availability. With such an integration to the system, RAN can be either a satellite NG-RAN or a non-3GPP satellite access network [21].

The main features of a satellite access network integrated in a 3GPP system are:

- Satellite terminal: referring directly to the UE or to a relay node in case the satellite does not serve directly UEs.
- Service link: that is the radio link between the UE and the satellite. In a MC scenario, the UE will simultaneously support also a terrestrial radio link.
- Gateways: to connect the satellite-accessed 5G RAN to the CN. It can be either a gNB or router interfacing the CN.
- Feeder link: referring to radio links between the gateways and the satellite
- Satellite payload: which may be either transparent or regenerative, thus serving as a relay node or gNB
- Inter-Satellite Links (ISLs): implemented in case of regenerative payload and a constellation of satellites.

Depending on the frequency and the bandwidth, satellite access network can be distinguished also in:

- Broadband access network serving very small aperture terminals fixed or mounted on a moving platform (e.g. bus, train, vessel, aircraft, etc.). This typology provides at least 50 Mbps data rate, up to hundreds of Mbps. The service links operate in frequency bands above 6 GHz.
- Narrow or wide band access network serving small terminals (e.g. handheld terminal). Data rate on the downlink is limited to 1 or 2 Mbps. The service links operate typically in frequency bands below 6 GHz [19].

The following paragraphs illustrate possible architectures for NTN access in a 5G system. A sysnthesis is listed in Table 3-3:. The content have been studied and reported during 3GPP study phases and eventually will be part of R16 in order to broaden 3GPP scope to NTN access technologies.

Within the scope of 5G-ALLSTAR, the candidate architecture is featuring a transparent satellite that will just relay the NR-Uu radio interface from the feeder link (Satellite Radio Interface) to the service link and vice versa, thus not terminating the NR-Uu. As per [19], the signal relayed must be an NR signal with “satellite friendly” features. Considered frequency range for the service link is Ka band while Frequency Division Duplexing (FDD) has been considered as access scheme.

Reference UP and CP protocol stacks for a Protocol Data Unit (PDU) session for bent-pipe satellite based NG-RAN architectures are depicted in Figure 3-13: and Figure 3-14:.

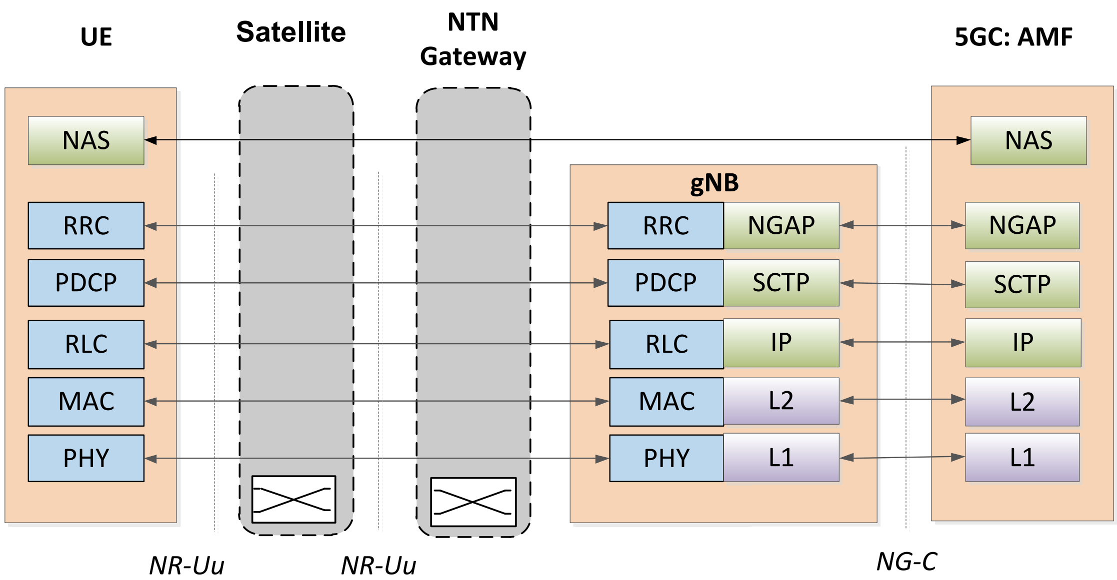

Figure 3-13: UE user plane protocol stack for a PDU session (transparent satellite).

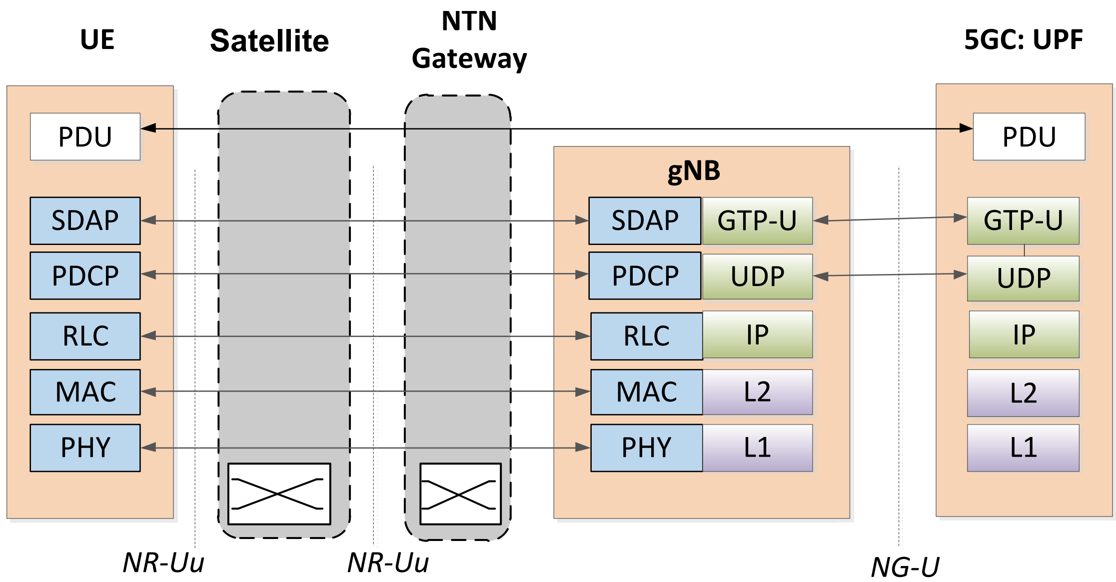

Figure 3-14: UE control plane protocol stack for a PDU session (transparent satellite).

The integration of a satellite in the 5G RAN will introduce issues in the stardard procedures of radio protocols. Such issues are currrently still under study, however one of the most relevant issues identified is the additional propagation delay introduced by the satellite. This larger delay will likely impact NR features such as MAC/RLC procedures, Physical-layer procedures (e.g. ACM and power control loops) and HARQ. Table 3-1: (inherited from [19]) gives an overview of the delay constraints introduced in a RAN by different types of Geostationary Orbit (GEO) satellite and Low Earth Orbit (LEO) satellite payloads. In this deliverable, GEO and LEO also respectively represent GEO satellite and LEO satellite.

Table 3-1: Satellite scenarios versus delay constraints

<table>
<tr><th>Payload</th><th>GEO transparent payload</th><th>GEO regenerative payload</th><th>LEO transparent payload</th><th>LEO regenerative payload</th></tr>
<tr><td>Maximum Round Trip Delay on the radio interface between the gNB and the UE</td><td>541.75 ms (Worst case)</td><td>270.57 ms</td><td>28.41 ms</td><td>12.88 ms</td></tr>
<tr><td>Minimum Round Trip Delay on the radio interface between the gNB and the UE</td><td>477.14 ms</td><td>238.57 ms</td><td>8 ms</td><td>4 ms</td></tr>
<tr><td>Maximum Delay variation as seen by the UE
(note 2)</td><td colspan="2">Negligible</td><td>Up to +/- 40 µs/sec (Worst case)</td><td>Up to +/- 20 µs/sec</td></tr>
<tr><td>Maximum delay difference within a NTN beam as seen by the UE
(note 3)</td><td colspan="2">16 ms (Worst case)</td><td colspan="2">4.44 ms</td></tr>
<tr><td colspan="5">NOTE 1: One way propagation delay considered as the delay:
• from the Gateway to the UE via the satellite (bent pipe payload)
• from the satellite to the UE (regenerative payload)
The Round Trip Time corresponds to the two way propagation delay:
• from the Gateway to the UE via the satellite and return (bent pipe payload)
• from the satellite to the UE and return (regenerative payload)
NOTE 2: The delay variation measures how fast the round trip delay (function of UE-satellite-NTN gateway distance) varies over time when the satellite moves towards/away from the UE. It is expressed in µs/s and is negligible for GEO scenario
NOTE 3: The delay difference compares the delay (function of UE-satellite-NTN gateway distance) experienced by two different UEs served by the same beam at a given time</td></tr>
</table>

Differential delay introduced by larger cell size of satellite beam footprint shall also be taken into account as it will impact Random Access (RA) procedure (e.g. timing advance (TA)) and Physical RA Channel (PRACH).

Another issue to consider is the Doppler shift (and its variation rate) on the signal received by the UE from the satellite, i.e. the shift of the signal frequency due to the motion of receiver/transmitter or both. In a 5G system Doppler shift would be impacted by the motion of the UE in addition to the motion of the satellite. This effect will continuously modify the carrier frequency, phase and spacing and may create Inter-Carrier Interference (ICI).

Table 3-2 (inherited from [19]) gives an overview of the main effects introduced by an NTN radio access (e.g. satellite) and their impact on 5G NR procedures.

Table 3-2: Areas of impacts on NR to support NTNs

NTN specifics	Effects	Impacted NR features
Motion of the space/aerial vehicles (especially for Non GEO based access network)	Moving cell pattern	Hand-over/paging
	Delay variation	TA adjustment
	Doppler	Initial synchronization downlink
		Demodulation Reference Signal (DMRS) time density
Altitude	Long latency	HARQ
		MAC/RLC Procedures
		PHY procedures (ACM, power control)
Cell size	Differential delay	TA in RA response message
		RACH
Propagation channel	Impairments	DMRS frequency density
		Cyclic prefix
Duplex mode	Regulatory constraints	Access scheme (TDD/FDD)
Satellite or aerial Payload performance	Phase noise impairment	Phase Tracking Reference Signal (PT-RS)
	Back-off	Peak-to-Average Power Ratio (PAPR)
Network architecture	RAN Mapping	Protocols

In the following subsections, seven identified Satellite Access Network (SAN) are described.

3.1.2.1 SAN1: UE directly accessing to transparent satellite-based NR RAN with RAN coordination via Xn interfaces

This architecture option entails:

- UE with direct access to RANs
- Transparent satellites (on-board RF switch and transponder)
- Either transparent gateway (like a transponder) or gateway as IP relay
- gNBs at gateway side, with gNBs coordination
- 5G Core Network
- DN

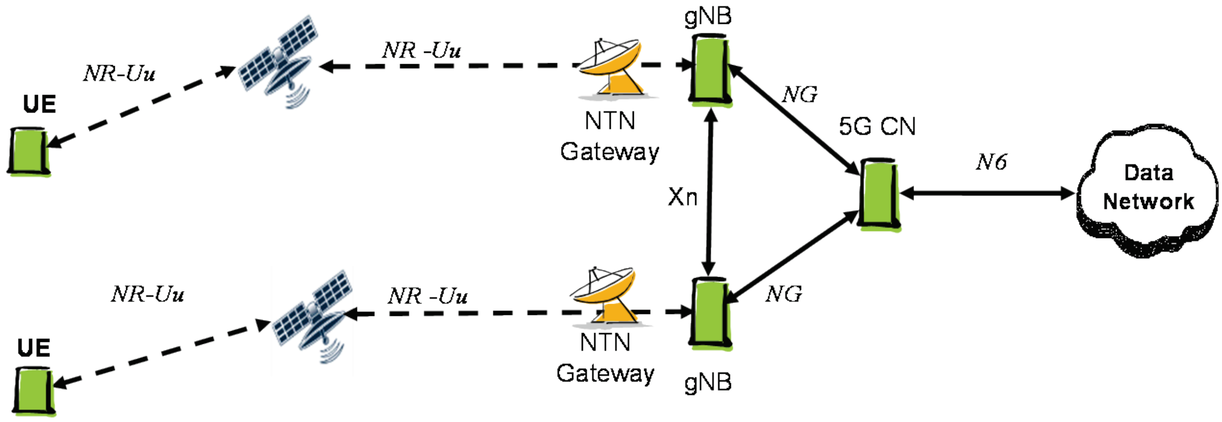

Figure 3-15: Architecture of SAN1.

3GPP R15 interfaces are positioned as following:

- NR interface is transported on the satellite service link and the feeder link
  - Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) on the DL direction, CP-OFDM or Single Carrier Frequency Division Multiple Access (SC-FDMA) for the UL direction.
- Xn interface is positioned between gNBs, in the Ground Segment (GS)
- NG interface is positioned in the GS

The gNBs coordination between gNBs enables spectrum sharing and interferences mitigation. No MC is involved as UEs are different.

This architecture inherits from [20] and conforms to 3GPP R15 [17].

3.1.2.2 SAN2: UE directly accessing to distributed transparent satellite-based NR RAN under central control via F1 interfaces

This architecture option entails:

- UE with direct access to RANs
- Transparent satellites (on-board RF switch and transponder)
- Either transparent gateway (like a transponder) or gateway as IP relay
- gNB DUs (gNB-DUs) at gateway side, under the control of gNB-CU
- gNB CU (gNB-CU), at gateway side
- 5G Core Network
- DN

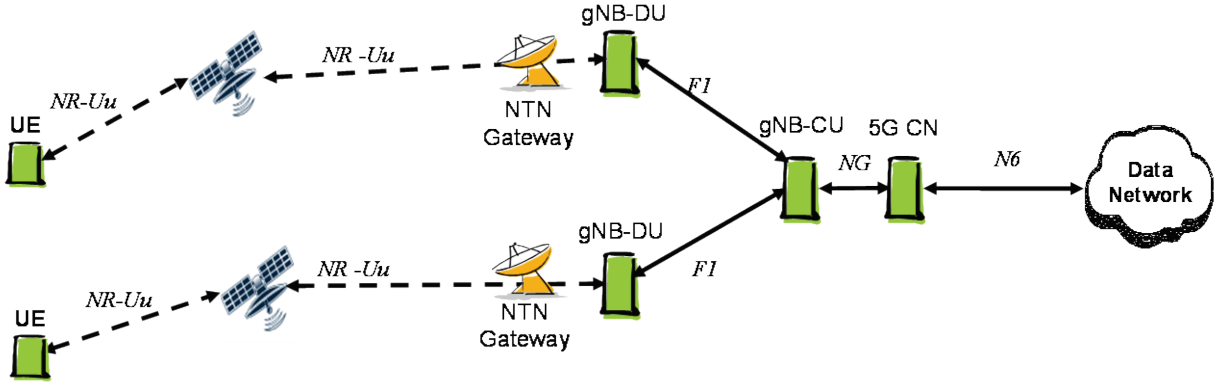

Figure 3-16: Architecture of SAN2.

3GPP R15 interfaces are positioned as following:

- NR interface is transported on the satellite service link and the feeder link
  - CP-OFDM on the DL direction, CP-OFDM or SC-FDMA for the UL direction.
- F1 interface is positioned in the GS

The coordination between gNB-DUs under the gNB-CU control enables spectrum sharing and interferences mitigation.

No MC is involved as UEs are different.

This architecture inherits from [20] and conforms to 3GPP R15 [17][21].

3.1.2.3 SAN3: UE directly accessing to OBP satellite-based NR RAN without gNB coordination

This architecture option entails:

- UE with Direct access.
- On-Board Processing (OBP) satellites with on-board gNB. The gNB is centralized, not distributed.
- Either transparent gateway (like a transponder) or gateway as IP relay
- 5G Core Network
- DN

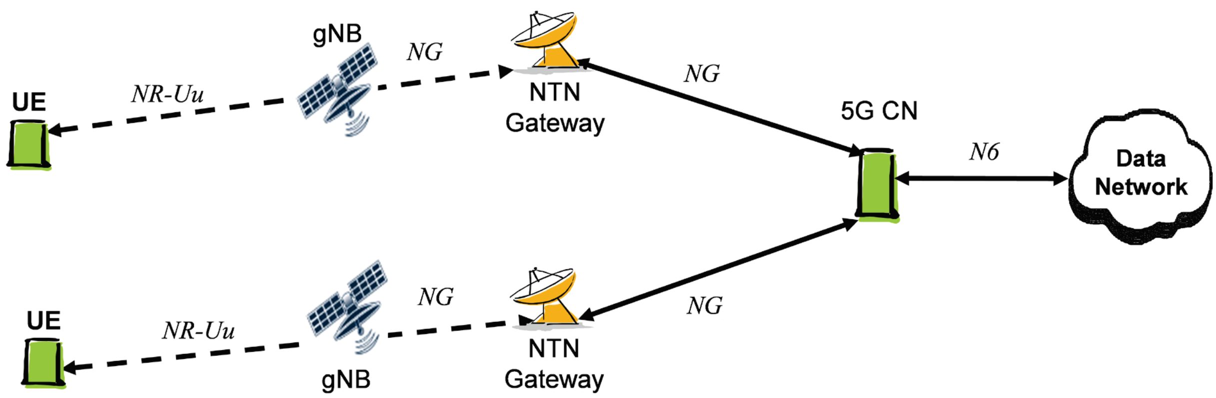

Figure 3-17: Architecture of SAN3.

3GPP R15 interfaces are positioned as following:

- NR interface is transported over the satellite service link
  - CP-OFDM on the DL direction, CP-OFDM or SC-FDMA for the UL direction.
- Data and signalling of NG interface are transported over the air, on the feeder link and in the GS

The on-board gNBs are not coordinated in this case. Therefore, spectrum sharing and interferences mitigation should be operated by the management plane, by configuration.

3.1.2.4 SAN4: UE directly accessing to OBP satellite-based NR RAN with onboard gNB coordination over ISL

This architecture option entails:

- UE with Direct access
- OBP satellites with on-board centralized gNB,
- Either transparent gateway (like a transponder) or gateway as IP relay
- 5G Core Network
- DN

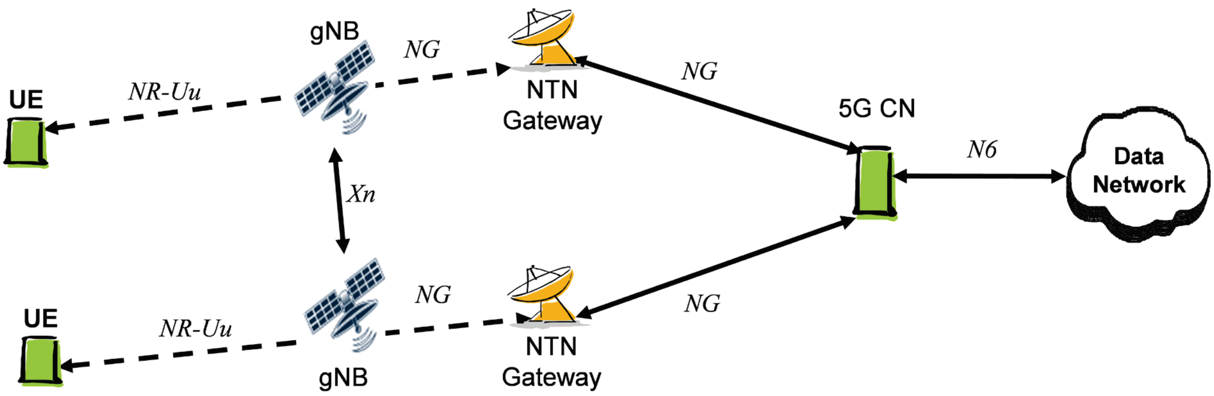

Figure 3-18: Architecture of SAN4.

3GPP R15 interfaces are positioned as following:

- NR interface is transported over the satellite service link
- Data and signalling of NG interface are transported over the air, on the feeder link
- Xn interface is positioned on ISL

The on-board gNBs are coordinated, via Xn interface over ISL. It enables spectrum sharing and interferences mitigation.

No MC is involved as UEs are different.

3.1.2.5 SAN5: UE directly accessing to distributed OBP satellite-based NR RAN with onboard gNB-DU coordination

This architecture option entails:

- UE with direct access
- OBP satellites with gNB DU (gNB-DU),
- Either transparent gateway (like a transponder) or gateway as IP relay
- gNB CU (gNB-CU) at gateway side, that serves the gNB-DUs
- 5G Core Network
- DN

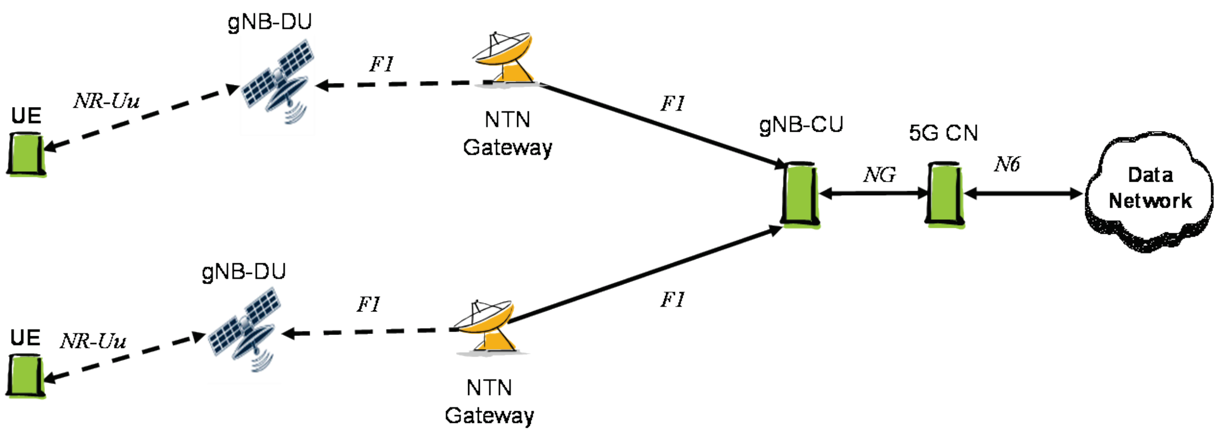

Figure 3-19: Architecture of SAN5.

3GPP R15 interfaces are positioned as following:

- NR interface is transported over the satellite service link
  - CP-OFDM on the DL direction, CP-OFDM or SC-FDMA for the UL direction.
- Data and signalling of F1 interface are transported over the air, on the feeder link and in the GS
- NG interface is positioned in the GS

The on-board gNB-DUs are coordinated, under the gNB-CU control, through the F1 interface. It enables spectrum sharing and interferences mitigation.

No MC is involved as UEs are different.

3.1.2.6 SAN6: UE directly accessing to OBP satellite-based NR RAN with NR relay support and IAB node coordination

This architecture option entails:

- UE with direct access
- OBP satellites with on-board Integrated Access and Backhaul (IAB) node. On-board IAB nodes encompass both gNB and NR interface relay over ISL functions.

- Either transparent gateway (like a transponder) or gateway as IP relay
- IAB donor at gateway side, that serves the IAB nodes
- 5G Core Network
- DN

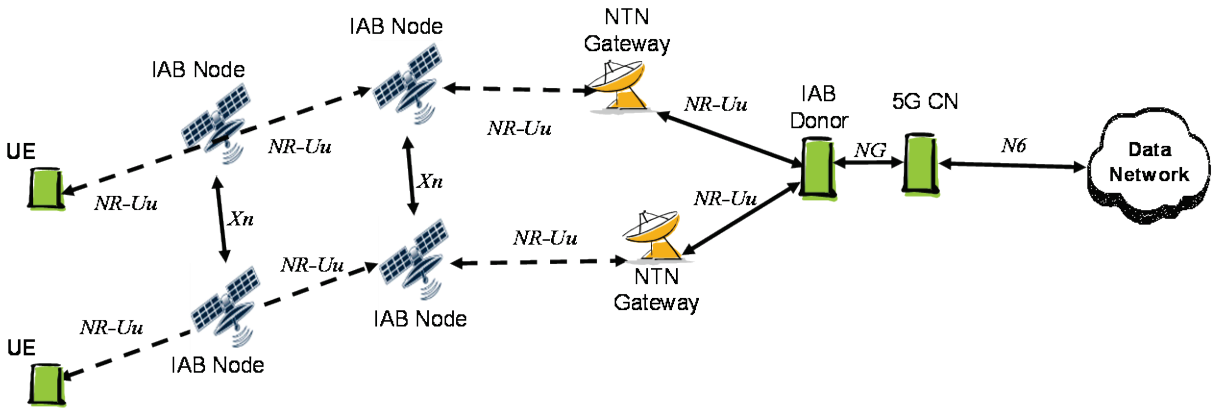

Figure 3-20: Architecture of SAN6.

3GPP R15 interfaces are positioned as following:

- Data and signalling of NR interface are transported over the air, on service link, the ISL and the feeder link
- NG interface is positioned in the GS, between the IAB donor and the 5GC

The on-board IAB nodes are coordinated, via Xn interface over ISL. It enables spectrum sharing and interferences mitigation.

No MC is involved as UEs are different.

Note: Protocols between IAB nodes and IAB donors are not yet specified and the study [18] is ongoing.

3.1.2.7 SAN7: UE directly accessing to OBP satellite-based NR RAN with F1 relay support and IAB nodes under central control

This architecture option entails:

- UE with direct access
- OBP satellites with on-board IAB node. On-board IAB nodes encompass both gNB-DU and F1 interface relay over ISL functions.
- Either transparent gateway (like a transponder) or gateway as IP relay
- IAB donor at gateway side, that serves the IAB nodes
- 5G Core Network
- DN

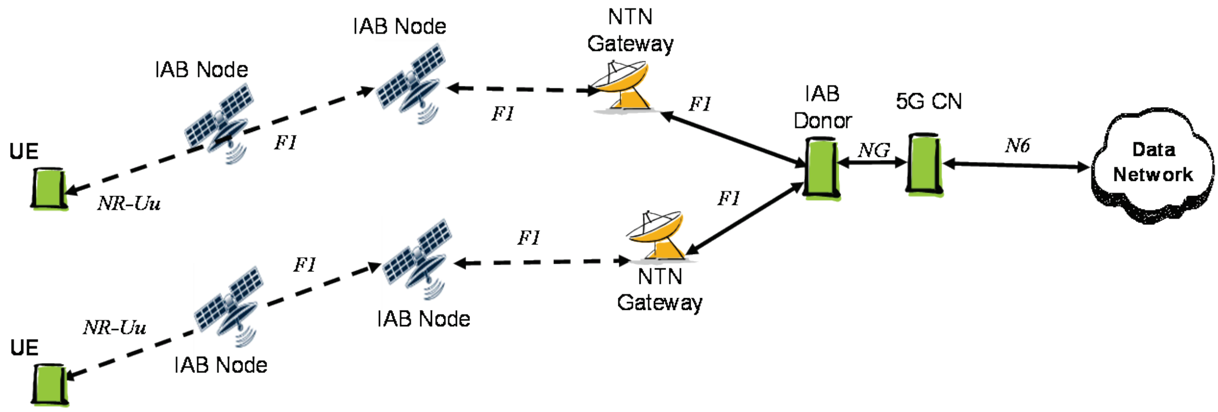

Figure 3-21: Architecture of SAN7.

3GPP R15 interfaces are positioned as following:

- Data and signalling of NR interface are transported over the air, on the satellite service link
- Data and signalling of F1 interface are transported over the air, on the ISL and the feeder link
- NG interface is positioned in the GS, between the IAB donor and the 5GC

The on-board IAB nodes are coordinated, under the IAB donor control, via F1 interface over ISL. It enables spectrum sharing and interferences mitigation.

No MC is involved as UEs are different.

Note: Protocols between IAB nodes and IAB donors are not yet specified and the study [18] is ongoing.

3.1.2.8 Synthesis and Characteristics of the architecture options

Table 3-3: Synthesis and characteristics of the architecture options

SAN	Main characteristics	Potential use for 5G-ALLSTAR
SAN1 (§3.1.2.1)	Transparent satellites. UE direct access to satellite based NR RANs, with RANs coordination (Xn interfaces). The coordinated gNBs are positioned in the GS, at gateway side. Single connectivity for each UE.	Conforms to 3GPP Technical Specification (TS) [16], [17] and 3GPP Technical Report (TR) [15], [20]. Not in line with the test bed / trial architecture, as foreseen during the Kick-Off meeting in June 2018, which makes use of one satellite only and supports MC.
SAN2 (§3.1.2.2)	Transparent satellites. UE direct access to distributed satellite NR based RANs, under central control (F1 interfaces). The gNB-DUs and the gNB-CU are positioned in the GS, at gateway side. Coordination between gNB–DUs under the control of the gNB-CU. Single connectivity for each UE.	Conforms to 3GPP TS [16], [17], [21] and 3GPP TR [15], [20]. Not in line with the test bed / trial architecture as foreseen during the Kick Off meeting in June 2018, which makes use of one satellite only and supports MC.

SAN	Main characteristics	Potential use for 5G-ALLSTAR
SAN3 (§3.1.2.3)	OBP satellites, UE direct to satellite NR based RAN, without gNBs coordination. The gNB is on-board the satellite. Single connectivity for each UE.	Conforms to 3GPP TS [16], [17] and 3GPP TR [15], [20]. As no coordination between gNBs is supported, the radio resource shall be configured by management plane. Not in line with the test bed / trial architecture as foreseen during the Kick-Off meeting in June 2018, which makes use of one transparent satellite only and supports MC.
SAN4 (§3.1.2.4)	OBP satellites. UE direct to satellite NR based RAN, with on-board gNBs coordination over ISL. Single connectivity for each UE.	Conforms to 3GPP TS [16], [17] and 3GPP TR [15], [20]. Not in line with the test bed / trial architecture as foreseen during the Kick-Off meeting in June 2018, which makes use of one satellite only and supports MC.
SAN5 (§3.1.2.5)	OBP satellites. UE direct to distributed satellite NR based RAN. Coordination between on-board gNB-DUs under the control of the on ground gNB-CU. Single connectivity for each UE.	Conforms to 3GPP TS [16], [17], [21] and 3GPP TR [15], [20]. Not in line with the test bed / trial architecture as foreseen during the Kick-Off meeting in June 2018, which makes use of one satellite only and supports MC.
SAN6 (§3.1.2.6)	OBP satellites. UE direct to satellites NR based RAN with NR interface relay support and IAB nodes coordination. Single connectivity for each UE. The IAB nodes host relay, gNB and Mobile Termination (MT) functions. The IAB donor serves the IAB nodes (MT and gNB).	Conforms to 3GPP TS [16], [17] and 3GPP TR [15], [20], [18]. Not in line with the test bed / trial architecture as foreseen during the Kick-Off meeting in June 2018, which makes use of one satellite only and supports MC.
SAN7 (§3.1.2.7)	OBP satellites. UE direct to satellites NR based RAN with F1 interface relay support and IAB nodes under central control. Single connectivity for each UE. The IAB nodes host relay, gNB-DU and MT functions. The IAB donor hosts a gNB-CU and serves the IAB nodes (MT and gNB-DU).	Conforms to 3GPP TS [16], [17], [21] and 3GPP TR [15], [20], [18]. Not in line with the test bed / trial architecture as foreseen as the Kick-Off meeting in June 2018, which makes use of one satellite only and supports MC.

4 Architecture and Interfaces for MC

4.1 MC in 3GPP and 5G-ALLSTAR

MC [14] can be defined as the capability to configure a UE which is able to exploits the resources provided by different nodes with different radio technologies.

3GPP introduces a precise example of MC, i.e., Multi-RAT DC (MR-DC) [14]. In MR-DC the multiple Tx/Rx UEs may be configured to use resources provided by two nodes: (i) the first node provides E-UTRA access, (ii) the second node provides NR access. The nodes have different roles acting either as MN or as SN. The MN and SN are connected via a network interface and at least the MN is connected to the core network. Furthermore, MR-DC with EPC and MR-DC with 5GC are taken into account by 3GPP.

In the 5G-ALLSTAR project we are designing a more general MC approach. In fact, it is not only limited to an E-UTRA and NR accesses, it also includes satellite and terrestrial radio technologies (at least NR). In addition, in the 5G-ALLSTAR project we consider only the MC with 5GC.

The main advantage of the MC is the possibility to send the user traffic through one or multiple RATs, able to satisfy the service requirements and user needs. This is possible thanks to the presence of specific radio bearers through the Uu interface (interface between UE and AN) for each technology.

3GPP defines three bearer types, i.e. Master Cell Group (MCG), Secondary Cell Group (SCG) and Split bearer. The transport of the user plane data, through the Uu interface, may involve the MCG, the SCG radio resources or both. In more detail, in the MCG bearers only the MCG radio resources are involved; in the SCG bearers only SCG radio resources are involved; in the Split bearers both MCG and SCG radio resources are involved.

These three bearer types are depicted in Figure 4-1.

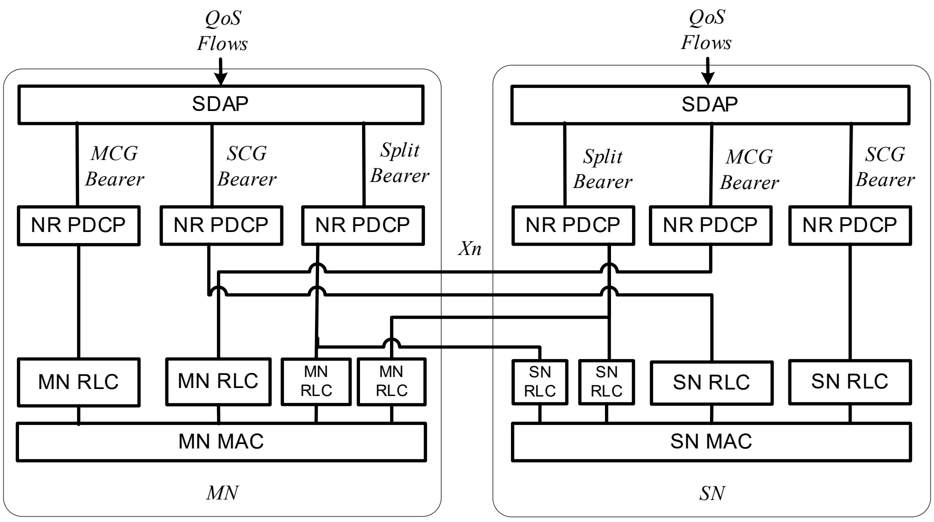

Figure 4-1: Network side protocol termination options for MCG, SCG and split bearers in MR-DC with 5GC [14].

In the MC scenario the QoS handling in RAN follows the architecture presented in Figure 4-2 and the following procedure:

- the 5GC establishes one or more PDU Sessions for each UE;

- the NG-RAN establishes Data Radio Bearer(s) (DRB(s)) for the QoS Flow(s) of the PDU Session,
- the NG-RAN maps packets belonging to different PDU Sessions to different DRBs;
- in the UE and in the 5GC, packet filters associate UL and DL packets with QoS Flows;
- in the UE and in the NG-RAN, mapping rules associate UL and DL QoS Flows with DRBs.

In the MC scenario, a PDU Session may be mapped to different bearer types, as result a PDU Session may have different Service Data Adaptation Protocol (SDAP) entities associated. Each SDAP entity is placed in one RAT. The MN decides which QoS flow should be assigned to each SDAP entity. The MN or SN node, that hosts the SDAP entity, for a given QoS flow decides how to map it to DBRs.

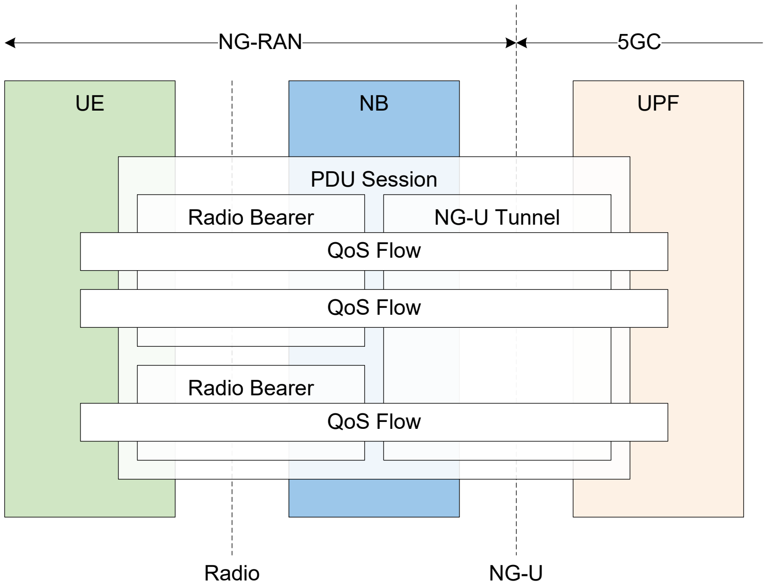

Figure 4-2: QoS architecture [17].

In 5G-ALLSTAR the QoS handling will be based on the 3GPP approach but providing a more agile, faster and experience-aware procedures. Moreover, in the project, MC will be used to reduce the latency, increase the reliability and the throughput. The designed approach is aimed at satisfying the target KPIs for the 5G-ALLSTAR scenarios (defined in D2.1 [1]) i.e., MC scenario; Broadband moving hotspot network scenario; UHD video streaming through interoperable networks scenario.

4.1.1 MC1: UE directly accessing to cellular-based NR RAN(s) and transparent satellite-based NR RAN(s) with RAN coordination

This architecture consists of the following components:

- UE, with direct access to both satellite RAN(s) and cellular RAN(s)
- Either transparent gateway (like a transponder) or gateway as IP relay
- Satellite gNBs at gateways side
- Cellular gNBs
- 5G Core Network
- DN

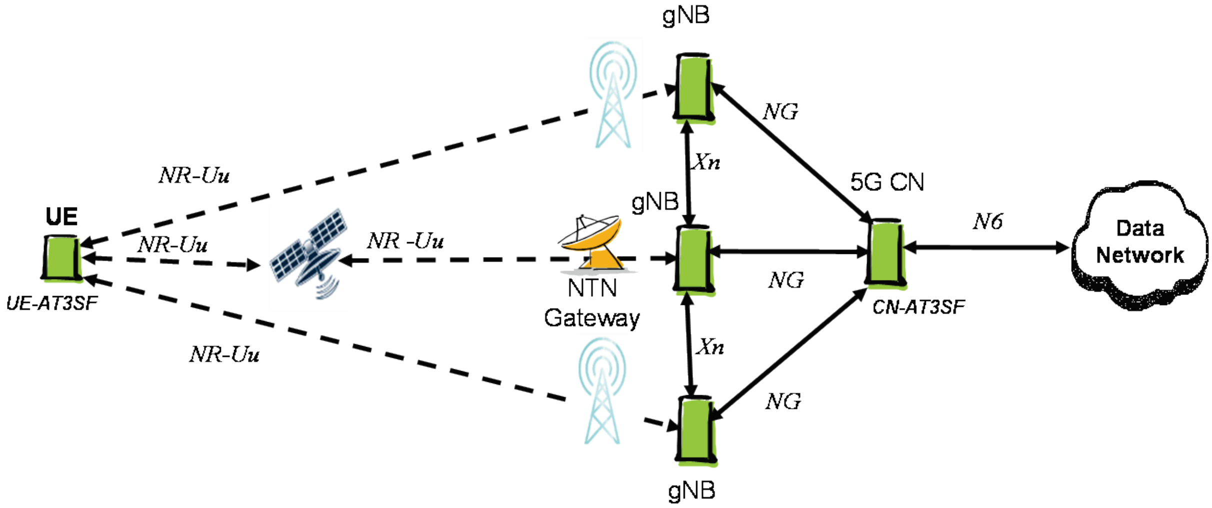

Figure 4-3: Architecture of MC1.

3GPP R15 interfaces are positioned as follows:

- NR interfaces are positioned over the air, on the cellular user link or the satellite service link and the feeder link
- Data and signalling of NG interfaces are transported in the GS
- Xn interfaces are positioned in the GS

The functional entities are coordinated as following:

- Coordination of RANS (gNBs), across Xn interfaces, between:
  - Satellite gNBs at gateways side
  - Satellite gNBs at gateway side and cellular gNBs
  - Cellular gNBs

This architecture conforms to 3GPP R15.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The Xn interface enables coordination between gNB, in the GS.

4.1.2 MC2: UE directly accessing to distributed cellular-based NR RAN(s) and distributed transparent satellite-based NR RAN(s) with RAN coordination under central control

This architecture consists of the following components:

- UE, with direct access to both distributed satellite RAN(s) and distributed cellular RAN(s)

- Cellular gNB-DU
- Either transparent gateway (like a transponder) or gateway as IP relay
- gNB-CU at gateways side, controlling both cellular gNB-DU and satellite gNB-DU
- 5G Core Network
- DN

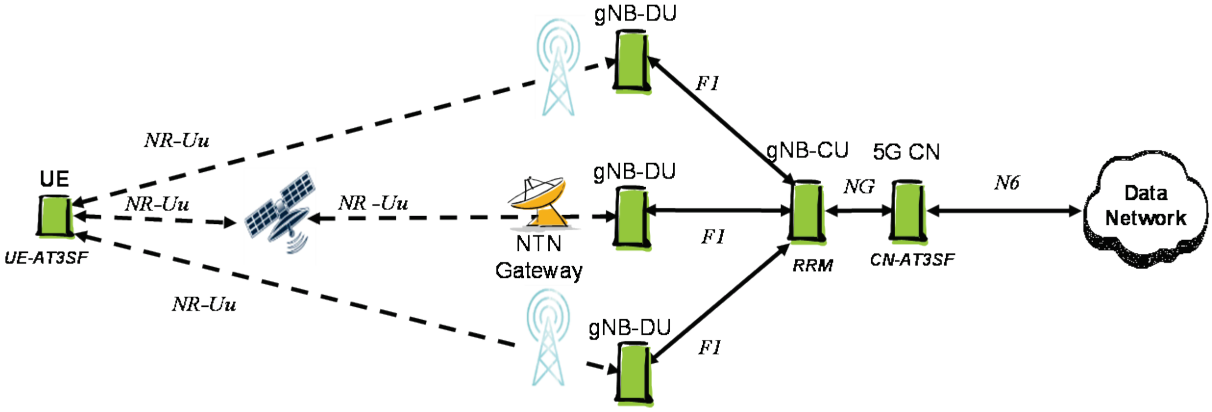

Figure 4-4: Architecture of MC2.

3GPP R15 interfaces are positioned as follows:

- NR interfaces are positioned over the air, on the cellular user link or the satellite service link and the feeder link
- Data and signalling of F1 interfaces are transported in the GS
- NG interface is positioned in the GS

The functional entities are coordinated as following:

- Coordination of gNB-DUs under the control of the gNB-CU, across F1 interfaces:
  - Satellite gNB-DU / cellular gNB-DU coordination
  - Satellite gNB-DU / satellite gNB-DU coordination
  - Cellular gNB-DU / cellular gNB-DU coordination

This architecture conforms to 3GPP R15.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The F1 interface between gNB-DU and gNB-CU enables coordination between gNB-DUs, in the GS, under the central control of the gNB-CU.

4.1.3 MC3: UE directly accessing to multi-access NR RANs with transmission points coordination

This architecture consists of the following components:

- UE, with direct access to both satellite link(s) and cellular link(s) under the control of a Multi-Access gNB (MA-gNB) (Note: like in 5G test bed)
- Either transparent gateway (like a transponder) or gateway as IP relay
- MA-gNB at gateways side
- 5G Core Network
- DN

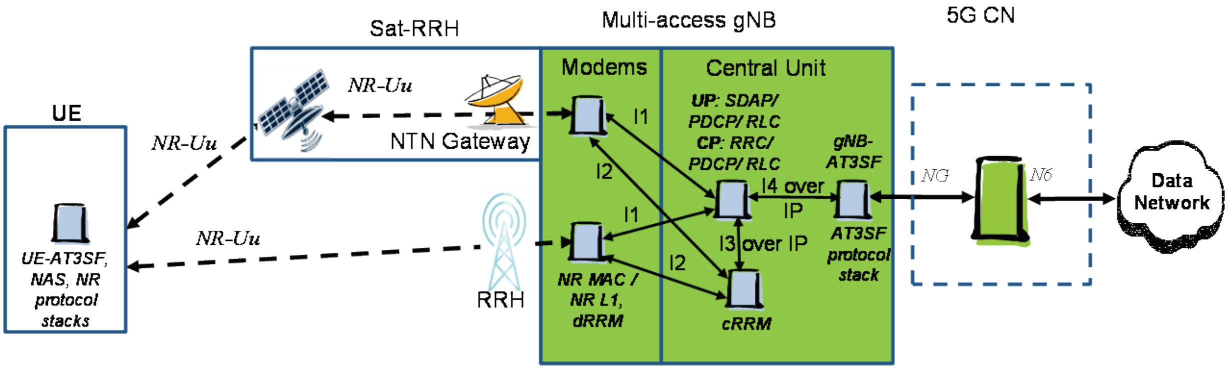

Figure 4-5: Architecture of MC3 (preliminary architecture for EU MC PoC).

3GPP R15 interfaces are positioned as follows:

- Data and signalling of NR interfaces are transported over the air, on the cellular user link or the satellite service link and the feeder link
- NG interface is positioned in the GS

The Tx/Rx Points are coordinated as following:

- Coordination between Tx/Rx Points (TRX PTs), under the control of the MA-gNB:
  - Between Satellite TRX PT and cellular TRX PT
  - Between Satellite TRX PTs
  - Between TRX PTs

Within the MA-gNB, the coordination between satellite and cellular TRX PTs is based on the coordination and the synchronization between:

- cRRM function, in the CU of the MA-gNB
- dRRM function, in each modem part, in order to exchange with cRRM and local MAC layers

The functional entities are coordinated as following:

- Coordination, over Xn interfaces, between the MA-gNB and:
  - Other MA-gNBs at gateways side,
  - Other Satellite gNBs at gateway side and
  - Other cellular gNBs

- Internal MA-gNB interfaces are to be defined: I1, I2, I3, I4. They are implementation-dependent and out of 3GPP scope.

Conformance to 3GPP TS and 3GPP inheritance aspects:

- This architecture does not conform to 5G standard (3GPP R15) but it is inherited from a 3GPP TR 38.801 R14 [19] which has proposed several protocols layers splits at different levels (freezed in 2017). Only the F1 interface splitting has been agreed in 3GPP R15.
- The AT3SFs (Access Traffic Steering, Switching and Splitting (ATSSS) Functions) are not positioned in the 5G Core Network (UPF), unlike 3GPP TR 23.793 [15], but inside the MA-gNB and closer to the Tx / Rx points.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The MA-gNB acts as two coordinated and co-located gNBs. The Xn interface, generally used for coordination between two remote gNBs, is replaced by a local but not standardized interface.

4.1.4 MC4: UE directly accessing to two transparent satellite-based NR RANs with RAN coordination

This architecture consists of the following components:

- UE, with direct access to both satellite RAN(s)
- Either transparent gateway (like a transponder) or gateway as IP relay
- Coordinated satellite gNBs, at gateways side
- 5G Core Network
- DN

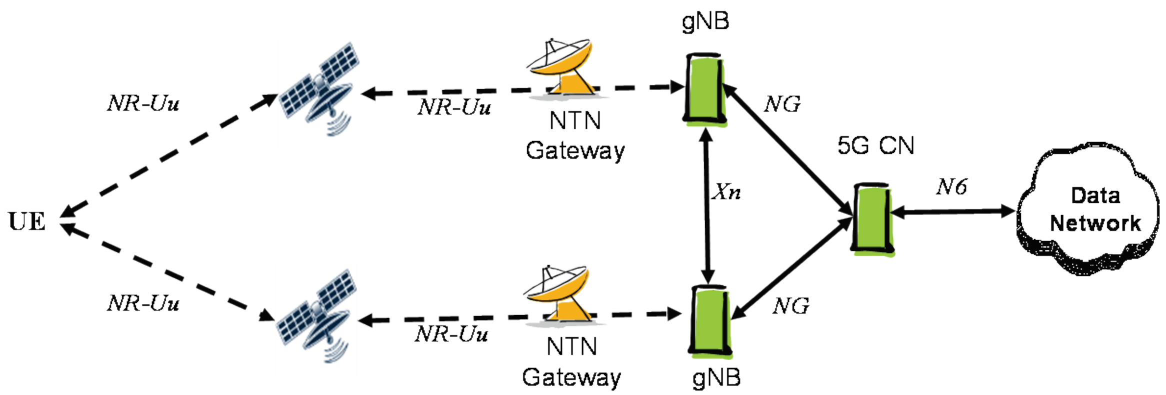

Figure 4-6: Architecture of MC4.

3GPP R15 interfaces are positioned as follows:

- NR interfaces are positioned over the air, on the satellite service links and the feeder links
- Data and signalling of NG interfaces are transported in the GS
- Xn interfaces are positioned in the GS

The functional entities are coordinated as follows:

- Coordination of RANs (gNBs) across Xn interfaces between satellite gNBs located at gateways side.

This architecture conforms to 3GPP R15.

Features of this network:

- The two satellites may be positioned at different orbits. One orbit may be LEO and the other one GEO. The LEO satellite access featuring relatively low latency would support the delay sensitive traffic while the GEO satellite access would provide additional band-width to meet the targeted throughput requirements.
- The Xn interface enables coordination between gNB, in the GS.
- This architecture, which is a special case of the archiecture specified in section 4.1.1, supports a UE with direct access to two NR based satellite RANs.

4.1.5 MC5: UE directly accessing to two OBP satellite-based NR RANs with RAN coordination

This architecture consists of the following components:

- UE, with direct access to both satellite RAN(s) and cellular RAN(s)
- Either transparent gateway (like a transponder) or gateway as IP relay
- Satellite gNBs at gateways side
- 5G Core Network
- DN

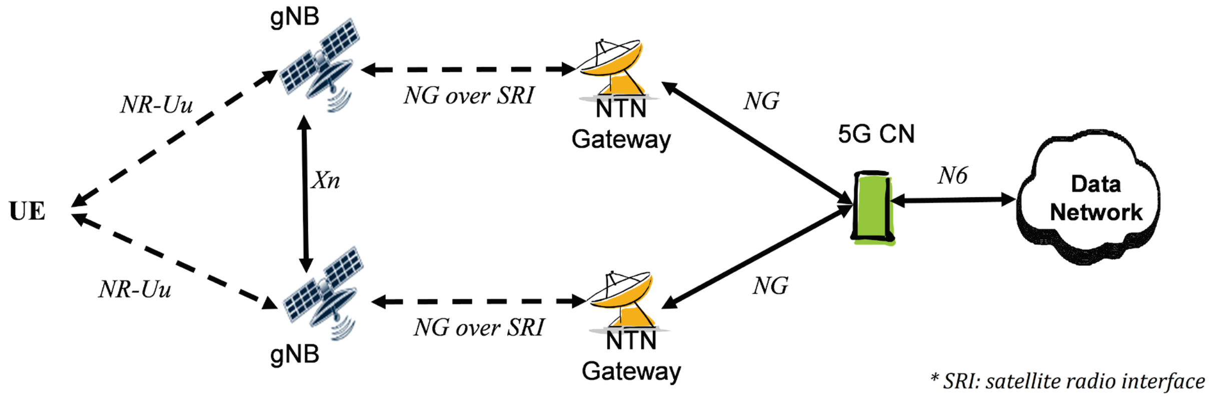

Figure 4-7: Architecture of MC5.

3GPP R15 interfaces are positioned as following:

- NR interfaces are positioned over the air, on the satellite service links and the feeder links
- Data and signalling of NG interfaces are transported both in the space segment (satellite radio interface (SRI)) and the GS
- Xn interfaces are positioned in the space segment, over ISL

The functional entities are coordinated as follows:

- Coordination of RANs (gNBs) across Xn interfaces between on-board Satellite gNBs

This architecture conforms to 3GPP R15.

Features of this network:

- The gNB acts as an access controller for the UE. When hosted in a regenerative satellite with processing capacities, the gNB is closer to the UE and can quickly give it an initial access or reconfigure the access, e.g. the MAC scheduling, the MODCOD used on the radio interface, whenever operational conditions changes on this interface (such as attenuation, traffic load, density of UE).
- The two satellites may be positioned at different orbits. One orbit may be LEO and the other one, GEO. The LEO satellite access featuring relatively low latency would support the delay sensitive traffic while the GEO satellite access would provide additional bandwidth to meet the targeted throughput requirements.
- The Xn interface over ISL enables coordination between gNB.

4.1.6 MC6: UE directly accessing to cellular-based NR RAN(s) and OBP satellite-based NR RAN(s) with RAN coordination

This architecture consists of the following components:

- UE with direct access
- OBP satellite gNBs
- Cellular gNBs
- Gateway as IP relay
- 5G Core Network
- DN

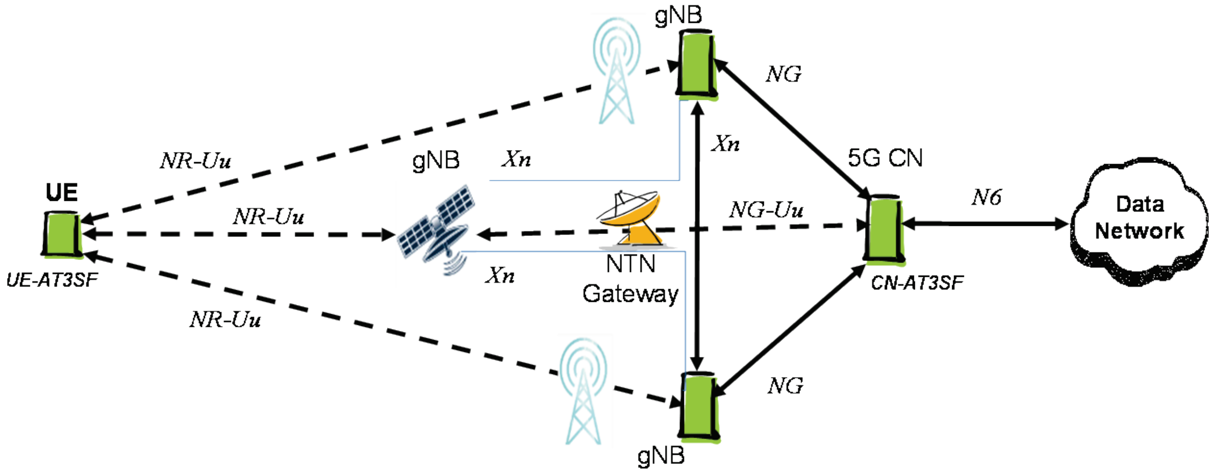

Figure 4-8: Architecture of MC6.

3GPP R15 interfaces are positioned as following:

- NR interfaces are positioned over the air, on the cellular user link or the satellite service link
- Data and signalling of NG interfaces are transported over the air on the feeder link and in the GS
- Xn interfaces are positioned over the air, on the feeder links and in the GS.

The functional entities are coordinated as follows:

- Coordination of RANS (gNBs) across Xn interfaces, between:
  - OBP satellite gNBs
  - OBP satellite gNBs and cellular gNBs
  - cellular gNBs (Xn interface positioned in the GS)

This architecture conforms to 3GPP R15.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The Xn interface enables coordination between gNBs.

Possible costs and issues:

- Xn over feeder link and ground link, through the NTN Gateway may need adaptations.
- Depending on the Feeder Link reliability, transporting the signalling and data of the Xn interfaces over this Feeder Link may lead to dysfunctions, such as transmission disruption and re-transmission, alarms raising, protocols reconfiguration on the Xn interface.

4.1.7 MC7: UE directly accessing to distributed cellular-based NR RAN(s) and OBP satellite-based NR RAN(s) under central control

This architecture consists of the following components:

- UE with direct access
- On-board gNB-DUs
- Cellular gNB-DUs
- Either transparent gateway (like a transponder) or gateway as IP relay
- Central gNB-CU at gateway side, controlling both on-board gNB-DUs and cellular gNB-DUs
- 5G Core Network
- DN

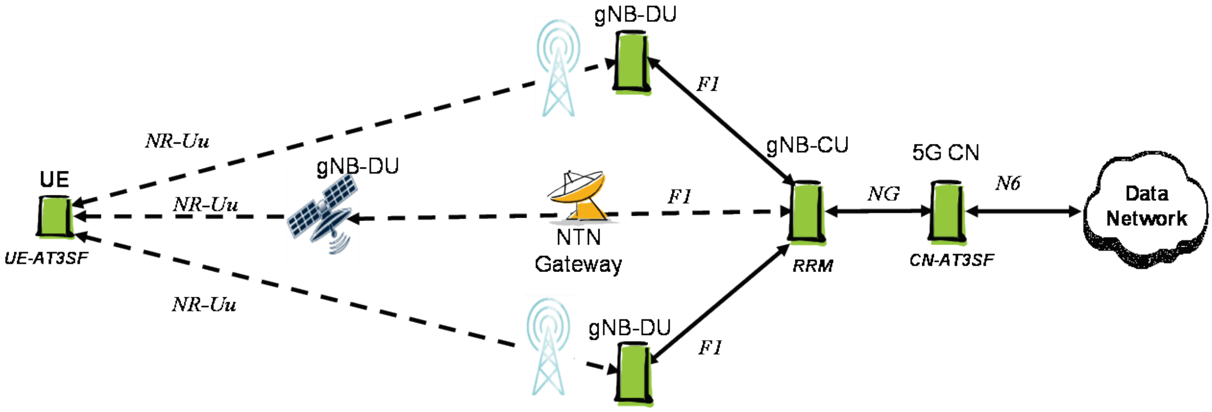

Figure 4-9: Architecture of MC7.

3GPP R15 interfaces are positioned as following:

- NR interfaces are positioned over the air, on the cellular user link or the satellite service link
- Data and signalling of F1 interfaces are transported over the air, on the feeder link and in the GS
- NG interface is positioned in the GS

The functional entities are coordinated as following:

- Coordination of gNB-DUs across F1 interfaces, under the control of the gNB-CU :
  - on-boards gNB-DUs
  - on-board gNB-DUs and cellular gNB-DUs
  - cellular gNB-DUs

This architecture conforms to 3GPP R15.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The F1 interface between gNB-DU and gNB-CU enables the coordination between gNB-DUs under the central control of the gNB-CU.

Possible costs and issues:

- F1 over feeder link and ground link, through the NTN Gateway may need adaptations.
- Depending on the Feeder Link reliability, transporting the signalling and data of the F1 interface over this Feeder Link may lead to dysfunctions, such as transmission disruption and re-transmission, alarms raising, protocols reconfiguration on the F1 interface.

4.1.8 MC8: UE directly accessing to distributed cellular-based NR RAN(s) and OBP satellite-based NR RAN(s) under central control via F1 interfaces

This architecture consists of the following components:

- UE with direct access
- On-board gNB-DUs, hosted by on-board IAB nodes
- Cellular gNB-DUs, hosted by on-ground IAB nodes
- MT function, hosted by IAB nodes
- Either transparent gateway (like a transponder) or gateway as IP relay
- On-ground central gNB-CU, at gateway side, controlling both on-board gNB-DUs and cellular gNB-DUs. The gNB-CU is hosted by the IAB donor.
- 5G Core Network
- DN

The MT function is defined as a component of the Mobile Equipment (see [18]).

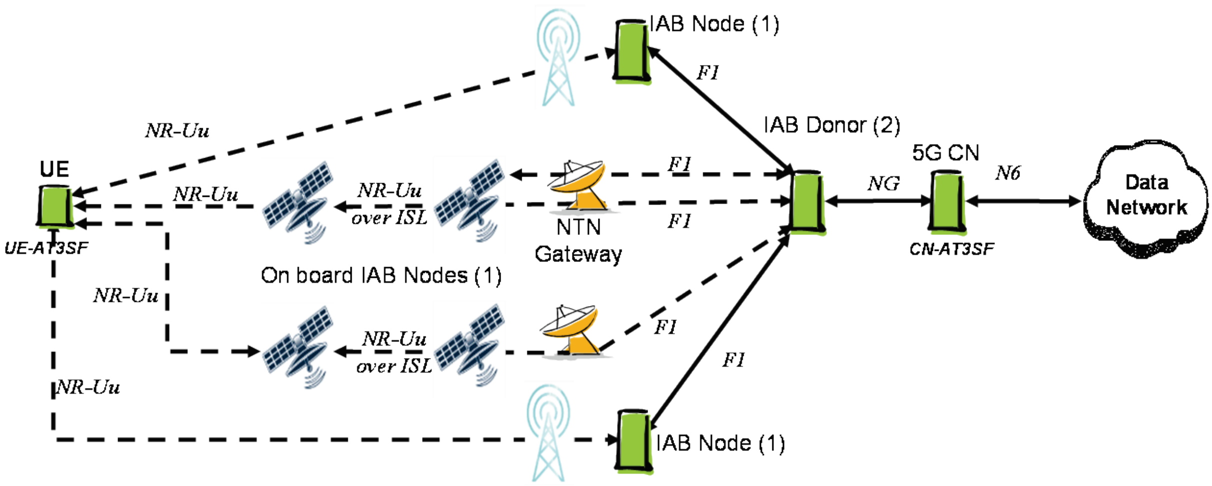

Figure 4-10: Architecture of MC8.

Notes inside the figure:

(1): including gNB-DU, relay and MT functions

(2): including gNB-CU functions

3GPP R15 interfaces are positioned as follows:

- NR interfaces are positioned over the air, on the cellular user links, the satellite service links and the ISL
- Data and signalling of F1 interfaces are transported over the air, on the ISL, the feeder links and on wired links, in the GS, between IAB nodes (gNB-DUs) and IAB donor (gNB-CU)
- NG interface is positioned in the GS

The functional entities are coordinated as follows:

- Coordination of gNB-DUs across F1 interfaces, under the control of the gNB-CU:
  - on-boards gNB-DUs
  - on-board gNB-DUs and cellular gNB-DUs
  - cellular gNB-DUs

This architecture conforms to 3GPP R15 regarding the split between gNB-DUs and gNB-DUs. It needs further RLC adaptations, according to 3GPP TR 38.874 [18].

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular access with a satellite access through a multi connectivity scheme.
- The F1 interface between gNB-DU (hosted in IAB-node) and gNB-CU (hosted in IAB-donor) enables the coordination between gNB-DUs under the central control of the gNB-CU.
- The IAB-nodes may relay signaling and data from / to IAB-donor, through several IAB-nodes, across the satellite network (non-GEO based), and over ISL.
- The two satellites may be positioned at different orbits. One orbit may be LEO and the other one, GEO. The LEO satellite access featuring relatively low latency would support the delay sensitive traffic while the GEO satellite access would provide additional bandwidth to meet the targeted throughput requirements.

Possible costs and issues:

- F1 over feeder link and ground link, through the NTN Gateway may need adaptations.
- Depending on the Feeder Link reliability, transporting the signalling and data of the F1 interface over this Feeder Link may lead to dysfunctions, such as transmission disruption and re-transmission, alarms raising, protocols reconfiguration on the F1 interface.

4.1.9 MC9: UE directly accessing to cellular-based NR RAN(s) and OBP satellite-based NR RAN(s) with RAN coordination via Xn interfaces

This architecture consists of the following components:

- UE with direct access
- On-board gNBs, hosted by on-board IAB nodes
- Cellular gNBs, hosted by on-ground IAB nodes
- MT function, hosted by IAB nodes
- Either transparent gateway (like a transponder) or gateway as IP relay
- On-ground central IAB donor, at gateway side, serving both on-board IAB nodes and cellular IAB nodes
- 5G Core Network
- DN

The MT function is defined as a component of the Mobile Equipment (see [18]). This architecture is inherited from “Architecture 2b” as described in [18].

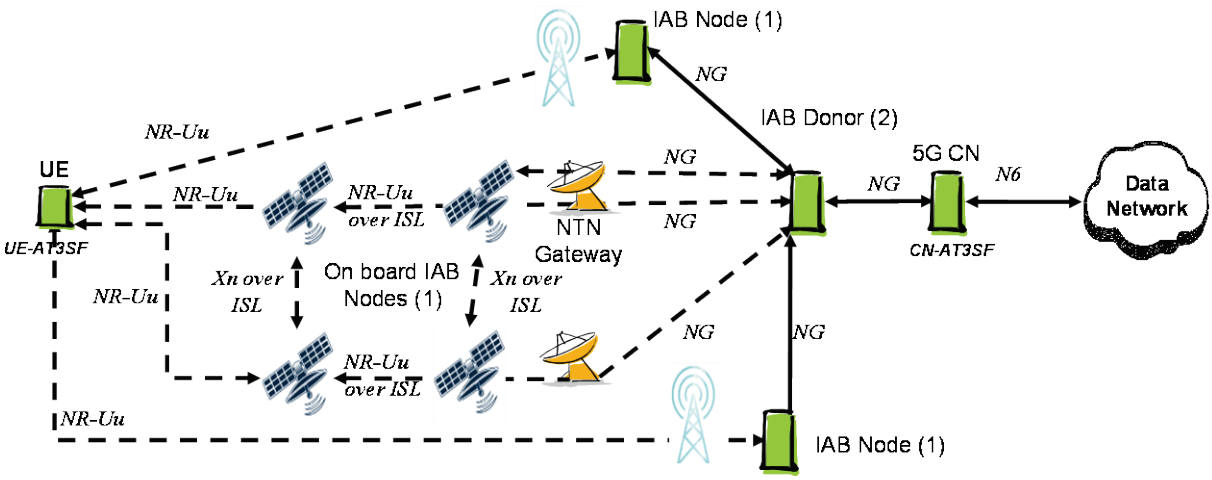

Figure 4-11: Architecture of MC9.

Notes inside the figure:

(1): including gNB, relay and MT functions

(2): including gNB functions, in order to serve local UE (not depicted)

All IP-based interfaces such as NG, Xn, F1, etc. are carried over the forwarding IP plane.

According to “Architecture 2a” of [18], each IAB-node may further support a routing function to forward data between UE served by the same IAB node or neighboured IAB nodes, which enables “shortcuts” set up in the Data plane, under the control of the IAB donor (not depicted).

3GPP R15 interfaces are positioned as following:

- NR interfaces are positioned over the air, on the cellular user links, the satellite service links and the ISL
- Data and signalling of NG interfaces are transported over the air on the ISL, feeder links and on wired links, in the GS, between the IAB nodes (gNBs) and the 5G CN, via the IAB donor
- Xn interfaces are positioned over the air, on the ISL, between the on-board IAB nodes (on-board gNBs)

The functional entities are coordinated as following:

- Coordination of RANs (gNBs), between:
  - On-board gNBs, across Xn interfaces over ISL
  - On-board gNBs and cellular gNBs, via the IAB donor: across an interface to be defined. It could be Xn, over ISL, Feeder Link and wired link in the GS.
  - Cellular gNBs
  - IAB donor – Other cellular gNB, across Xn interface, in the GS (not depicted).

This architecture conforms to 3GPP R15. Xn interface transport over feeder link and ground link, through the NTN Gateway may need adaptations.

Features of this network:

- At cell edge, the cellular access generally provides less performance than at cell center, without any beamforming operations.
- One way to increase the throughput provided to the UE, would be to combine the cellular ac-cess with a satellite access through a multi connectivity scheme.
- The Xn interface enables the coordination between gNBs (hosted by IAB-nodes).
- The IAB-nodes may relay signaling and data from/to IAB-donor, through several IAB-nodes, across the satellite network (non-GEO based), and over ISL.
- The two satellites may be positioned at different orbits. One orbit may be LEO and the other one, GEO. The LEO satellite access featuring relatively low latency would support the delay sensitive traffic while the GEO satellite access would provide additional bandwidth to meet the targeted throughput requirements.

Possible costs and issues:

- Xn over ISL, feeder link and ground link, through the NTN Gateway may need adaptations.
- Depending on the Feeder Link reliability, transporting the signalling and data of the Xn interface over this Feeder Link may lead to dysfunctions, such as transmission disruption and re-transmission, alarms raising, protocols reconfiguration on the Xn interface.

4.1.10 MC10: V-UE accessing to cellular-based NR RAN and/or non-NR-based satellite RAN

This architecture consists of the following components:

- Vehicle UE (V-UE) carrying two independent receivers: one is for receiving V2I signal, the other is for receiving satellite signal
- GEO satellite operating in Ku band (downlink: 12.25-12.75 GHz, uplink: 14.0-14.5 GHz)
- Synchronous 5G NR gNB-DUs distributed along the road are interconnected with centralized 5G NR gNB-CUs that are connected to gateway/5G core network
- Earth station connected to gateway/5G core network
- 5G Core Network
- DN

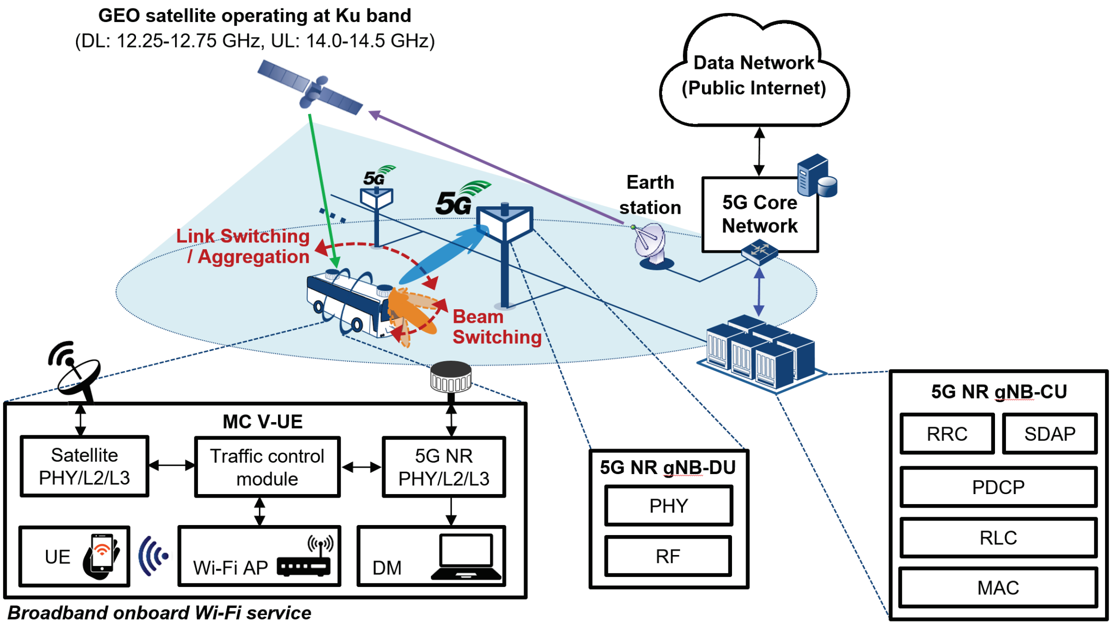

Figure 4-12: Architecture of MC10 (preliminary architecture for KR MC PoC).

3GPP R15 interfaces are positioned as following:

- NR interfaces are used for links between V-UEs and gNB RUs

The functional entities are coordinated as following:

- Coordination of RANs (gNBs) between
  - Cellular gNBs

Features of this network:

- Due to propagation charateristics of mmWave band to be used for cellular/vehicular communications, the performance of the cellular access is generally vulnerable to not only the misalignment between Tx and Rx beams due to the constant motion of the vehicles, but also the limited coverage.
- One way to increase the throughput and link reliability provided to the V-UE would be to switch between the cellular access link and the satellite access link based on the channel quality of them or to aggregate both links.

- The Xn interface (not depicted) enables the coordination between gNBs.
- The radio inferface of satellite RAN is not based on NR.

Possible issues:

- It is necessary to investigate which layer is suitable for performing traffic control (link switching/aggregation) of satellite traffic and cellular traffic, and to study an algorithm for link switching/aggregation.

4.2 Synthesis and Characteristics of the MC Architecture Options

This section provides a brief summary of the MC architectures investigated in section 4.1 , and recommends a set of architectures for 5G-ALLSTAR project depending on their usages and implementation constraints

- An architecture for WP3/T3.4 simulator
- Architectures for test bed / trial
- Architectures for 3GPP contributions

Amongst all multi-access architectures identified in §4.1, the selected compatible architectures and their potential use for 5G-ALLSTAR are summarized in the following table:

Table 4-1: Synthesis and characteristics of the MC architecture options

MC	Main characteristics	Potential use for 5G-ALLSTAR
MC1 (§4.1.1)	One transparent satellite (Bent-Pipe). UE direct access to both cellular NR based RANs and satellite NR based RAN with RANs coordination.	Agreement of any contribution to 3GPP, based on standardized Xn interfaces will be easier. Candidate model for the simulator of WP3/T3.4.
MC2 (§4.1.2)	One transparent satellite. UE direct access to both distributed cellular NR based RANs and distributed satellite NR based RAN, with RANs coordination under central control.	Agreement of any contribution to 3GPP, based on standardized F1 interfaces, will be easier. BUT: Less close to the Test bed architecture than in §4.1.3.
MC3 (§4.1.3)	One transparent satellite. UE direct multi-access NR based RAN, with transmission points coordination.	Close to the WP5 test bed architecture as foreseen during the Kick Off meeting in June 2018. BUT: Multi-access RAN or MA-gNB are not specified in 3GPP. Agreement by 3GPP partnership will be difficult to achieve on such RAN architecture. Dedicated/Non-standardized interfaces and ICD to design and develop between: • RLC and MAC • PCDP/RLC and gNB-AT3SF • RRM and MAC • Radio Resource Control (RRC) and RRM

MC	Main characteristics	Potential use for 5G-ALLSTAR
MC4 (§4.1.4)	Transparent satellites. UE direct access to two satellite NR based RANs, with RANs coordination.	Agreement of any contribution to 3GPP, based on standardized Xn interfaces will be easier. Candidate model for the simulator of WP3/T3.4.
MC5 (§4.1.5)	OBP satellites. UE direct access to two satellite NR based RANs	Agreement of any contribution to 3GPP, based on standardized Xn interfaces will be easier but less than in §4.1.1, since: The Xn interface transport over Feeder Link and Ground link has to be adapted. OBP satellite with on-board gNB, is not in line with the 5G-ALLSTAR test bed architecture.
MC6 (§4.1.6)	One OBP satellite. UE direct access to both cellular NR based RANs and satellite NR based RAN with RANs coordination.	Agreement of any contribution to 3GPP, based on standardized Xn interfaces will be easier but less than in §4.1.1, since: The Xn interface transport over Feeder Link and Ground link has to be adapted. OBP satellite with on-board gNB, is not in line with the 5G-ALLSTAR test bed architecture.
MC7 (§4.1.7)	One OBP satellite, UE direct access to NR based distributed cellular and satellite NR based RAN, under central control	Agreement of any contribution to 3GPP, based on standardized F1 interfaces, will be easier but less than in §4.1.1, since: • The F1 interface transport over Feeder Link and Ground link has to be adapted. • OBP satellites with on-board gNB are not in line with the 5G-ALLSTAR test bed architecture.
MC8 (§4.1.8)	Several OBP satellites. Multi-hop forwarding in the space segment. UE direct access to NR based distributed cellular and satellite NR based RAN, under central control (F1 interfaces between on-board gNB-DUs and a gNB-CU).	Medium Earth Orbit (MEO), LEO satellites compatible. Contribution to 3GPP, based on standardized F1 interfaces, will be easier but less than in §4.1.1, since: • The F1 interface transport over the ISL, the Feeder Link and Ground link has to be adapted. • IAB nodes and IAB donor based architecture (see TR 38.871 [18]) is a relevant candidate for 5G relay mechanism specifications but not yet specified. F1 interface transport is agreed in [18] for further 5G specifications. OBP satellites with on-board gNB are not in line with the 5G-ALLSTAR test bed architecture.

MC	Main characteristics	Potential use for 5G-ALLSTAR
MC9 (§4.1.9)	Several OBP satellites, Multi-hop forwarding in the space segment. UE direct access to both cellular NR based RANs and satellite NR based RAN with RANs coordination (Xn interfaces between on-board gNBs)	MEO, LEO satellites compatible. All IP-based interfaces such as NG, Xn, F1, etc... are carried over the forwarding IP plane. Contribution to 3GPP, based on standardized F1 interfaces, will be easier but less than in §4.1.1, since: • The F1 interface transport over the ISL, the Feeder Link and Ground link has to be adapted. • IAB nodes and IAB donor based architecture (see TR 38.871 [18]) is a relevant candidate for 5G relay mechanism specifications but not yet specified. NG interface transport is described in [18] but not yet agreed for further 5G specifications. Support of a routing function to forward data between UE served by the same IAB node or neighboured IAB nodes (shortcuts). OBP satellite with on-board gNB is not in line with the 5G-ALLSTAR test bed architecture.
MC10 (§4.1.10)	V-UE is equipped with two antennas for satellite link and cellular link, GEO satellite	Korean testbed/field trial

5 Key Components and Enabling Technologies in Access Network

5.1 Key Components in Cellular Access Network

5.1.1 Key components for Korean access network

- Baseband
  - Waveform
    - Only CP-OFDM is supported for both downlink and uplink transmissions
  - Duplex mode: TDD
  - Supported Numerology
    - Both μ=2 and μ=3 are under consideration while μ=2 is prioritized

Table 5-1: Supported numerology

Parameter / Numerlogy (μ)	2	3
Max. number of CCs per gNB	10	10
Max. number of CCs per VUE	3	3
Bandwidth per CC (MHz)	100	100
Subcarrier spacing (kHz)	60	120
Number of PRBs per CC	132	66
FFT size	2048	1024
Sampling rate (MHz)	122.88	122.88
TTI (μs)	250	125
OFDM symbol duration (μs)	16.67	8.33
Cyclic Prefix duration (μs)	1.17	0.57
OFDM symbol including CP (μs)	17.84	8.92

  - Transmission scheme:
    - Only non-codebook-based transmission is supported for both downlink and up-link transmissions
  - Baseband processing (transmitter)
    - Encoding
      - ✓ Transport block Cyclic Redundancy Check (CRC) attachment
      - ✓ Code block segmentation and code block CRC attachment
      - ✓ Channel coding (Turbo coding instead of Low-Density Parity-Check (LDPC) coding)
      - ✓ Physical-layer hybrid-ARQ processing
      - ✓ Rate matching
    - Scrambling, Modulation (QPSK, 16QAM, 64QAM), Layer mapping (up to 2 spatial layers in downlink and one spatial layer in uplink), Precoding, Mapping to assigned resources and antenna ports

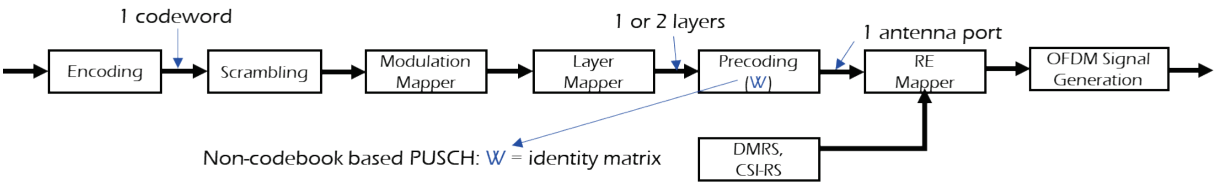

Figure 5-1: Downlink baseband processing.

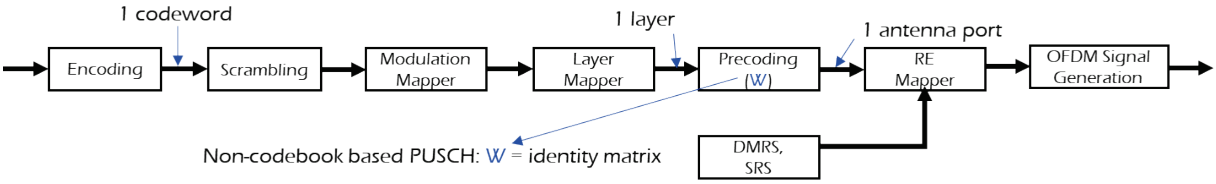

Figure 5-2: Uplink baseband processing.

- Antenna and RF
  - In Korean access network, slotted waveguide array antenna will be employed for each antenna panel both at BS and V-UE, also known as Terminal Equipment (TE). The array antenna consists of 4x4 radiating elements with an array gain of around 19~20 dBi and it forms fixed beam in a desired direction. Since the target system will be designed to be operated in Flexible Access Common Spectrum (FACS), it is mandatory to comply with the Effective Isotropic Radiated Power (EIRP) requirement regulated by Korean government where the maximum allowable RF power emitted by the TX antenna is 36 dBm
  - Antenna module of BS consists of two antenna panels that have orthogonal polarization angles and are placed with enough distance between one another
  - Antenna module of V-UE consists of six physically independent antenna panels. Three of them, each of which forms a beam in different direction, have orthogonal polarization angles and are placed with enough distance between the other three antenna panels

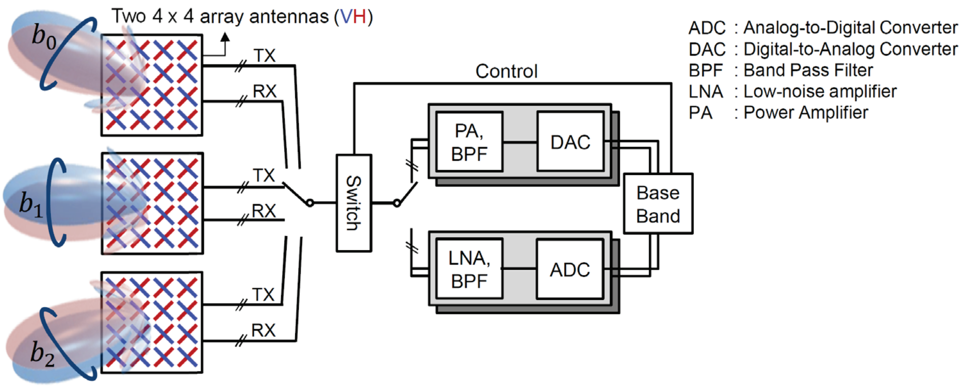

Figure 5-3: Basic idea of antenna and RF module design for beam switching at V-UE.

  - Target beam radiation pattern of each antenna panel

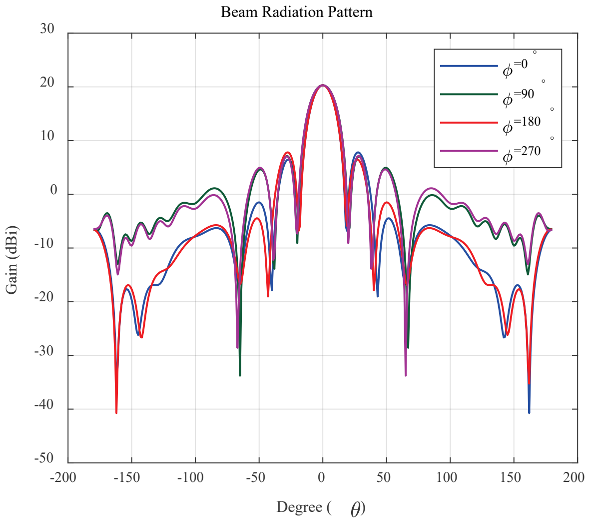

Figure 5-4: Target beam radiation pattern of each antenna panel.

5.2 Key Components in Satellite Access Network

The key components in a Satellite Access Network for communications can be grouped in two main segments:

- GS
- Space Segment

Following paragraphs give an overview of the main components of a satellite access network inherited from [19], [22] and [23].

5.2.1 Space Segment

The space segment contains one or multiple satellites organised into a constellation. A satellite is build up by:

- Payload, consisting in the antennas and all electronics necessary to receive and transmit carriers. Two possible type of payload are:
  - Bent-pipe payload: also known as transparent payload, carrying out basic functions of transparent communications payloads, that is RF filtering, frequency conversion and amplification
  - Regenerative payload: carrying out demodulation/decoding and switch and/or routing and, coding/modulation on top of the basic communication payloads functions. On-board signal processing (OBP) is enabled by the availability of baseband signal.
- Platform, consisting of all the subsystems necessary for the operations of the payload

Within the scope of [24], different types of space segments listed in Table 5-2: have been identified.

Table 5-2: Types of satellites

Satellite	Altitude range	Orbit	Typical beam footprint size	One-Way Max Propagation Delay
LEO (3GPP case)	300 – 1500 km	Circular around the earth	100 – 500 km	30 ms
MEO	7000 – 25000 km		100 – 500 km	90 ms

GEO (3GPP case)	35 786 km	Notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point	200 – 1000 km	280 ms
HEO	400 – 50000 km	Elliptical around the earth	200 – 1000 km	Wide range of values [from tens of milliseconds to hundreds of milliseconds] depending on orbit choice

Possible architectures for the satellite access are summarized in paragraph 3.1.2.

5.2.2 Ground Segment

The ground segment (GS) contains earth stations through which data traffic is flowing and that are therefore part of a network. Earth stations are distinguished by size and type of traffic. Earth stations may be either interface stations to a terrestrial network (i.e. gateway), user stations (UTs e.g. handsets, UEs or small stations directly connected to UTs, e.g. VSATs) or a service station (i.e. hub or feeder run by service providers).

The main components of an earth station are organised as follows:

- Antenna subsystem:
  - Diplexer (for transceiver stations)
  - Tracking module
  - Command module
- RF subsystem:
  - On the transmitting side:
    - RF High Power Amplifiers (HPA)
    - Combiner
  - On the receiving side:
    - RF front-end Low Noise Amplifier (LNA)
    - Divider
  - In each direction, frequency converters are used to interface with the communication subsystem, which operates at intermediate frequency (IF).
- Communication subsystem:
  - On the transmitting side:
    - Up converter
    - IF modulator
  - On the receiving side:
    - Down converter
    - IF demodulator
  - Signal processing equipment
- Terrestrial network interface subsystem
  - Multiplexing/Demultiplexing equipment
  - Connection with terrestrial network

- Tracking module
- Monitoring, Alarm & Control modules
- Power Supply modules

This paragraph will also report the main characteristic features of a user station enabling satellite access to mobile communication network.

Antenna Subsystem

GS antennas are normally working both in transmission and reception through the use of diplexers and orthogonal polarisations.

The tracking system is necessary to keep the antenna pointing in direction to the satellite. For an earth station the antenna is also required to have high directivity in the direction of the satellite position and low side-lobe radiation in other directions to limit interference.

The antenna is sized after the link budget analysis. Diameter may span from 0.1 m (e.g. UEs, handsets) to dozens of meters (very large antennas).

Antenna used in earth stations are usually parabolic reflectors which can be grouped according to the mounting:

- Symmetrical mounting
- Offset mounting
- Cassegrain mounting

The main parameters for characterisation of the antenna are:

- Gain, which is determining then EIRP and G/T (figure of merit)
- Beamwidth, which has direct impact on the tracking system to use
- Polarization isolation, which is required to be as high as possible
- Noise temperature, originating from the sky and surrounding ground radiation and required to be as low as possible
- Antenna efficiency, required to be as high as possible

RF subsystem

The RF subsystem is containing:

- Receiving equipment: namely LNAs and equipment to route carriers (feeders, power splitter/divider)
- Transmitting equipment, namely a combiner and HPAs

The receiving equipment is part of the receiver front-end and is characterising the figure of merit G/T of the system by means of the system noise temperature T to which it is adding up noise temperature through its different stages. Normally, in order to reduce the overall system noise is necessary to use a first stage with low noise and sufficiently high gain. For small stations, RF front-end and LNA can be combined in a Low Noise Block (LNB) converter, an equipment mounted just behind the source but that brings as a drawback a non-negligible rise of noise temperature between the down converter and the following stages.

Usually located at the first stage of the receiver front-end, the LNA is setting the effective input noise temperature and therefore must operate in order to keep the noise figure as low as possible. LNA and frequency downconverter together are commonly known as receiver. The frequency downconversion is necessary to convert to lower intermediate frequency which is the operating frequency of the communication subsystem for the performance of operations of filtering and signal processing.

In the transmitter front-end, the principal parameter for characterisation of the link is the power per carrier which is determining the EIRP. The available power at the antenna input depends on the output power of the HPA and on the losses at the different stages. The main technologies used for HPAs are Travelling Wave Tube Amplifiers (TWTA) and solid state power amplifiers (SSPA). This equipment can be associated with a preamplifier and a lineariser. Also, control equipment and cooling system might be included [23].

Communication subsystem

This subsystem is containing:

- Equipment for up-conversion of baseband signals to RF carriers at the transmitting side. The main functions performed are:
  - IF modulation
  - filtering and equalisation of group propagation delay
  - upconversion of the modulated carriers from IF to RF
- Equipment for conversion of the carriers at the output of the LNA to baseband signals at the receiving side. The main operations performed are:
  - downconversion from RF to IF
  - filtering and equalisation of group propagation delay
  - demodulation

Terrestrial network interface subsystem

This subsystem serves as an interface between the communication subsystem and the terrestrial network. The baseband signal in input to/output from the communication equipment is adapted from/to the terrestrial network format. The main operations performed are multiplexing/demultiplexing.

5.2.3 User Segment

This paragraphs contains a short overview of user stations which are part of the GS and are often identified as a separate segment. The most relevant terminals in a satellite access network are UTs and VSATs.

Very Small Aperture Terminal

VSATs are small stations equipped with dish antennas of 0.6-1.2 m in diameter. UTs are directly connected to the VSAT and therefore enabled to transmit and receive satellite signals. These stations are easy to transport and to install and are able to support the most common services including broadcast and communication services.

User Terminal

User Terminals (UT) consist in equipment that is connected directly to a terrestrial network or to user stations such as VSAT. It may consists of a handset or a standard-specific terminal e.g. 3GPP UE).

Being the satellite operating in radio frequency band licenced for satellite services, the performance are usually characterised by the following parameters:

- Polarization

- Noise figure
- Transmit power, which sets the EIRP
- Antenna gain, which arises in both EIRP and G/T (figure of merit), depending on the direction of the link. UTs are generally equipped with Omni or semi directional antenna.

Table 5-3, as result of studies reported in [19], gives the minimum RF characteristics of the user stations operating respectively in Ka band (e.g. VSATs) and in S band (e.g. handheld terminals) in a 5G system.

Table 5-3: Typical minimum RF characteristics of UE in Satellite and aerial access networks

	Very Small Aperture Terminal (fixed or mounted on moving platforms)	Handheld or IoT devices (3GPP class 3, see [2])
Transmit Power	2 W (33 dBm)	200 mW (23 dBm)
Antenna type	60 cm equivalent aperture diameter (circular polarisation)	Omnidirectional antenna (linear polarisation)
Antenna gain	Tx: 43.2 dBi Rx: 39.7 dB	Tx and Rx: 0 dBi
Noise figure	1.2 dB	9 dB
EIRP	45.75 dBW	-7 dBW
G/T (NOTE 1)	18.5 dB/K	-33.6 dB/K
Polarisation (NOTE 2)	Circular	Linear

NOTE 1: For the computation of G/T or figure of merit, following formula applies in dB:

$$G/T = Ga - NF - 10*LOG\,(To+(Ta-To)/(10^{0.1*NF}))$$

Where:

- Antenna Gain : Ga in dBi
- Ambient Temperature : T0 (usually 290 K)
- Antenna temperature : Ta (typically 290 K with 0 dBi gain and 150 K with >30 dBi gain)
- Noise Figure: NF in dB

NOTE 2: For S band, we assume that the UE has an omni-directional antenna of linear polarization, while the antenna on-board space-borne or airborne platforms features typically employs circular polarization. Hence a polarization mismatch of 3 dB has to be taken into account for the radio link budget computation. This will impact the UE RF characteristics as below:

- Equivalent EIRP of 20 dBm (-10 dBW) under satellite coverage.
- Equivalent G/T of -36,6 dB/K under satellite coverage.

5.3 Key Enabling Technologies for Multi-RAT Integration and Target Performances Achievement

5.3.1 Integrated RRM in MC

5.3.1.1 RRM functions

According to 3GPP TS 38.300 [17] and TS 36.300 [27], the 4G/5G RRM is a set of functions which consists to:

- Radio Bearer Control (RBC):
  - Signalling Radio Bearers (SRBs), DRBs establishment, maintenance and release, which involve the configuration of radio resources associated with them.

- RAC:
  - It consists to admit or reject the establishment requests for new radio bearers.
- Interface with RRC layer for
  - RRC connections control,
  - Addition, modification and release of Carrier Aggregation (CA) and
  - Addition, modification and release of DC in NR based RAN or between 4G RAN and NR based RAN
- Connection Mobility Control (CMC).
  - It is concerned with the management of radio resources in connection with idle, inactive or connected UE modes mobility.
- (miscellaneous) Interface with RRC layer for:
  - Mobility functions including:
    - Handover and context transfer
    - UE cell selection and reselection and control of cell selection and reselection
    - Inter-RAT mobility
- DRA and Packet Scheduling (PS).
  - DRA and PS in RRM consist to allocate and de-allocate resources (including buffer and processing resources and resource blocks (i.e. chunks)) to user and control plane packets.
  - DRA involves several sub-tasks, including the selection of radio bearers whose packets are to be scheduled and managing the necessary resources (e.g. the power levels or the specific resource blocks used).
  - PS typically, takes into account the QoS requirements associated with the radio bearers, the channel quality information for UEs, buffer status, interference situation.
- Inter-Cell Interference Coordination (ICIC)
- Load Balancing (LB), at MAC level
- Inter-RAT RRM
- Subscriber Profile ID for RAT/Frequency Priority
- Inter-eNB Coordinated Multi-Point (CoMP) and Inter-gNB CoMP
- Cell on/off and cell discovery
- (miscellaneous) Interfaces with RRC layer for :
  - QoS management functions;
  - UE measurement reporting and control of the reporting;
  - Detection of and recovery from radio link failure;

The 4G/5G RRM architecture, as specified, may be either:

- Centralised:
  - Cell re-selection across cells under the control of the same gNB or
- De-Centralised:

  - For subsequent handover preparations over S1 or X2 interfaces (4G) or NG or Xn interfaces (5G) or
  - When NR based RAN is split into gNB-DUs and gNB-CU over F1 interface or
- Coordinated:
  - gNBs are coordinated in order to mitigate inter-cell interference, across X2 (4G) / Xn (5G) interfaces and
  - Optionally, when an elected master gNB takes the lead to propose RRM schemes, to secondary neighboured gNBs

Only the RRM functions that are involved in interference mitigation mechanisms will be considered. This will be studied in 5G-ALLSTAR WP3.

5.3.1.2 Interference mitigation mechanisms in a MC context

In a context of multi-technology access, combining satellite Transmission Points (TPs) and cellular TPs, with sharing spectrum, interferences may occur from a TP towards other ones.

The Service Area, served by the satellite beam, may be seen as a super-cell, interfering uplink signals from UE to cellular gNB as well as downlink signals, from cellular gNB to UE.

The reverse case is applicable: the cells served by terrestrial gNBs may interfere the uplink signals from UE to the satellite and the downlink signals from the satellite to the UE.

In order to reduce / mitigate interferences between TPs, several mechanisms, inherited from 4G /5G systems could be re-used and adapted, in a shared spectrum context, such as:

- CoMP-based mechanisms
- Enhanced ICIC
- CA with carrier-cross- scheduling

These mechanisms rely on coordination between satellite gNB and cellular gNBs, and between cellular gNB. This coordination relies on:

- Measurements of interference impact on signals, such as SNR (Signal To Noise Ratio), and identification of the critical regions where interferences occur and needs mitigation
- Agreement on sets of radio resource and cell regions (e.g.: edge) where the coordination is required:
  - A set of shared resource, used for coordination
  - A set of not-shared resource, which cannot be used for coordination
- Set up of coordination of the shared resource within critical regions:
  - In time domain, using for example, Almost Blank Sub-frame (ABS). When a gNB transmits ABS with lower transmit power, for a given critical region, the neighboured cells can take benefits of these ABS to transmit with a higher power
  - In the frequency domain, for examples:
    - Splitting the shared band into sub-bands, each one being allocated to a gNB or
    - Sharing the PRBs between neighboured gNBs, each gNB using its own subset of PRB, in order to not interfere with the other ones
    - Sharing the Component Carriers (CCs), between gNB, when CA. While a CC is seen as a Primary CC (PCC) by a gNB and used with a high transmit power by a gNB, its neighbour gNB may use this CC as Secondary CC (SCC) with a lower

transmit power. In a complementary way, the neighbour gNB may use a CC as PCC, with a lower transmit power, while the gNB use it as a SCC.

The key issues for hybrid satellite / cellular systems are due to:

- The RTD between the measurement and the command to configure the coordination is longer for the satellite system than for cellular systems. The cellular systems are more reactive. While the cellular gNB has a quick time response to coordination request, the satellite gNB has a longer response. While the satellite gNB is receiving and answering a coordination request, the cellular signals may have experienced several changes (attenuation, power). The response of the satellite may be received too late by the cellular gNB, while the coordination may need new coordination requests.
- In a satellite / cellular MC context, the coordination between the satellite gNB and the cellular gNB should be operated for all the cellular gNBs that experiences interferences with the satellite signals, within the whole beam footprint. Unlike the coordination between cellular gNBs, that is operated only within the neighbourhood.

Therefore, the coordination mechanisms inherited from 4G/5G should be analysed and their adaptation to satellite / cellular MC should be evaluated.

The dynamic behaviour of such coordination is a huge issue, especially in transit states of interferences, when interference measurements have temporary values.

Therefore, and for simplification purposes, we will focus:

- on stationary interference measurements and
- the coordination to mitigate interferences will be addressed for stationary / permanent states of interferences (when measurements have temporary / transitory values).

These mechanisms will be studied in 5G-ALLSTAR WP3 and some of them, tested in WP5.

5.3.2 Traffic Flow Control in MC

The 5G-ALLSTAR is investigating Traffic Flow Control algorithms which will be integrated into the Traffic Flow Control modules (see Figure 3-1) and will be based on both the QoS handling procedures and the traffic selection as defined in [14][15][16]. The Traffic Flow Control (i. e., traffic steering, splitting and switching) algorithms will be devoted to the dynamic association of the personalized 5GALLSTAR QoS Flow(s) with the DRB(s) established with one or more RATs. The personalized QoS Flow(s) are defined in the CN by the QoE Control. The control strategies shall be performed by considering a set of inputs such as available radio resources in each RAT, radio link condition between UE and RATs, the type of service and traffic, and the UE characteristics.

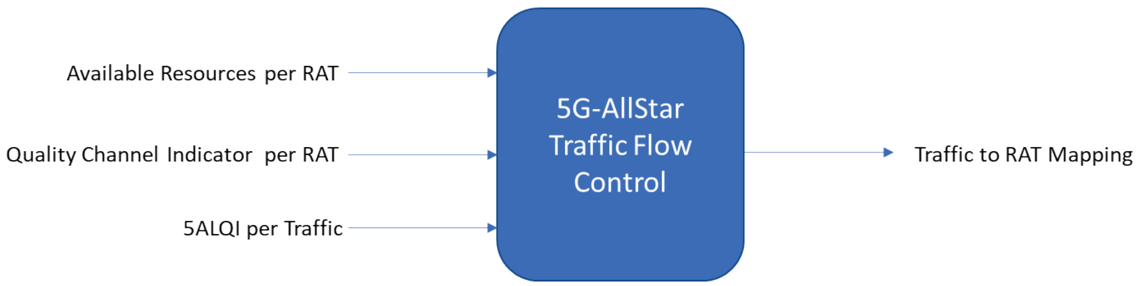

Figure 5-5: 5GALLSTAR traffic scheduling.

The 5G-ALLSTAR traffic flow control system, depicted in Figure 5-5, contains the set of control algorithms dedicated to the dynamic and context-aware (related to the personalized QoE measures) traffic selection for the MC RAN. The outputs will be dynamically produced during the UE connection taking into account the Quality Channel Indicators (QCI) of each RAT (e.g., BER, latency), the available resources of each RAT (e.g., bandwidth) and the personalized QoS Flows of each traffic (e.g., QoS parameters, personalized parameters, etc…).

The algorithms characteristics and description will be properly detailed in the WP4 deliverables (e.g. D4.1 and D4.2).

5.4 Key Enabling Technologies for Korean Access Network

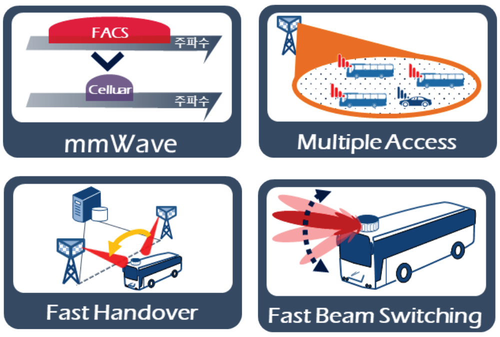

Figure 5-6: Key enabling technologies for vehicular communications.

- mmWave-based vehicular communications: by taking advantage of a vast amount of spectrum underutilized, mmWave enables high data rate transmission
  - Target system will be designed to support the maximum bandwidth of 1 GHz through CA of up to 10 CCs
- PHY design for high-mobility support
  - Numerology: the target system will be designed to operate in the FACS that is close to FR2 band in NR. In addition, it is specified in NR specification that in the FR2, μ=2 and μ=3 are supported. Therefore, the target system also supports both of them that have large enough subcarrier spacings to combat high Doppler frequency spread while μ=2 is prioritized
  - Doppler mitigation by automatic frequency control: this technique can compensate not only Doppler frequency shift caused by the mobility of vehicle, but also frequency offset by local oscillator
  - Efficient DMRS patterns for high-mobility scenario under given numerology

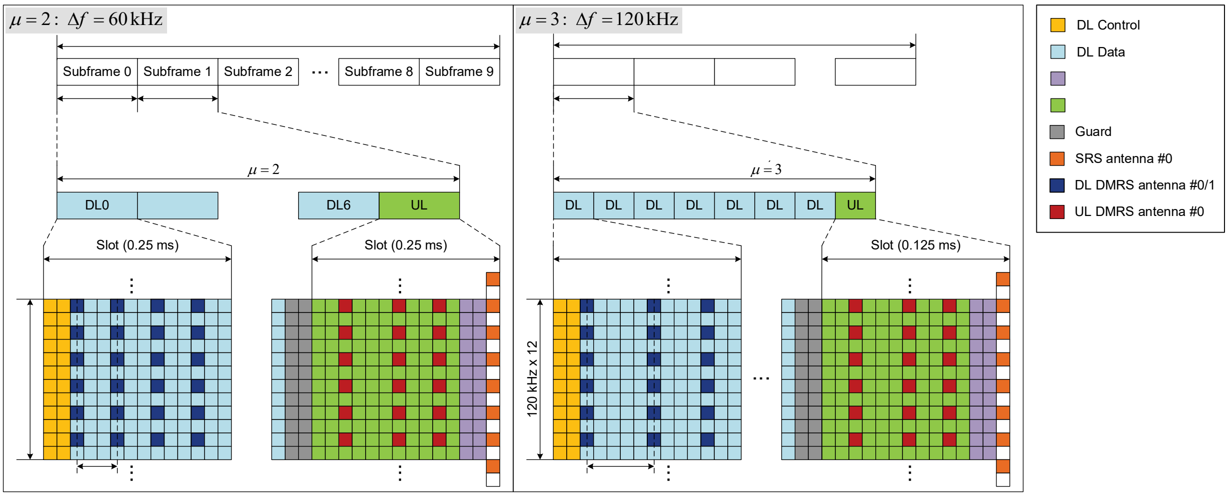

Figure 5-7: Frame structure (numerology and DMRS pattern).

- MIMO transmissions [29]
  - Array beamforming is one of the key solutions to dealing with serious propagation loss in mmWave-band communications
  - Polarization-based multi-antenna scheme will be used since it is particularly effective in a line-of-sight (LOS) dominant channel environment like in mmWave-band communications. With the polarization antenna, spatial multiplexing technique of supporting up to 2 spatial layers will be introduced
- Multiple access: a technology that allows multiple vehicles in a cell covered by a RU to simultaneously receive MWB links for broadband Wi-Fi services. In addition, by effectively scheduling radio resources to vehicles in the coverage, multiple access technique is able to offer increased system throughput
- Fast handover: a key technology to provide seamless handover to minimize the communication interruption time when a vehicle crosses cell edge.
- Fast beam switching: a technology to align TX/RX beam in the best direction in order to maximize received signal quality and to combat unexpected signal blockage by motion of vehicle and/or surrounding
  - Beam sweeping is performed at a specific period by measuring the received power of synchronization signal, and measurement mechanisms like measuring the received power of Channel State Information Reference Signal (CSI-RS) or DMRS can be also considered. For beam selection, the best beam is chosen for Tx or Rx at each time instance (e.g. slot)
  - An example of beam switching (beam sweeping and beam selection) with three available beams

$$b^* = \underset{b \in B}{\operatorname{argmax}}(P_{\mathrm{RSRP},b}), \text{ where } B = \{b_0, b_1, b_2\} \tag{5-1}$$

  - $P_{\mathrm{RSRP},b}$ in Eq. (5-1) represents Reference Signal Received Power (RSRP) at b-th beam

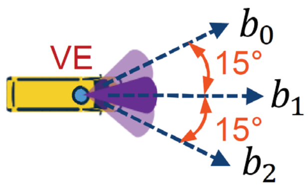

Figure 5-8: An example of beam switching with three available beams.

6 Intercontinental Interoperability between Korean and EU Systems

The 5G-ALLSTAR plans to showcase the first fully integrated satellite and cellular prototype system at a big event (the consortium is aiming at the Roland Garros tennis tournament) to provide visitors with a wide ranges of services targeted in the project. At this event, 5G-ALLSTAR plans not only to demonstrate with one of our testbed located at the main exhibition hall, but also to show an intercontinental interoperability demonstration with the other testbed located in Korea. To this end, possible solutions to the intercontinental connection between the two testbeds have been investigated, and one possible solution is to utilize a dedicated network / VPN (e.g., KREONET) for the connection as shown in Figure 6-1 and Figure 6-2. However, this is still under discussion since the final PoC scenarios at the event is still to be elaborated. Therefore, the final interface specification will be specified in D2.3, while the following two subsections describe the preliminary design of two testbeds, European system and Korean system, which may be respectively located at the event in Europe and Yeonggwang proving ground in Korea.

6.1 European System

As per D2.1 [1], the European system in 5G-ALLSTAR will enable MC between between heterogeneous access links, namely cellular and satellite access. Terrestrial and non-terrestrial links will be operating at different frequencies, namely mmWave for the former and Ka band for the latter. Satellite payload in GEO orbit will be transparent and operating in FDD mode.

The system aims at enabling 5G UEs to access multiple RATs through cellular 5G NR access and satellite friendly 5G NR modem. According to the nature of use-cases targeted in 5G-ALLSTAR, the multi-access UE will be able to access eMBB services such 8K streaming. To this purpose, an 8K video server generating video streaming traffic will be integrated into the system.

The European system will require tight integration between the modules developed within the scope of different WPs, namely:

- RRM module containing functions for interference analysis and mitigation (addressed in WP3)
- RLC/PDCP module containing functions for dynamic traffic switching, splitting and steering (SSS)
- PHY/MAC modems developed for both the satellite friendly and cellular links (addressed in WP5)

Therefore, dedicated interfaces will be defined and agreed among partners. Some of the possible interfacs that will be designed and developed in the EU system are:

- Interface between gNB SSS module and RRM
- Interface between CN QoE/QoS management module and gNB RRM module
- Interface between gNB SSS module and CN QoE/QoS management module
- Interface between RRM module and MAC layer
- Interface between gNB SSS module and MAC layer
- Interface between RRC and RRM module
- Interface between UE MAC layers and UE SSS module

An overview of the system is depicted in Figure 6-1:.

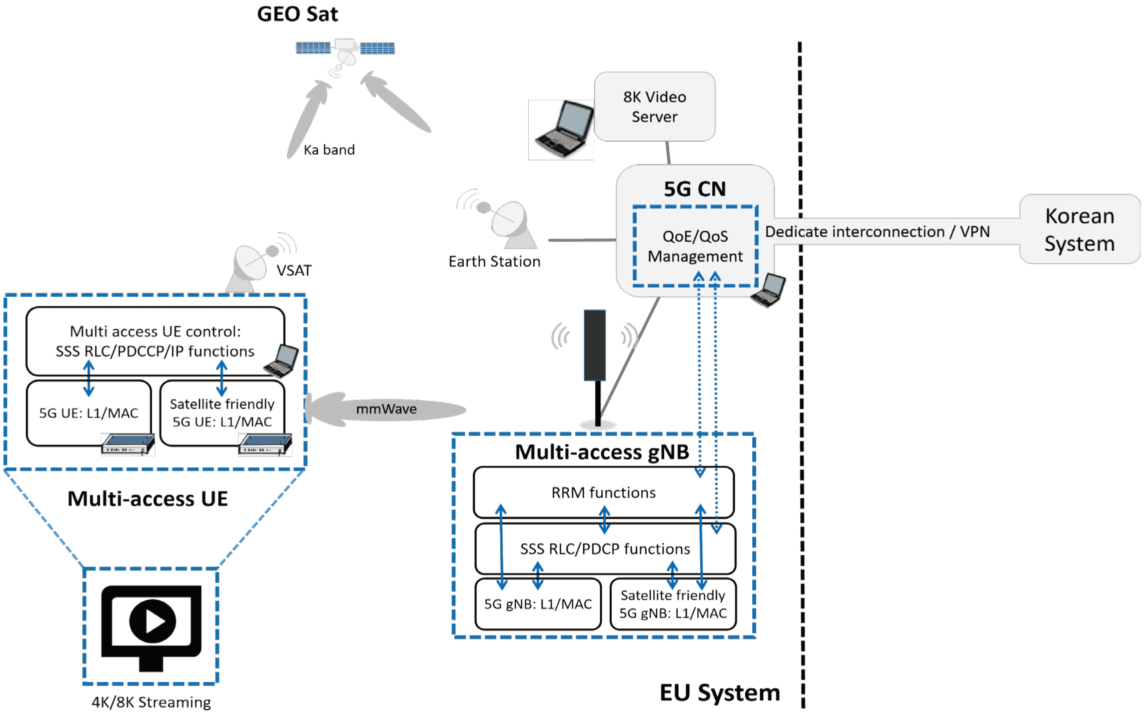

Figure 6-1: Overview of the EU system and interfaces between the different sub-modules.

6.2 Korean System

6.2.1 Overall Architecture and Required Interfaces

The Korean system called Moving Network system (MN system) aims to provide vehicles with broadband mobile wireless backhaul using mmWave bands. As illustrated in Figure 6-2, the system for vehicular communications, is based on the two-hop architecture similar to the network architecture of Mobile Hotspot Network (MHN) system for high-speed train (HST) communications [30][31].

In the network, each BS is composed of two radio units (RUs) covering sectors in different directions, and a V-UE, also known as a TE, is responsible for transmitting/receiving MWB signals to/from a RU of a BS. Generally, in highway environments, the BSs are installed along on the road side at regular intervals, and in urban environments, they can be installed on the roof of a building or on a street structure. The V-UE may be set up inside or on top of the vehicle, and a vehicle can carry multiple V-UEs depending on the size of the vehicle.

On-board users can connect their devices to the access link (e.g. Wi-Fi) connected to the V-UE. This two-hop system architecture is not only particularly advantageous for overcoming high penetration loss caused by vehicle body made of metal, but also capable of avoiding huge signalling overhead caused by group handover [30]. Each BS in the network is interconnected with the gateway (GW) and the GW is connected to the public Internet. The BS is mainly responsible for physical-layer processing and higher-layer functionalities, and the RU consists of RF transceivers and beamforming antennas for transmission and reception of MWB signals. In addition, the MN system basically supports the transmission (TX) / reception (RX) beam switching (BSW) technology at V-UE, and the multi-hop relaying technology between V-UEs to enable the V-UE to receive better signals in the mmWave-band vehicular communications.

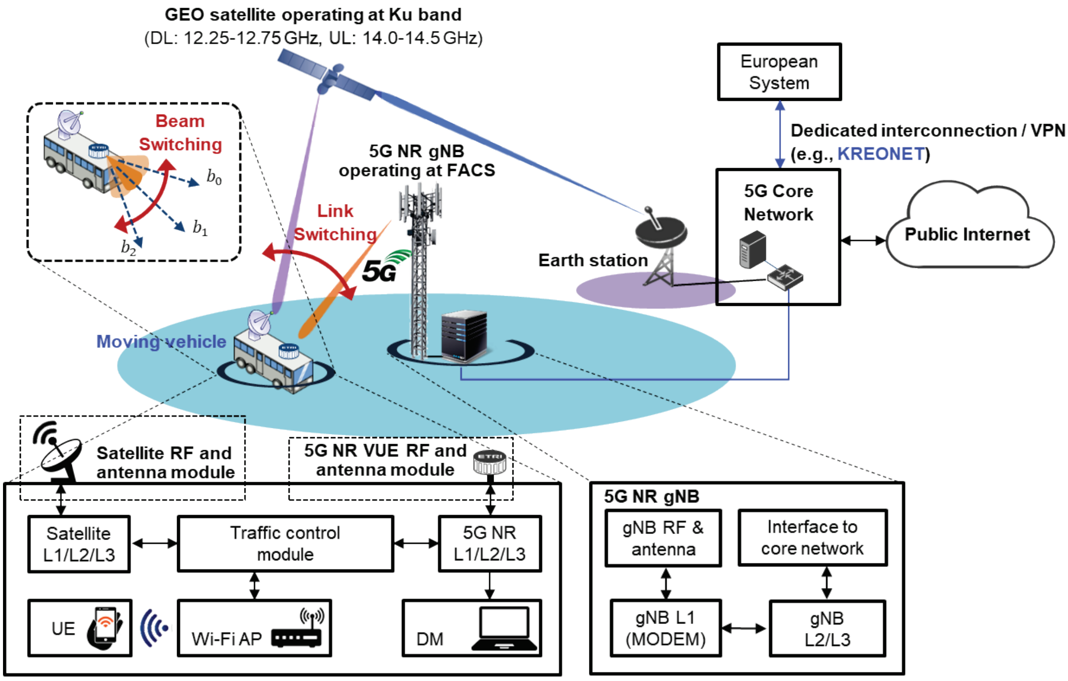

Figure 6-2: Overall architecture and interface for Korean access system.

In Korean system for PoC field trial, V-UE is equipped with two different receivers including independent antenna, RF, MODEM. The satellite access system operates in Ku band while the cellular access system operates in FACS. Therefore, traffic aggregation module in V-UE plays a crucial role in the MC between cellular and satellite links. In addition, following interfaces are required:

- Interface between traffic aggregation and satellite/cellular MODEM
- Interface between Wi-Fi Access Point (AP) and traffic aggregation module

6.2.2 Submodule Architecture and Required Interfaces

- Architecture and interface of BS modem
  - Interface between submodules in baseband modem and L1 controller
  - Interface between L1 controller and L2/SW
  - Interface between L1 front-end controller
  - Interface between Analog-to-Digital Converter / Digital-to-Analog Converter (ADC/DAC)

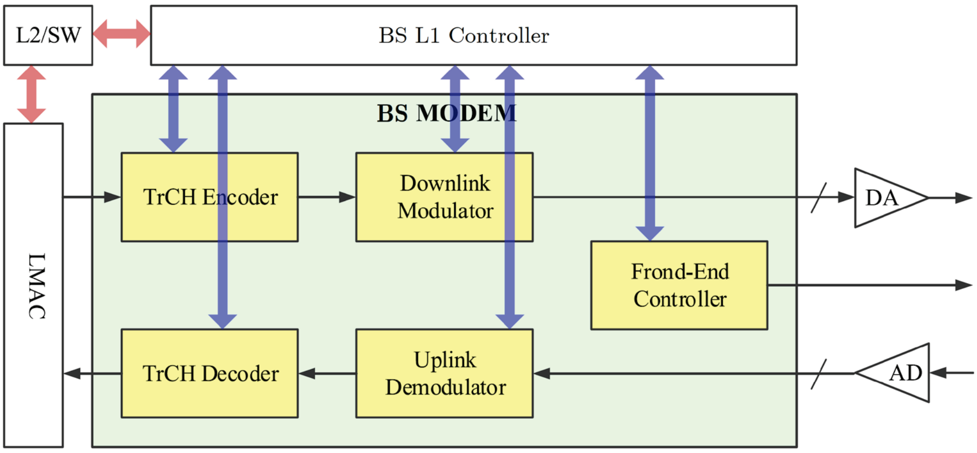

Figure 6-3: Architecture and interface of BS modem.

- Architecture and interface of V-UE (a.k.a. TE) modem
  - Interface between submodules in V-UE modem and L1 controller
  - Interface between L1 controller and L2/SW
  - Interface between L1 front-end controller
  - Interface between ADC/DAC

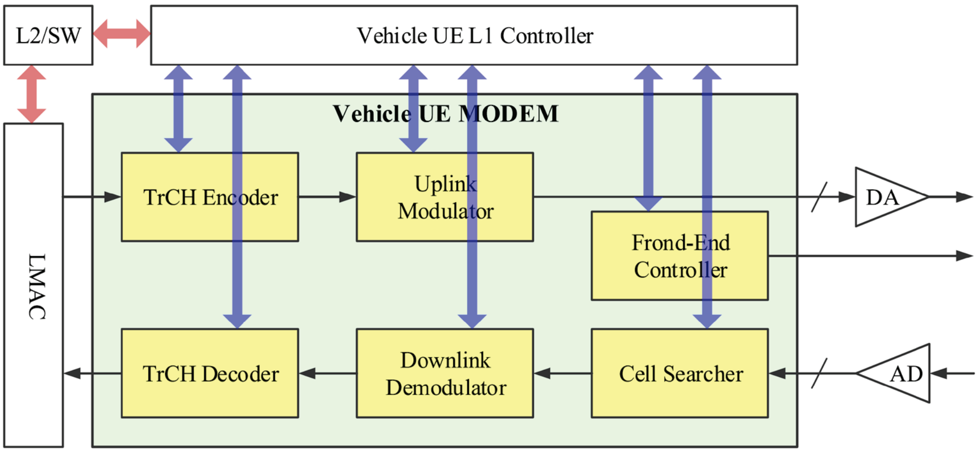

Figure 6-4: Architecture and interface of V-UE modem.

7 Conclusions

In order to support targeted use cases and preliminary PoC service scenarios as described in D2.1, WP2 has conducted a preliminary study on the overall system architecture and required interfaces for the targeted 5G-ALLSTAR systems supporting mmWave-band cellular access, satellite access, and multi connectivity combining the cellular and satellite access, and this deliverable reports the results of the study. More specifically, in addition to defining the overall system architecture and key functionalities, the detailed architecture and interfaces for MC support are investigated, and key components and enabling technologies for mmWave-band cellular access (vehicular communications), satellite access, and multi connectivity are also discussed. Furthermore, a preliminary design of European and Korean PoC testbeds and the interface for intercontinental interoperability between two systems with respect to the final demonstration at a big even (e.g., Roland Garros) are presented. WP2 plays a crucial role in providing a baseline to other tasks and WPs, and this deliverable will be a starting point for the study of spectrum sharing and multi connectivity as well as the PoCs of the project.

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9 Appendices

9.1 3GPP AT3SF / ATSSS architecture: 3GPP access only

The figure below depicts the AT3SF / ATSSS architecture according to 3GPP TR 23.793 [15], for 3GPP access only. Non-3GPP access is not depicted because it is out of 5G-ALLSTAR scope.

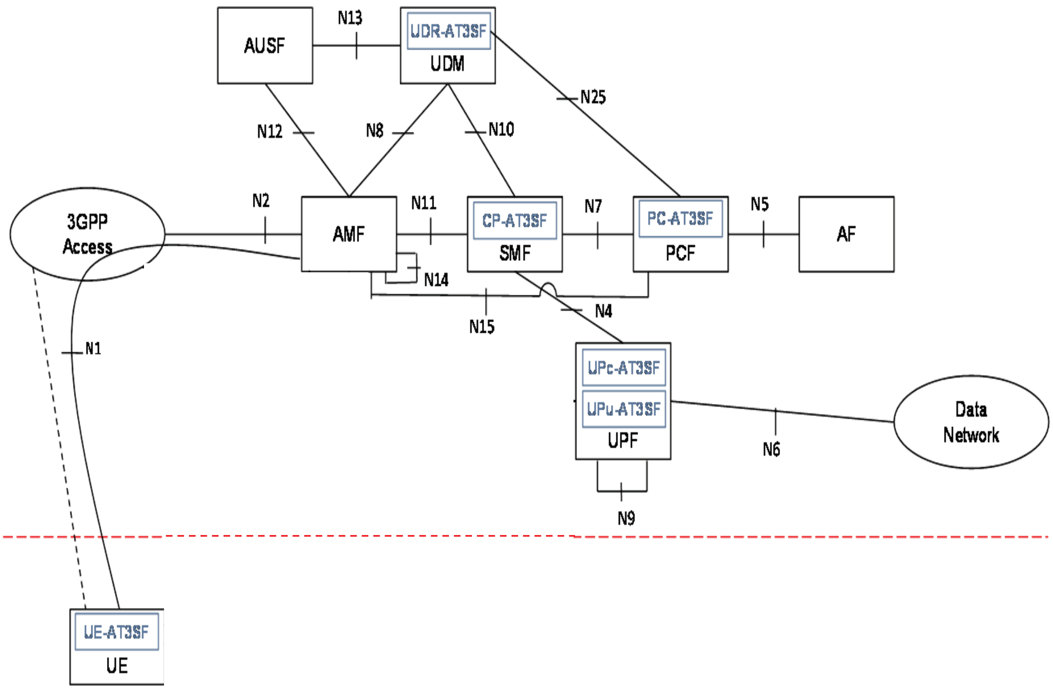

Figure 9-1: 3GPP AT3SF / ATSSS architecture (3GPP access only).

In [15], AT3SF (AT3SSS) are in UPF and thus, in the 5G CN.

AT3SF interfaces 5G RAN via N3 reference point through NG reference point.

In 5G-ALLSTAR, it is proposed to positioned ATS3F in the MA-gNB (RAN), closer to the link terminations (transmission / reception points).

9.2 3GPP R15 Definitions extension

The following 3GPP R15 definitions are applicable to / extended (see notes 1,2) for the need of the multi-access RAN (Multi Access gNB):

- Access Traffic Steering [15]: The procedure that selects an access network for a new data flow and transfers the traffic of this data flow over the selected access network (see 1). Access traffic steering is applicable between 3GPP and non-3GPP accesses.
- Access Traffic Switching [15]: The procedure that moves all traffic of an ongoing data flow from one access network (see 1) to another access network (see 1) in a way that maintains the continuity of the data flow. Access traffic switching is applicable between 3GPP and non-3GPP accesses.
- Access Traffic Splitting [15]: The procedure that splits the traffic of a data flow across multiple access networks (see 2). When traffic splitting is applied to a data flow, some traffic of the data flow is transferred via one access (see 1) and some other traffic of the

same data flow is transferred via another access (see 1). Access traffic splitting is applicable between 3GPP and non-3GPP accesses.

- Multi-Access PDU Session [15]: A PDU session whose traffic can be sent over 3GPP access, or over non-3GPP access, or over both accesses.

Note 1: by extension for 5G-ALLSTAR: “access link”

Note 2: by extension for 5G-ALLSTAR: “multiple access links”.