Ref. Ares(2022)8963754 - 23/12/2022

Twin Transition for The Timber Industry

Deliverable 1.8 Initial specification of functional and technical requirements of 5G NPN implementations for pilots and beyond

5G-TIMBER | Work Package 1, Task 1.5

Final Delivery Date: 21-12-2022

Stephen, Parker

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Grant Agreement No 101058505.

Document Information

Project Acronym & Full Title	5G-TIMBER Secure 5G-Enabled Twin Transition for Europe's Timber Industry Sector
Project Number	101058505
Type of Action	HORIZON Innovation Actions
Topic	HORIZON-CL4-2021-TWIN-TRANSITION-01-08
Project start date/duration	01 June 2022 / 36 months
Work Package/ Result	WP1 / D1.8 Initial specification of functional and technical requirements of 5G NPN implementations for pilots and beyond
Result Type/ Dissemination level	Report/ PU
Lead partner	Accelleran NV
Due date	M7
Responsible Author/Authors	Stephen Parker (Accelleran NV), Simon Pryor (Accelleran NV), Antonio Garcia (Accelleran NV), Kiran Chackravaram (Accelleran NV), Sidharth Udani (Accelleran NV), Daniele Munaretto (Athonet), Daniele Ronzani (Athonet), Nicola di Pietro (Athonet), Jens Engelmann (Thales DE), Thomas Ulrich, (Thales DE), Florian Denzin (Thales DE), Muhammad Mahtab Alam (TalTech), Yannick Le Moullec (TalTech), Alar Kuusik (TalTech)
Project URL	https://www.5g-timber.eu/

Review Process Detail

Date	Responsible	Action
19 October 2022	Jari Halme (VTT)	Quality Assurance and Risk Manager (QRM) sends a request for the deliverable-to-Deliverable Responsible Person (DRP). Request is also sent to the WP Leader and the Reviewers.
26 October 2022	Stephen Parker (ACC)	DRP initially freezes the Table of Contents (ToC) in agreement with the WP Leader.
2 November 2022	Stephen Parker (ACC)	DRP sends the draft for the named reviewers (2 or 3 persons: WP leader unless DRP & deliverable consumer(s)). Includes both Word version and PDF version. PDF version is needed to check e.g., broken cross-references, fonts, layout, etc. In addition, QRM to be informed.
7 December 2022	POLIMI (Marcello Urgo), Harmet (Mari Emmus) and TalTech (Mahtab Alam).	Reviewers send their reviews back to DRP for revision. QRM is also informed about the reviews.
14 December 2022	Stephen Parker (ACC)	DRP addresses the comments in one week
14 December 2022	POLIMI (Marcello Urgo), Harmet (Mari Emmus) and TalTech (Mahtab Alam).	Reviewers approves the deliverable and send it coordinator/technical manager. QRM is also informed
23 December	Jari Halme (VTT)	Quality review process done.

23 December 2022	Anet Tammets (TalTech)	Project Coordinator approves and saves the deliverable as the final version. Project Coordinator submits the deliverable to the European Commission.

History of changes

Version	Issue Date	% Complete	Changes	Contributor(s)
V0.1	12/10/2022	5	Initial Deliverable Structure and ToC	Stephen Parker (Accelleran NV), Simon Pryor (Accelleran NV), Antonio Garcia (Accelleran NV), Muhammad Mahtab Alam (Taltech)
V0.2	20/10/2022	40	Additional Content from Partners	Stephen Parker (Accelleran NV), Simon Pryor (Accelleran NV), Antonio Garcia (Accelleran NV), Yannick Le Moullec (TalTech), Daniele Munaretto (Athonet)
V0.3	24/10/2022	60	Additional Content	Stephen Parker (Accelleran NV), Simon Pryor (Accelleran NV), Antonio Garcia (Accelleran NV), Yannick Le Moullec (TalTech)
V0.4	28/10/2022	70	Additional Content and Cross References	Stephen Parker (Accelleran NV), Antonio Garcia (Accelleran NV)
V0.5	31/10/2022	80	Additional Content	Stephen Parker (Accelleran NV)

V0.6	21/11/2022	85	Updated Chapter 2	Yannick Le Moullec (TalTech)
v0.7	12/12/2022	90	Peer review	Marcello Urgo (POLIMI), Mari Emmus (Harmet), Yannick Le Moullec (TalTech), Muhammad Mahtab Alam (Taltech), Muhammad Mahtab Alam (Taltech), Priit Roosipuu (Taltech)
v0.8	15/12/2022	95	Updated version based on peer review comments	Stephen Parker (Accelleran NV), Yannick Le Moullec (TalTech)
v1.0	23/12/2022	100	Quality review	Jari Halme (VTT)

Table of Contents

List of Figures

List of Tables

Glossary of terms and abbreviations

Abbreviation / Term	Description
3GPP	The 3rd Generation Partnership Project
5G	5th Generation
5G-ACIA	The 5G Alliance for Connected Industries and Automation
5GC	5G Core Network
5GS	5G System
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
B2B	Business to Business
B2C	Business to Consumer
COTS	Commercial off-the-shelf
CU	Central Unit
CUS	Control User Synchronization
DL-AoD	Downlink Angle of Departure
DL-TDOA	Downlink Time Difference Of Arrival
DN	Data Network
DU	Distributed Unit
EAS	Edge Application Server
EU	European Union
FCAPS	Fault, Configuration, Accounting, Performance, Security,
FDD	Frequency Division Duplex
FH	Fronthaul
FHI	Fronthaul Interface
gNB	Next Generation NodeB

GNSS	Global Navigation Satellite System
GSA	Global Mobile Suppliers Association
IoT	Internet of Things
IP	Ingress Protection
LTE-M	Long-Term Evolution Machine Type Communications
LPWA	Low Power Wide Area
MANO	Management And Network Orchestration
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MOCN	Multi-Operator Core Network
MORAN	Multi-Operator RAN
NB-IoT	Narrowband IoT
NF	Network Function
NodeB	Radio Base Station
NG-RAN	Next Generation RAN
NPN	Non-Public Network
NR	New Radio
NRF	Network Repository Function
NSA	Non-Standalone
NSSF	Network Slice Selection Function
NSSMF	Network Slice Subnet Management Function
OAM	Operations, Administration and Maintenance
O-RAN	Open Radio Access Network
PCF	Policy Control Function
PLMN	Public Land Mobile Network
PNI-NPN	Public Network Integrated NPN

PSU	Power Supply Unit
PTP	Precision Time Protocol (IEEE-1588)
RAN	Radio Access Network
rAPP	RIC software application for non real-time network automation
RAT	Radio Access Technology
RIC	RAN Intelligent Controller
RF	Radio Frequency
RTT	Round Trip Time
SA	Standalone
SDL	Supplementary Downlink
SMF	Session Management Function
SMO	Service Management and Orchestration
SNPN	Stand-alone Non-Public Network
SUL	Supplementary Uplink
TDD	Time Division Duplex
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UL-AoA	Uplink Angle of Arrival
UL-TDOA	Uplink Time Difference of Arrival
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
vCU	Virtual Central Unit
vDU	Virtual Distributed Unit
VNF	Virtual Network Function
xAPP	RIC software application for near real-time network automation

1. Executive Summary

This document is the deliverable D1.8 "Initial specification of functional and technical requirements of 5G NPN (Non-Public Networks) implementations for pilots and beyond" of the Horizon Europe Innovation Action project "5G-TIMBER: Secure 5G-Enabled Twin Transition for Europe's TIMBER Industry Sector" (hereinafter also referred to as "5G-TIMBER", project reference: 101058505).

This deliverable presents the status of the work that has been carried out primarily in the task "T1.5 Functional specifications and long-term strategies for full scale deployment of 5G NPN infrastructures in manufacturing and material tracking" that runs from M2 to M24.

The purpose of D1.8 is to detail the functional and technical requirements of a 5G Non-Public Network (NPN) that can address the Use Cases and KPIs defined in D1.1 (Initial Descriptions of Use Cases with Expected Outcomes and Impact Projections to 3 Target Domains) and D1.3 (Initial KPIs Definition Report), respectively. Chapter 10 of this Deliverable describes the initial SNPN deployment in Estonia.

A second version of this deliverable (D1.9) is scheduled for delivery in M24 of the project. This version of the deliverable reflects the status, recommendations and technical possibilities as of M7 (December 2022) of the project. It primarily focuses on an Standalone NPN network that can be deployed initially using equipment that is available to the project partners today. As such, the "beyond" aspect of the title of this deliverable is not yet significantly addressed. The D1.9 version of this deliverable will look beyond the initial imperatives of the project pilot trials to address more general requirements of deploying NPNs in industrial environments.

As this is the initial version of the deliverable, some background is provided and fundamental 5G concepts are introduced. An introduction to NPNs is provided and high level descriptions of the major components of a 5G NPN network and some key network interfaces are also presented.

Spectrum availability also has consequences on NPN deployment possibilities. The currently fragmented nature of spectrum allocated for NPN use in the EU is also covered in this deliverable.

The deliverable finishes with “Conclusions” chapter and an appendix detailing the equipment that will initially be deployed at the pilot sites.

2. Introduction

2.1. Mapping 5G-TIMBER Outputs

This section maps the components described in the 5G-TIMBER's Description of Action (DoA)/Grant Agreement (GA), i.e., the description of the deliverable and task description in the DoA/GA, against the chapters included in this deliverable and the justification of the work conducted in the project. See Table 1.

5G-TIMBER GA Element	5G-TIMBER GA Element Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D1.8	INITIAL SPECIFICATION OF FUNCTIONAL AND TECHNICAL REQUIREMENTS OF 5G NPN IMPLEMENTATIONS FOR PILOTS AND BEYOND	CHAPTERS 3,4,5,6,7,8,9,10,11	THESE CHAPTERS GIVE AN OVERVIEW OF NPN NETWORKS, THE KEY NETWORK ELEMENTS AND INTERFACES OF OPEN-RAN NPN NETWORKS AND A RECOMMENDATION FOR NPN DEPLOYMENTS TO COVER THE USE CASES DEFINED IN D1.1
TASKS			

T1.5 FUNCTIONAL SPECIFICATIONS AND LONG-TERM STRATEGIES FOR FULL SCALE DEPLOYMENT OF 5G NPN INFRASTRUCTURES IN MANUFACTURING AND MATERIAL TRACKING	GROUNDING ON THE INITIAL REQUIREMENTS (T1.1, T1.2) AND THE DESIGN OF THE CASE PILOTS (WP2, WP3), REQUIREMENTS, SPECIFICATIONS FUNCTIONAL NEEDS AND INDUSTRY ACCEPTANCE CRITERIA (COST, SLA, MAINTENANCE COMPLEXITY) WILL BE BROADENED AIMING AT A LONG-TERM AND LARGER-SCALE ADOPTION OF 5G NPN NETWORKS IN MANUFACTURING. THE SPECIFICATIONS WILL ADDRESS PRINCIPAL ARCHITECTURAL SOLUTIONS AS WELL AS HARDWARE EQUIPMENT AND SOFTWARE DESIGN CRITERIA.	CHAPTERS 3, 4	THESE CHAPTERS GIVE AN OVERVIEW OF NPN NETWORKS
		CHAPTERS 5,6	THESE CHAPTERS PRESENT THE KEY NETWORK ELEMENTS AND INTERFACES OF OPEN-RAN NPN NETWORKS AND AN OVERVIEW OF FREQUENCIES ALLOCATED FOR NPNS IN THE EU

		CHAPTERS 7,8,9,10,11, 12, 13	THESE CHAPTERS PRESENT THE 5G CORE NETWORK AND UE ECOSYSTEM AND PROVIDE A RECOMMENDATION FOR NPN DEPLOYMENTS TO COVER THE 5G-TIMBER USE CASES DEFINED IN D1.1, CONCLUDE THE DELIVERABLE, AND PROVIDE SAMPLE NPN EQUIPMENT LIST INFORMATION IN AN APPENDIX.

Table 1. Adherence to 5G-TIMBER's GA Deliverable & Tasks Descriptions

2.2. Deliverable Overview and Report Structure

As this is the first project deliverable that deals with 5G Non-Public Networks (NPNs) and as not all project partners come from a Telecoms background, some fundamental 5G network concepts are introduced here.

The 5G-TIMBER pilots will use a Standalone NPN that is also Open Radio Access Network (O-RAN) compliant. This is a network that is further disaggregated beyond what is defined by the 3rd Generation Partnership Project (3GPP) standards. An overview of the O-RAN 5G network architecture is also presented.

The title of this deliverable mentions 5G-TIMBER "pilots and beyond". With this in mind, issues and concepts are introduced that might not be particularly relevant for the 5G-TIMBER pilots but could very pertinent for wider NPN network deployments e.g., spectrum issues are discussed and although a Standalone NPN (SNPN) will be used for the

5G-TIMBER pilots, an overview of Public Network Integrated NPNs (PNI-NPN) is also provided.

Chapter 3 introduces the concept of NPNs and provides an overview of the different deployment options that are possible with NPN networks.
Chapter 4 explains how the O-RAN Alliance specifications build upon and extend the 3PGG 5G standards.
Chapter 5 summarises some key 3GPP and O-RAN Alliance specified network interfaces.
Chapter 6 outlines the current state of spectrum allocation for NPN networks in the EU.
Chapter 7 gives an overview of the functionality of the 5G Core Network
Chapter 8 outlines the general UE ecosystem and provides details of the UE that is currently available for use in 5G-TIMBER trials.
Chapter 9 details some considerations for an NPN deployment that is suitable for the 5G-TIMBER pilot trials.
Chapter 10 summarises the specific NPN deployment strategy for the 5G-TIMBER trials.
Chapter 11 draws conclusions.
Chapter 12 Lists the References used in this document
Chapter 13 Gives a sample list of the equipment that will be used in the pilots in Estonia.

2.3. Other project outputs

This section describes the interdependencies with the other project tasks and activities.

1. Interdependencies between the task of this deliverable and the other WPs:
    - WP2 will take into account the details of the *initial* specification of functional and technical requirements of 5G NPN implementations for pilots defined in T1.5/D1.8 when executing the federation, integration and orchestration of the technological developments at the core of WP2. Moreover, the experience and lessons learned during WP2 (mainly via the cycles of lab trials) will feedback to WP1 to elaborate the *final initial* specification of functional and technical requirements of 5G NPN implementations for pilots and beyond in T1.5/D1.9.

- WP3: The *initial* specification of functional and technical requirements of 5G NPN implementations for pilots defined in T1.5/D1.8, together with the technologies developed in WP2, will be taken into account for carrying out the system level and operational readiness for UC pilots' activities. Moreover, the experience and lessons learned during WP3 (mainly via the cycles of lab trials) will feedback to WP1 to elaborate the *final* specification of functional and technical requirements of 5G NPN implementations for pilots and beyond in T1.5/D1.9.

- In WP4, the deployment of 5G-TIMBER applications into demonstration sites will consist of the cycles of field trials during which the *initial* specification of functional and technical requirements of 5G NPN will be assessed (by means of the KPIs defined in T1.2); the experience and lessons learned during these field trials will feedback to WP1 to **freeze** the *final* specification of functional and technical requirements of 5G NPN implementations for pilots and beyond in T1.5/D1.9.

- WP5: The commercialisation, innovation management and standardisation initiatives that will be carried out in WP5 will focus on the relevant service and business KPIs of the project, for which the 5G NPN plays a central enabling role. Moreover, the experience gained in WP5 will also feedback to WP1 to elaborate the final specification of functional and technical requirements of 5G NPN implementations for pilots and beyond in T1.5/D1.9.

2. Interdependencies between the task(s) of this deliverable and the other -same- WP Tasks
    1. The *initial* UCs and general requirements defined in T1.1, and the specific requirements and KPIs defined in T1.2 frame the scope of the project and thus provide the basis for defining the *initial* specification of functional and technical requirements of 5G NPN implementations for pilots in T1.5.

    2. T1.3 elaborates the *initial* version of the architecture for data sharing and exchange of feedbacked material processing chain and related UCs; the architecture devised in T1.3 and the recommendation for NPN deployments proposed in T1.5 must be aligned in terms of functionalities, compatibility, and performance.

- Finally, the network elements identified in T1.5 have to be reflected in T1.4 as central elements of the software and hardware inventory list for analysing data interoperability and integration in the diverse UCs.

Table 2 provides a list of the other deliverables that produce inputs to this deliverable or consume outputs from this deliverable.

Table 2. *List of the other deliverables that produce inputs to this deliverable or consume outputs from this deliverable.*

5G-TIMBER GA Element	Contribution and Value of linkage
Input from D1.1 (Initial descriptions of use cases with expected outcomes and impact projections to 3 target domains) for D1.8	The initial structured description of the 3 UC categories and the underlying 9 UCs was provided in D1.1. This includes the general requirements for implementing the UCs and the field trials. D1.8 has taken into account the relevant UC descriptions and general requirements as a starting point for defining the functional specifications of the 5G NPN and the recommended NPN deployment strategy.
Input from D1.3 (initial KPIs definition report) for D1.8	The initial definitions of the 5G-TIMBER UCs' requirements and KPIs have been documented in D1.3. This includes networking related requirements and KPIs. D1.8 has taken into account the relevant details of these requirements and KPIs when defining the functional specifications of the 5G NPN and the recommended NPN deployment strategy.
Input from D1.5 (Initial 5G-TIMBER data flow architecture for the circular material and production process management) for D1.8	The initial 5G-TIMBER flow architecture for the circular material and production process management are documented in D1.3, including the principles for data exchange, with respect to different flows (material, digital twin assisted production, and production monitoring). D1.8 has taken into account the relevant details of this flow architecture when defining the functional specifications of the 5G NPN and the recommended NPN deployment strategy.
Input from D1.7 (Hardware/software/standard inventory list and blueprint for data sharing) for D1.8	D1.7 documents the hardware/software/standard inventory list and blueprint for data sharing; it is a tool for mapping these technologies and assisting the creation of the open standards based digital twin. D1.8 has taken into account the relevant details of this inventory list when defining

	functional specifications of the 5G NPN and the recommended NPN deployment strategy.
Input from D7.1, D7.4, and D7.7 for D1.8	As all other deliverables, D1.8 strives to follow the guidelines, recommendations, and rules documented in the Project Coordination, Technical & Innovation Management (D7.1), Implementation of quality assurance procedures (D7.4), and Data Management, Ethics and Ethical Compliance (D7.7).
Output from D1.8 for D2.5	D2.5 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the 5G NPN network monitoring, close-loop automation for optimization of industrial manufacturing.
Output from D1.8 for D2.7	D2.7 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the AI-driven edge computing and precise indoor localization.
Output from D1.8 for D2.9 and D2.11	D2.9 and D2.11 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the security by design and AI-driven digital forensics in manufacturing.
Output from D1.8 for D2.13	D2.13 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the use of IoT live data for predictive machine maintenance and structural health monitoring.
Output from D1.8 for D3.1	D3.1 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the

	development of cross-enterprise data exchange software framework implementation.
Output from D1.8 for D3.3	D3.3 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the design, development and configuration of 5G NPN network infrastructure for the use-cases.
Output from D1.8 for D3.5	D3.5 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the augmented reality supported manufacturing and machine servicing system setup.
Output from D1.8 for D3.7	D3.7 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of the use-cases for sawmill machinery.
Output from D1.8 for D3.9	D3.9 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of use-cases for wood-based modules manufacturing.
Output from D1.8 for D3.11	D3.11 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the development of use-cases for construction, renovation and **possibly** waste valorisation (desk UC).
Output from D1.8 for D4.1	D4.1 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 required for the

	development of the infrastructure and IT preparation on pilot sites.
Output from D1.8 for D4.3	D4.3 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 when conducting the field trials for sawmill machinery production and operations use-cases.
Output from D1.8 for D4.5	D4.5 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 when conducting the field trials for wooden houses use-cases.
Output from D1.8 for D5.1	Where applicable, D5.1 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 for conducting the EU Landscape market sector assessment, impact and sustainability study.
Output from D1.8 for D5.2	D5.2 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 for conducting the business models development, commercialisation/business plan and commercial acceleration/sustainability.
Output from D1.8 for D5.4	D5.1 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 for creating the commercial ecosystem cluster to accelerate commercial revenues and growth.
Output from D1.8 for D5.7	Where applicable, D5.1 will consider the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 when preparing the standardisation recommendations.

Output from D1.8 for D6.1 and D6.2	D6.1 and D6.2 will take into account the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 when conducting the dissemination and communication activities, **especially how the 5G NPN technology help SMEs achieving and demonstrating the overall project targets (PTs).**
Output from D1.8 for D7.10	D7.10 (technical report for the first project review) will include a summary of the relevant details of the initial functional specifications of the 5G NPN and the recommended NPN deployment strategy defined in D1.8 and how these are reflected in the other deliverables and tasks that will be covered in that technical report.

3. Non-Public Networks

3.1. An Introduction to NPNs

The term Non-Public Network (NPN) is used to identify a Network deployment that is not intended to provide services to the general public. NPNs are also sometimes called private industrial networks. These terms are typically used in the context of 5G Networks, but the concept is also applicable to previous generation networks. In this document only 5G networks are considered.

NPNs are typically envisioned to be deployed by organisations, either at a single location or spread across multiple sites e.g., at a manufacturing plant or at campus facilities.

3GPP has identified [1] two distinct NPN deployment types:

1. A Stand-alone Non-Public Network (SNPN): operated by an NPN operator and not relying on network functions provided by a PLMN
2. A Public Network Integrated NPN (PNI-NPN): a non-public network deployed with the support of a PLMN.

Multiple factors need to be considered when deciding which of these types of deployment is most suitable i.e., there is no single solution for deploying NPN networks.

Factors that can influence the NPN deployment type can include:

- Spectrum availability,
- Equipment availability,
- Use Case requirements,
- Deployment and operation costs,
- Privacy requirements,
- Regulatory requirements.

3.2. 3GPP 5G Standalone (SA) Network Architecture

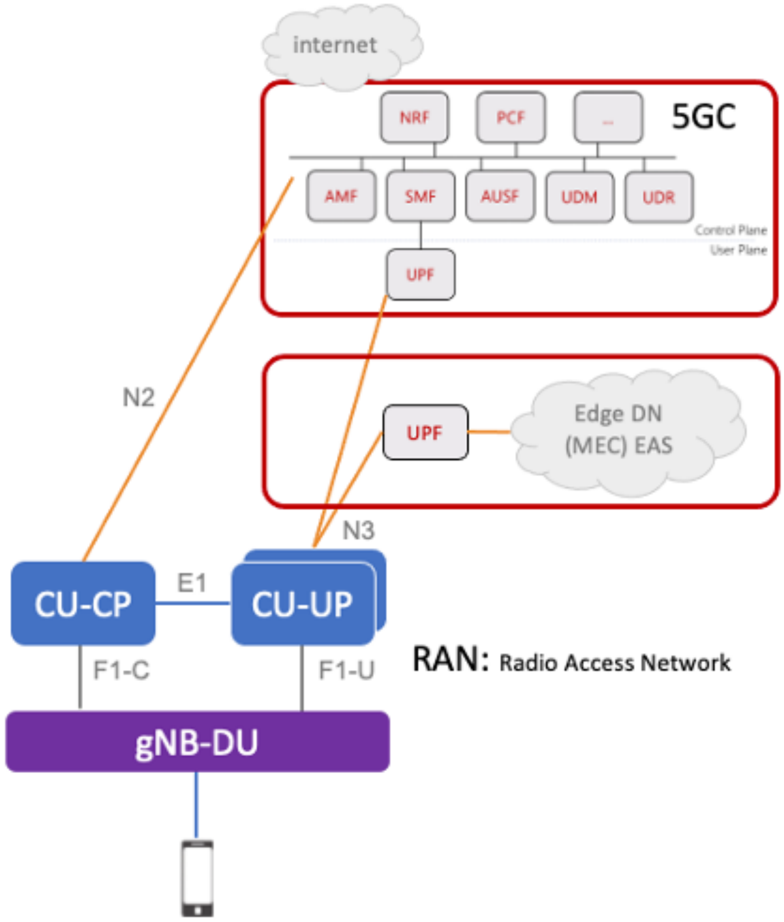

Figure 1 *3GPP 5G Network - Logical Architecture*

Figure 1 shows some of the key network components of a 5G Network. An overview of the 5G Core Network is provided in chapter 7. The Radio Access Network (RAN) Central Unit (CU) and Distributed Unit (DU) components are described in Chapter 4 and the 3GPP interfaces are described in section 5.1. As shown here, the CU can be further disaggregated into the Central Unit Control Plane (CU-CP) and Central Unit User Plane (CU-UP).

3.3. The Open-RAN Network Logical Architecture

One objective of the O-RAN Alliance [2] is to further disaggregate the 3GPP defined RAN with additional standard interoperable interfaces with a view to promoting 'open' multi-vendor solutions, stimulating competition and innovation, increasing supplier diversity, reducing cost and bringing intelligence to the RAN (the RIC or RAN Intelligent Controller). The RIC is further described in Section 4.1.

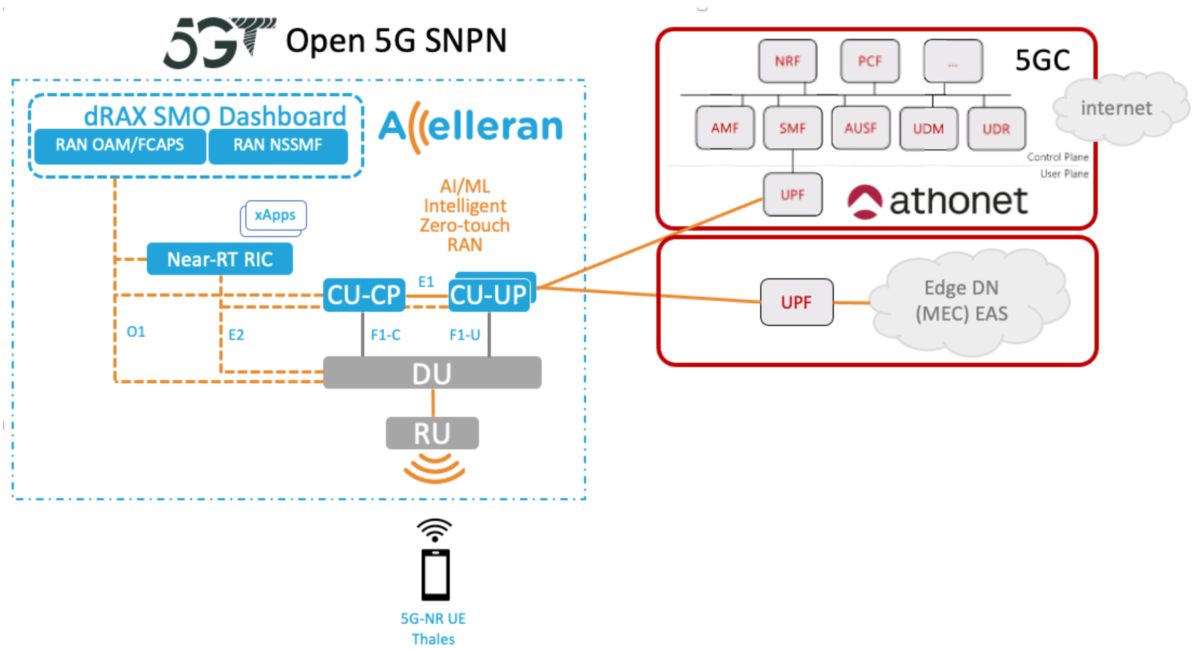

***Figure 2** O-RAN 5G Network for 5G-TIMBER - Logical Architecture*

Figure 2 is similar to the 3GPP architecture shown Figure 1, except that as a result of O-RAN standardisation, some new components and interfaces are introduced in the RAN with the 3GPP gNB-DU being split into Distributed Unit (DU) and Radio Unit (RU) network functions. The RAN Intelligent Controller is described in section 4.1 and the new O-RAN interfaces are covered in section 5.2.

3.4. O-RAN NPN Deployment Considerations

The stated aim of the 5G-TIMBER project is to deploy an O-RAN based NPN.

Taking into account the two deployment types, mentioned in section 3.1, (SNPN and NPI-NPN) and the additional disaggregated interfaces defined the O-RAN Alliance, we can further examine possible O-RAN NPN deployment scenarios that are potentially suitable for consideration in the 5G-TIMBER project. These are described in the following sections.

3.5. An O-RAN Compliant Standalone NPN (SNPN)

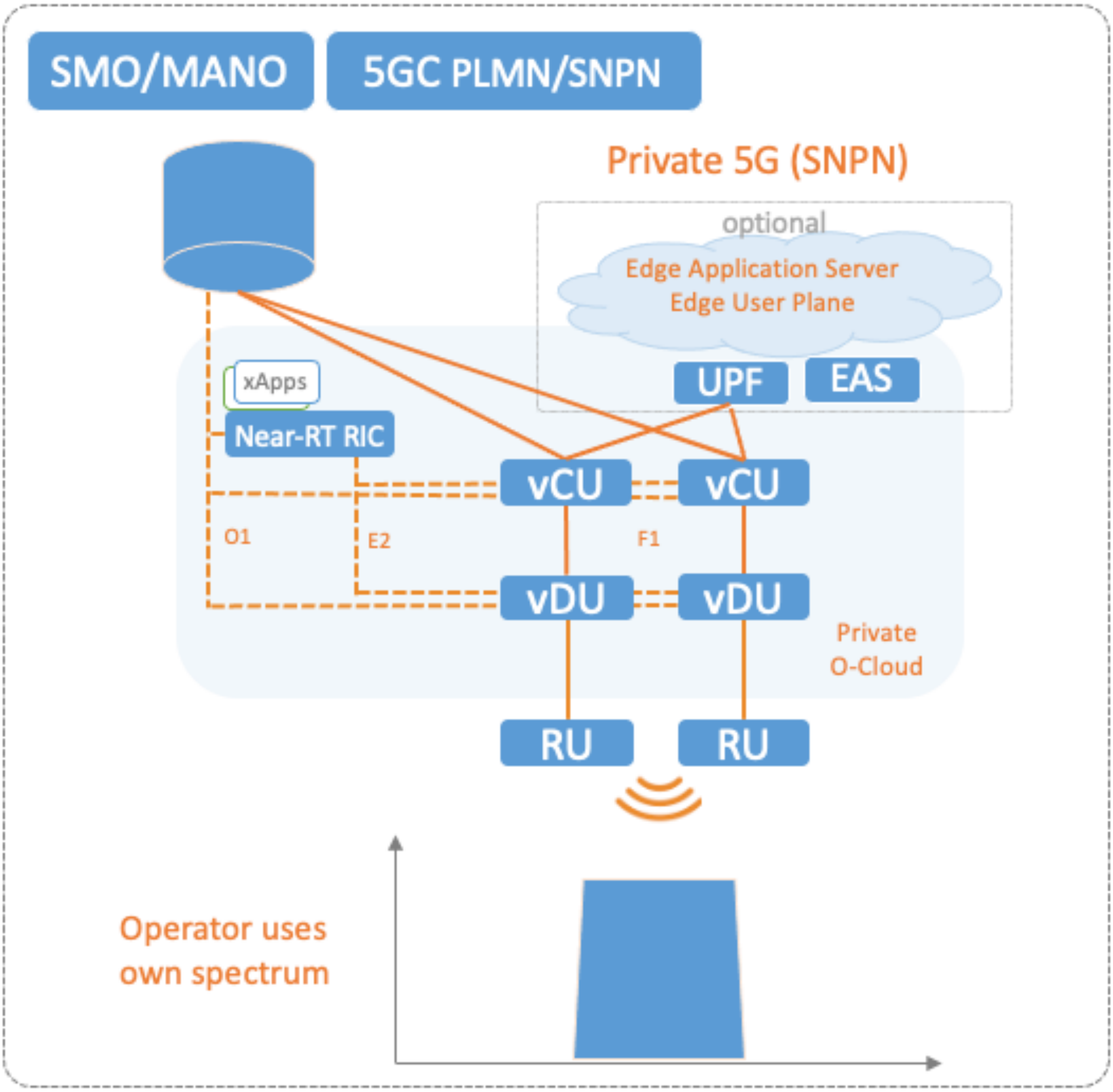

Figure 3 *An O-RAN Compliant Standalone NPN*

Figure 3 shows the logical deployment of an O-RAN compliant Standalone NPN (SNPN). This deployment type assumes that there is no dependency on an MNO and that there is spectrum available to use for an NPN deployment i.e., either "own" spectrum is available via a regulator or spectrum that is leased from and can be used independently of, an MNO, can be made available. **Figure 3** shows all available spectrum (blue colour) being allocated to the SNPN.

In such an SNPN deployment, there are several possibilities that need to be considered when determining the layout of the physical infrastructure that hosts the SNPN deployment. For example, to simplify the operation and maintenance of the network it might be useful to host the majority of the 5G core components and some of the RAN components (e.g., CU-CP) in an off-premises cloud (not shown). On the other hand, any Use Cases that require low latency or higher data throughput would suggest that, at a minimum, all the RAN components and the UPF functionality of the 5G Core are hosted locally on premises. Furthermore, to comply with security or operational policies of individual SNPN operators, restrictions on locations of physical infrastructure may apply (some Industrial factories require fully on-premises solutions and will not permit any data ingress/egress from the factory).

Advantages of an SNPN deployment:

- Low Latency. The UPF is located on premises, so latency is minimised as user data does not need to traverse onto an external public network and is not dependent on the existence or quality of a backhaul link from the business premises. As detailed in D1.1, Low Latency is an important factor in several 5G-TIMBER use cases
- Privacy and Security. All subscriber information and all data generated on the network can be managed and stored on premises.
- Resilience from external outages. As all network equipment is controlled and operated locally, it can be better protected from external factors e.g. public network or external power outages

Disadvantages of an SNPN deployment:

- Deployment and operating costs. All network equipment will need to be sourced, deployed and operated by the NPN operator (with possible sub-contracting of some aspects like System Integration or installation). 5G Networks can be complex to configure and deploy and deployment and operational issues can be difficult to understand and resolve. In this type of deployment all such issues are the responsibility of the NPN operator
- Potential Equipment issues. As discussed in chapter 4, different frequency bands have been allocated for deploying NPN networks in different parts of Europe and not all frequency bands are available in all locations. The ability to deploy a NPN in a specific location is

contingent on finding RAN equipment (UEs, gNBs) that can operate in the allocated band. Longer term this will be less of an issue but earlier 5G radio equipment tends to be focused on frequencies that have been allocated to public network operators.

It should be noted that while it might be technically possible to deploy an SNPN using MNO provided equipment along with spectrum leased from the MNO, such an NPN deployment would almost certainly not be O-RAN compliant, and it would therefore preclude the use of a RIC component. For this reason, an MNO provided SNPN is not further considered.

An SNPN deployment, as shown in this section, is the type of deployment that will be used for the 5G-TIMBER category 1 and category 2 (D1.1) trials.

3.6. An MOCN based O-RAN Compliant PNI-NPN

An example of the second deployment type, mentioned in section 3.1 (PNI-NPN), is shown in **Figure 4**. A PNI-NPN network is essentially a network where some of the available network bandwidth ("a RAN slice") of a Public Network's resources are set aside for private use. **Figure 4** shows the available spectrum is divided (sliced) up between the green and blue networks.

This approach uses a network sharing technique called a Multi-Operator Core Network (MOCN). The concept here is that the RAN part of the network is shared by the MNO and the NPN Operator. The MNO and NPN Operator both have their own independent 5GCs.

One advantage of this solution is that the UE SIMs can be programmed with both the preferred PNI-NPN (which is used when 'onsite') and the MNO PLMN, for continued connectivity via the public network when travelling outside the coverage area of the PNI-NPN, albeit at lower speeds and SLAs. This is valuable for 'asset tracking' applications such as raw materials shipped to factories and distribution of finished products, etc.

For this type of deployment to work in a 5G-TIMBER context one of two things has to happen:

1. The MNO deploys the RAN equipment and the MNO RAN is O-RAN compliant or

2. The 5G-TIMBER project partners deploy the RAN equipment, and the MNO agrees to connect the 5G-TIMBER to their 5GC

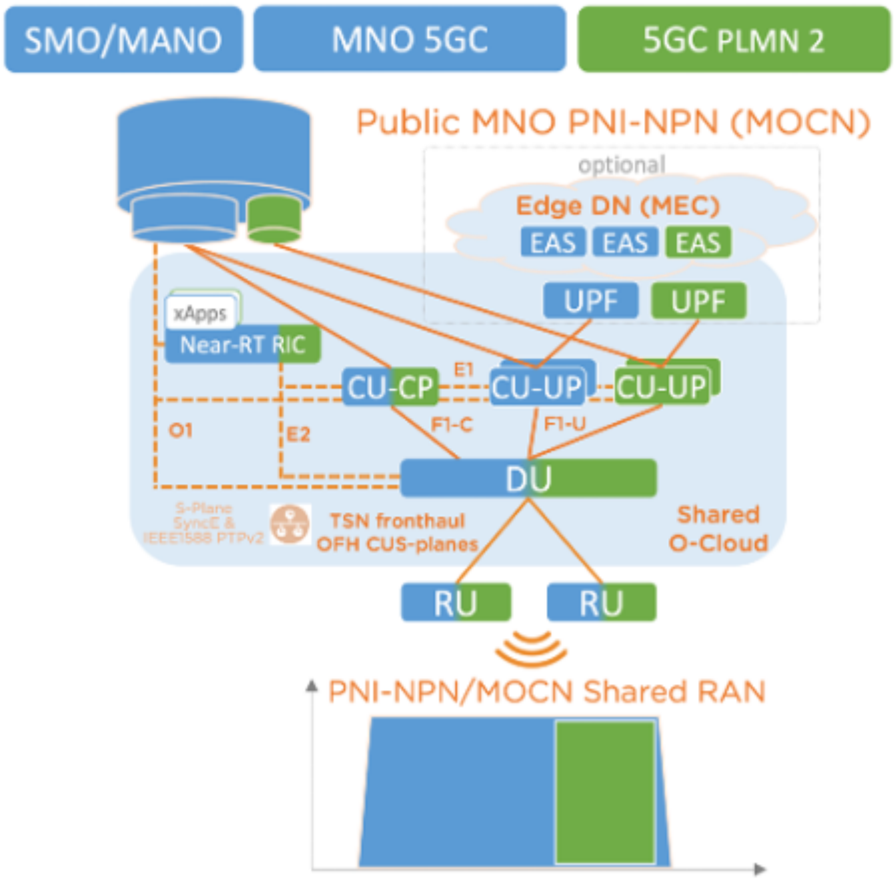

Figure 4 *A MOCN based O-RAN Compliant PNI-NPN*

As it stands today, the first deployment option (an O-RAN compliant MNO RAN) is unlikely to be possible as currently very few MNOs are even trialling O-RAN deployments.

The second option (MNO agrees to connect 5G-TIMBER RAN to their 5GC) is probably the more technically feasible option but unfortunately it is also, in practice, unlikely to happen. Very few MNOs will be willing to allow equipment that has not been verified or certified by them, to connect to a key part of their network infrastructure (their 5GC).

3.7. A MOCN based Neutral Host O-RAN Compliant PNI-NPN

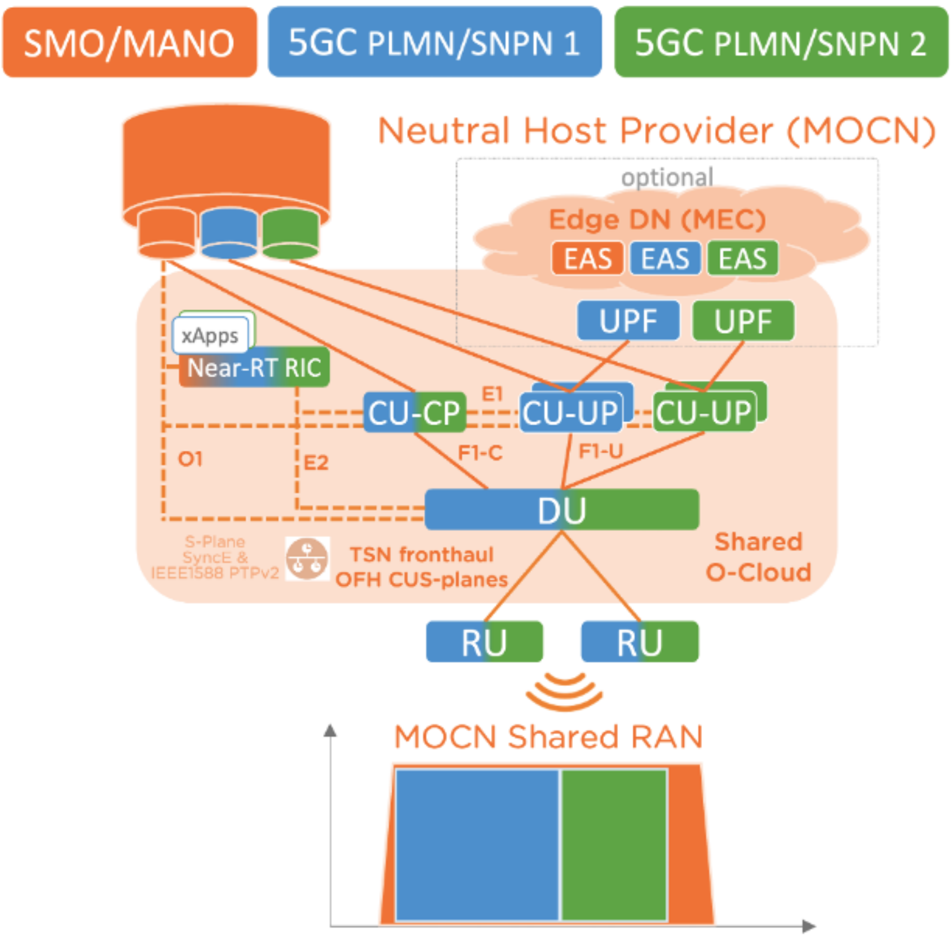

Figure 5 A MOCN based Neutral Host O-RAN Compliant PNI-NPN

A Neutral Host is an entity that invests in telecommunications infrastructure and then leases that equipment to 3rd parties. A Neutral Host would typically be a private company or a government entity or municipality that wishes to generate additional income from existing "street furniture" (Electricity poles, traffic lights, bus stops and shelters, …).

As many Public MNOs have sold off their infrastructure assets (transmission towers and fibre infrastructures), the growing number of Tower Companies (TowerCos) are also interested in becoming neutral host providers, sharing RAN infrastructure between multiple public and private network tenants.

The deployment in **Figure 5**, is similar to that shown in **Figure 4** except that the network infrastructure is owned by a Neutral Host and leased to an MNO and a NPN Operator. In this case the available spectrum is divided up into two separate networks (blue and green slices)

Due to the added complexity and probable lack of Neutral Host O-RAN support, this deployment type is not seen as a viable solution in 5G-TIMBER and is only shown here for completeness.

3.8. A MORAN-based Neutral Host O-RAN Compliant PNI-NPN

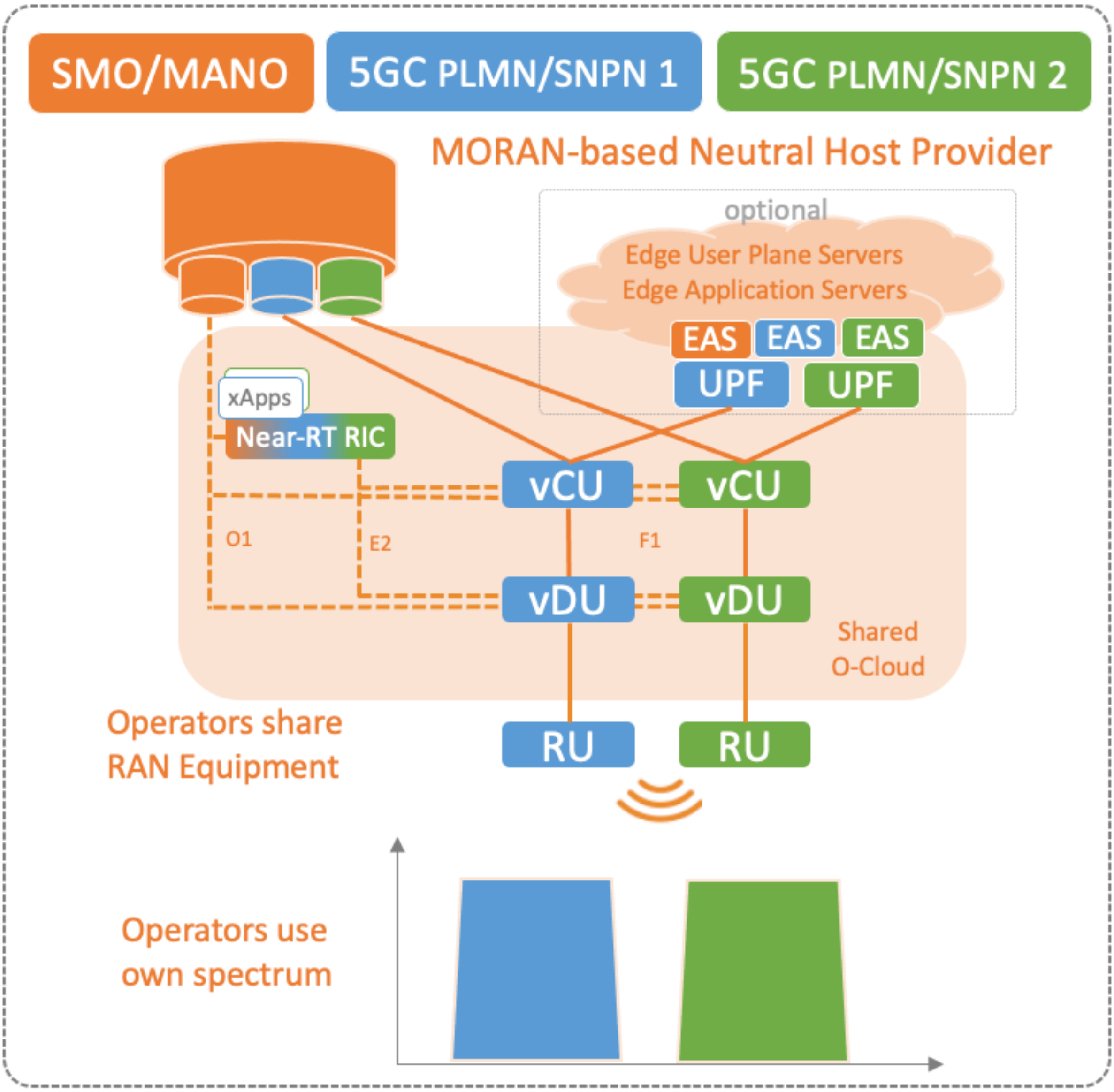

Figure 6 *A MORAN-based Neutral Host O-RAN Compliant PNI-NPN*

As in **Figure 5**, **Figure 6** shows a shared Neutral Host deployment. The difference is that this deployment is based on MORAN. MORAN is another approach to RAN sharing but in this case the RAN hardware is shared but each operator provides their own spectrum. In this case the blue and green spectrum are separately owned.

Again, given the added complexity and the probable lack of Neutral Host O-RAN support, this deployment type is not deemed to be viable in a 5G-TIMBER context and is shown here for completeness.

3.9. Zero-Touch and NPN Networks

5G networks are fundamentally different to the cellular networks that preceded them. Whereas earlier network generations were designed to provide mobile connectivity to people (initially voice, then latterly data), the ultimate goal of 5G is to provide "connectivity everywhere" i.e., the ability to connect any device that might benefit from being connected.

5G networks have significant additional complexities when compared to previous cellular generations. 5G is access agnostic and has disaggregated Radio Access Network (RAN); fronthaul and/or midhaul are introduced; The 5GC has new elements; Control and User planes are separated; and edge computing is introduced. O-RAN specifications build on this complexity as the RAN if further disaggregated and also has new elements.

On top of all this additional complexity, the advent of NPN networks will see deployments outside of the usual MNO space i.e., where there is unlikely to be much domain expertise.

To tackle all of this complexity, several standardisation bodies and working groups are active in trying to bring network automation to the 5G sphere. This paper from Cisco [3] provides a comprehensive overview of the issues, actors and standards involved in 5G network automation. These network automation principles, models and architectures are often referred to collectively as "Zero-Touch".

ETSI ZSM [4] focuses on the definition of an end-to-end architecture and solutions for "Zero Touch network and Service Management". As they state:

The pivotal deployment of 5G and network slicing has triggered the need for a radical change in the way networks and services are managed and orchestrated. In particular there is a need to handle:

- the increase in the overall complexity resulting from the transformation of networks into programmable, software-driven, service-based and holistically managed architectures, and
- the unprecedented operational agility required to support new business opportunities enabled by technology breakthroughs, such as Network Slicing.

The high-level architecture defined by ETSI ZSM is shown in **Figure 7** and how it applies to the RAN management domain and the RAN Intelligent Controller (RIC) is shown in **Figure 8**. In terms of ZSM in the 5G-TIMBER project the focus will be on the development of RIC based xApps/rApps.

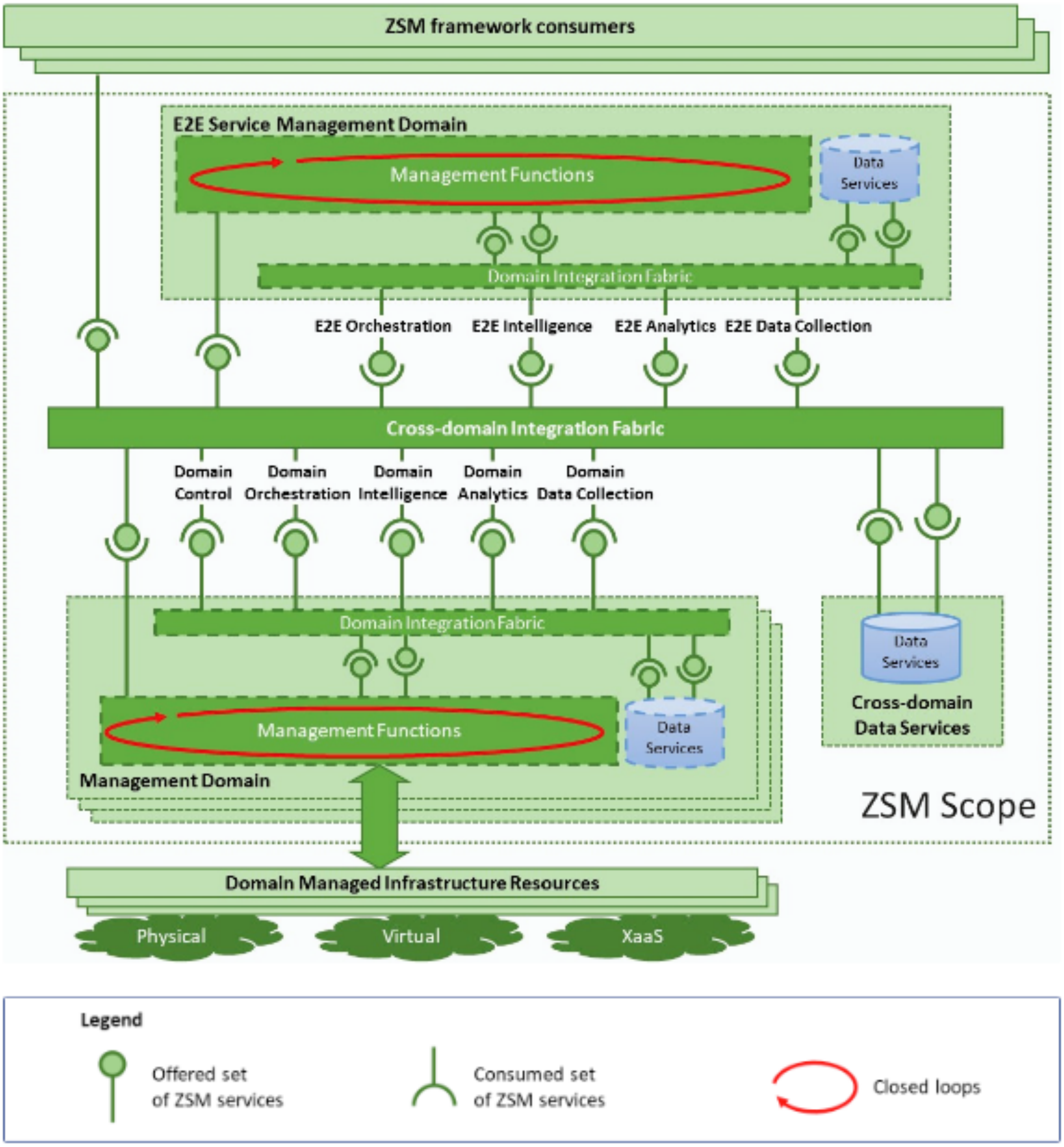

Figure 7 *ETSI ZSM High Level Architecture*

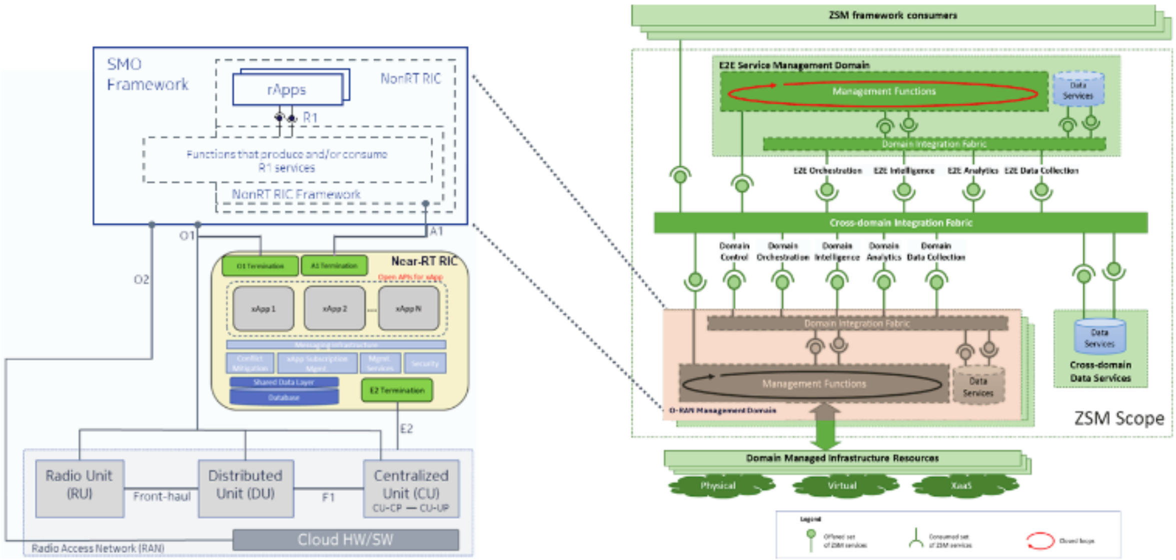

Figure 8 *ETZI ZSM Radio Access Network Management Domain*

4. An ORAN based NPN

As mentioned in sections 3.2 and 3.3, the 3GPP 5G NR specifications allows for splitting the gNB functionality into three logical components:

1. The Radio Unit (RU), provisioned with RF circuitry.
2. The Distributed Unit (gNB-DU or DU), hosting gNB real-time functions.
3. The Centralised Unit (gNB-CU or CU), hosting gNB non-real-time functions.

This 3GPP split has been further extended by the O-RAN Alliance. This chapter gives a high-level overview of the functionality of these network components.

4.1. Overview of the RAN Intelligent Controller

The O-RAN architecture introduces a new software-based network element called the RAN Intelligent Controller (RIC). The RIC is designed to monitor, control and optimise the RAN Network operation. It is involved in controlling and optimising aspects such as Radio Resource Management, Power Management, Interference Management and Mobility Management. The RIC provides a set of APIs to developers to enable them to build RAN intelligence in the form of applications called xApps or rApps.

The RIC consists of two components

1. The non-real-time RAN Intelligent Controller (non-RT RIC)
2. The near-real-time RAN Intelligent Controller (near-RT RIC)

The non-RT RIC manages events and resources with a response time of one second or more. rApps is the term for applications that are developed to control and manage the non-RT RIC.
The near-RT RIC manages and events and resources requiring a faster response down to 10 milliseconds (ms). xApps is the term for applications that are developed to control and manage the near-RT RIC.

Due to the required response times, the near-RT RIC would typically be deployed on the network edge. As it has less stringent response times, the non-RT RIC can either be deployed centrally or on the network edge.

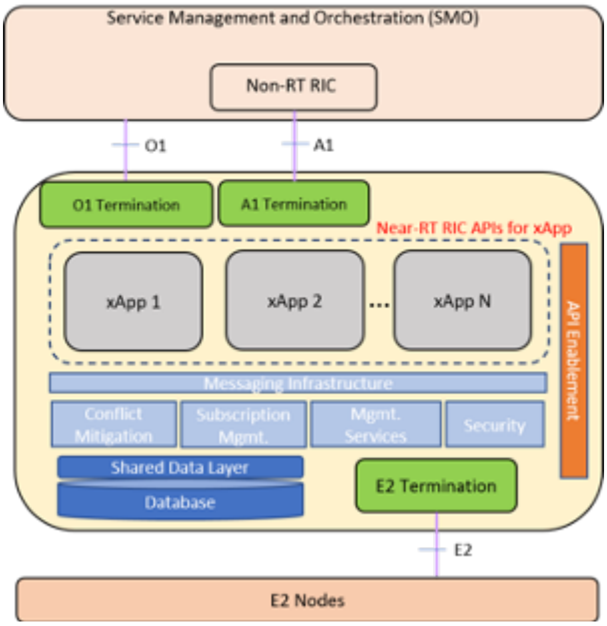

Figure 9 *O-RAN near-RT RIC Architecture*

Accelleran has developed a dRAX™ product line which includes an O-RAN Alliance aligned near-RT RIC (**Figure 9**). This software will be provided to the 5G-TIMBER project for use over the duration of the project. The software provides a framework for developing xApps.

xApps are self-contained software applications that are able to analyse the RAN and as a consequence, control and optimise the RAN performance by controlling the behaviour of the CU and DU through the E2 interface. The CU and DU are further described in sections 4.2 and 4.3, respectively.

It is also worth noting that Accelleran dRAX™ RIC and SDK is a fully distributed cloud native platform that can also be used to develop rApps without having to communicate with an external non-RT-RIC, making it a very suitable enterprise platform to deliver the use cases needed when xApps and rApps are used in combination without the need for a separate A1 interface.

4.2. Overview of the CU

The Central Unit (CU), implements the 'Layer 3' part of the NG-RAN gNB. The CU interfaces to the gNB DU via the F1 mid-haul interface and the mobile core (5GC) via the N2 and N3 backhaul interfaces (NG-C/NG-U).

The CU is split between the control plane and user plane:

- CU-CP: Control-plane of CU, implementing the RRC functions as described in [15] chapter 7. It communicates with the DU via the F1-C interface and to the AMF (5GC control-plane) via the N2 interface.
- CU-UP: User plane function of CU, implementing the PDPC ([TS 38.300 [15] section 6.4) and SDAP (mapping of PDU sessions and their QoS flows to the access stratum DRB Data Radio Bearers, [15] section 6.5). The CU-CP controls the CU-UP via the E1 interface.

The 3GPP CU interfaces are further described in Chapter 5.
The Accelleran CU-CP and CU-CP software implementations are cloud native and can be instantiated on COTS Servers (both ARM and x86 are supported) either as software containers or as Virtual Machine (VM) instances. The CU-CP and CU-UP software can be deployed on a central or edge cloud or on dedicated edge infrastructure. There is no requirement for the CU-CP and CU-UP to be co-located i.e., they can be hosted on different servers and for both low-latency and high throughput use-cases the CU-UPs will almost certainly be hosted on an edge server.

4.3. Overview of the DU

The 5G NR architecture adopts a split into CU and DU by means of the F1 functional split, as defined in TS 38.401 [16]. The DU is usually located in a range of several kilometres from the RU and runs parts of the 3GPP PHY layer, MAC and Radio Link Control (RLC) layers (see **Figure 10**). This logical node includes a subset of the gNB functions, depending on the functional split option, and its operation is controlled by the CU via the 3GPP F1 interface, and possibly by the RIC via the O-RAN E2 interface. A single DU controls one or more RUs via a Fronthaul Interface (FHI) such as the O-RAN 7.2x functional split.

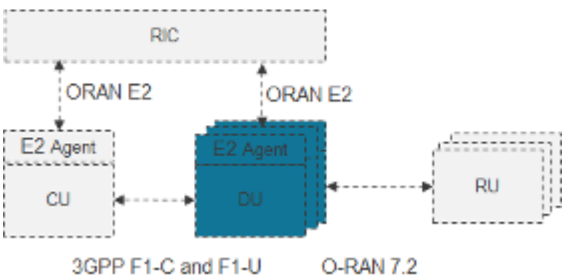

***Figure 10** Disaggregated 5G gNB DU*

The CU-DU functional split, aggregate the PDCP layer and above in a CU, and the RLC layer and below in a DU. The standard interface between them is specified as F1. The F1 interface, connecting a gNB CU to a gNB DU, is a standardized interface that is specified in 3GPP TS 38.425 [17], TS 38.470 [18] and TS 38.473 [19].
The F1 Interface is further described in section 5.1.4.

4.4. Overview of the RU

The RU or O-RAN Radio Unit O-RU is the unit at the edge of the access network. It interfaces with the O-DU northbound via standardized O-RAN Interfaces and with the 5G User Equipment via air Interface.
All the O-RU interfaces are following standards based on:

- O-RAN Interface between the O-RU and O-DU (Option 7.2) over 10Gbps Ethernet links.
- Orthogonal Frequency-Division Multiple Access (OFDMA) Air Interface between the O-RU and the User Equipment according to the 3GPP standard (Sub 6GHz band).

The RU that will be deployed in 5G-TIMBER is the Benetel RAN650 [20] outdoor 4x4MIMO O-RU, with 100MHz bandwidth in n77/n78 C-band FR1.

5. 3GPP and O-RAN Defined RAN Interfaces

Figure 2 shows the Logical Architecture of an O-RAN 5G Network. Several standardised interfaces are shown and a further explanation of these interfaces is provided in this chapter.

5.1. 3GPP Defined RAN Interfaces

This section outlines the 5G network RAN interfaces that have been standardised by 3GPP (see **Figure 1**).

5.1.1. 3GPP N1 Interface

The N1 interface [21] is an interface between the UE and the Access and Mobility Management Function (AMF) of the 5GC. It is used to transfer UE information (related to connection, mobility and sessions) to the AMF.

5.1.2. 3GPP N2 Interface

The N2 interface (also known as NG-C) [21] connects between the gNB and the Access and Mobility Management Function (AMF) of the 5GC. It is primarily concerned with connection management, UE context and PDU session management, and UE mobility management.

5.1.3. 3GPP N3 Interface

The N3 interface (also known as NG-U) [21] connects the gNB and the User Plane Function (UPF) of the 5GC. The interface transfers user data between the RAN and the UPF.

The distance between the gNB and the UPF can have a significant impact on the throughput and latency of the system so for applications with low latency and/or high-performance requirements it often makes sense to locate the UPF at the edge of the network

5.1.4. 3GPP F1 Interface

The F1 interface [18], [19], as shown in Figure 1, is the interface that sits between the CU and the DU. It is further divided into the F1-C (F1 Control) and F1-U (F1 User Plane) sub-interfaces.
On the F1-C interface, the F1AP protocol runs over SCTP, and the F1-U interface uses GTP-U. Whereas NGAP and S1AP transfer NAS messages in containers, F1AP transfers (UE-dedicated) RRC messages in containers. F1AP has a specific message to convey to the DU the System Information that is to be broadcast.

5.1.5. 3GPP E1 Interface

The E1 interface [22] as shown in Figure 2, sits between the CU-CP and CU-UP. It is a control interface and is responsible for interface configuration, setup, reset and error reporting.
Standard E1AP runs over SCTP. This interface allows for a separation of the CU-CP and CU-UP i.e., they do not need to be co-located.
Unlike NGAP and F1AP, the E1AP specification allows the setup procedure to be initiated by either of the endpoints.

5.1.6. 3GPP NR-UU Interface

The NR-UU interface [15] is the interface between the UE to the gNB. It is often referred to as the Air-Interface. The UU interface protocol stack consists of a user-plane protocol stack for transferring user data and a control-plane protocol stack for transferring control signalling.

5.2. O-RAN Defined RAN Interfaces

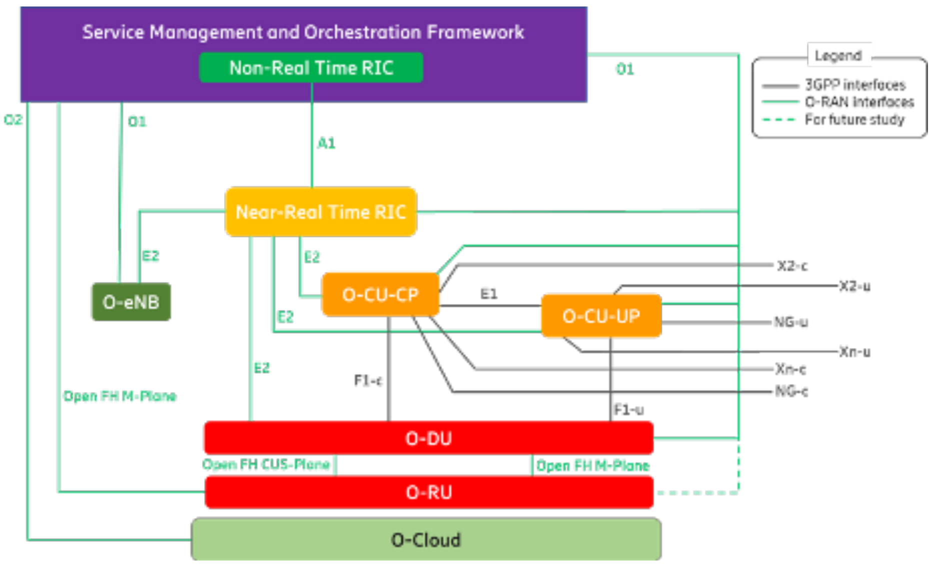

Figure 11 *O-RAN Logical Architecture*

Figure 11 shows the Logical O-RAN Architecture and the following sections provide an overview of these O-RAN defined interfaces.

5.2.1. O-RAN E2 Interface

The E2 interface [23] links the RIC and the CU and the RIC and the DU. When referring to the E2 interface the CU and DU are called E2 Nodes. This interface allows the RIC to control the behaviour of the E2 nodes also to collect RAN metrics from them. These metrics can either be triggered or sent periodically.
The interface uses SCTP over IP for sending and receiving messages to/from an E2 node.
A publish-subscribe paradigm is used on the E2 interface. E2 nodes publish data which xApps can subscribe to. xApp algorithms can then make control decisions based on the input data they subscribe to. The published metrics can either be cell-specific or user-specific.

5.2.2. O-RAN O1 Interface

The O1 interface [24] is the interface between the Service Management and Orchestration (SMO) and O-RAN managed network elements i.e., it is the interface between the SMO and the CU, the SMO and the DU and the SMO and the near-RT RIC. It is a management interface and it covers aspects such as element discovery, registration, provisioning and monitoring.

5.2.3. O-RAN O2 Interface

The O2 interface [25] is how the SMO communicates with the "Cloud" that it resides in. It is used by the network operator to (re)configure and deploy network elements and upgrade the system.

5.2.4. O-RAN A1 Interface

The A1 interface [26] links the non-RT RIC and the near-RT RIC and is purpose is to support policy management, service enrichment and machine learning. It provides a non-real-time control loop towards the near-RT RIC used for example, for sharing policy-based guidance with the near-RT RIC e.g., for setting near-RT RIC high-level optimisation goals.

5.2.5. O-RAN Open Fronthaul Interface

The Open FH (Fronthaul) Interface [27], [28], links the DU and RU. It includes the CUS (Control User Synchronization) Plane and M (Management) Plane.

6. An Overview of Frequencies for NPN deployments in Europe

6.1. Introduction

As per 3GPP [5], the 5G-NR frequency bands are divided into frequency range FR1 and frequency range FR2 as shown in **Figure 12**.

Frequency range designation		Corresponding frequency range
FR1		410 MHz – 7125 MHz
FR2	FR2-1	24250 MHz – 52600 MHz
	FR2-2	52600 MHz – 71000 MHz

Figure 12 *3GPP Definition of Frequency Ranges*

FR1 and FR2 are differentiated not only in the range of the spectrum they are defined for (sub-7Ghz for FR1 and mmWave for FR2), but also in the allowed subcarrier spacing configurations, wider for FR2 to allow the support of wider bandwidths in that frequency range. While FR1 can be used, depending on the specific band, with TDD, FDD, SDL or SUL modes, FR2 is defined in TDD mode.

Until now FR1 has been the traditional licensed spectrum for previous generation systems which now with 5G and its flexible numerology [6] is going to be extended into the mmWave ranges defined in FR2.

6.2. 5G Public Networks Spectrum

As of end of September 2022 the Global Mobile Suppliers Association (GSA) reported [7] that 505 operators in 155 countries had been investing in 5G networks through tests, pilots, licence acquisitions, planned deployments and actual deployments.

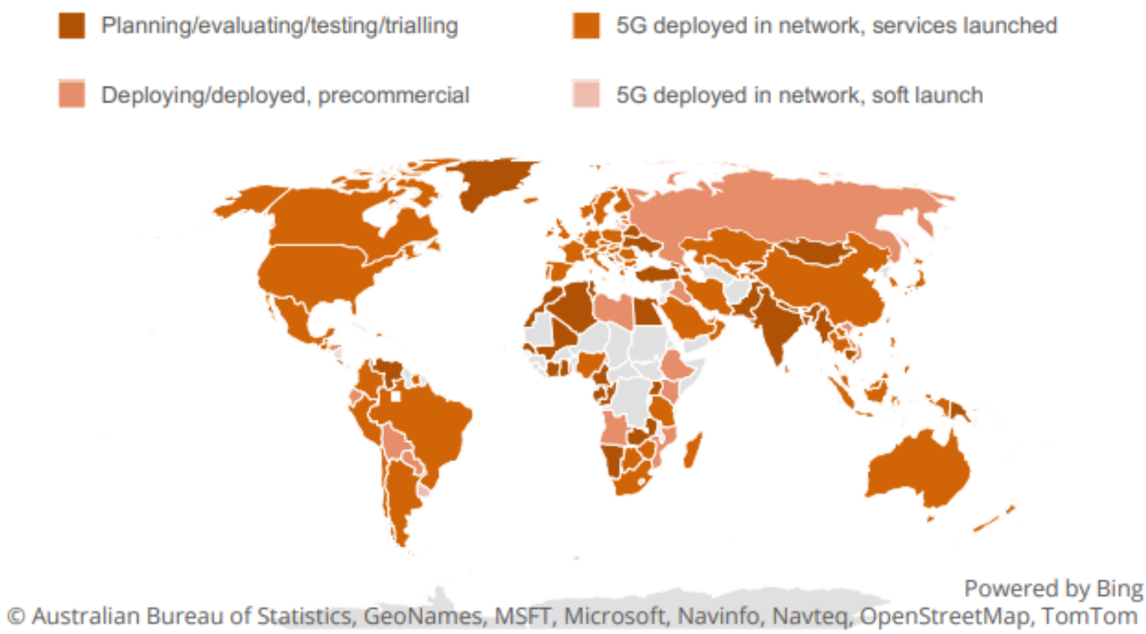

Figure 13 *GSA's Operator Investment 5G Status (September 2022)*

228 operators in 92 countries have launched commercial 5G services for mobile or fixed wireless access. 111 of those operators are targeting investments in standalone public networks of which 35 were already launched (**Figure 13**).

6.3. Private Network Spectrum

As described in [8], a total of 889 customers were deploying private mobile networks located in 70 countries by the end of June 2022 as shown in **Figure 14**

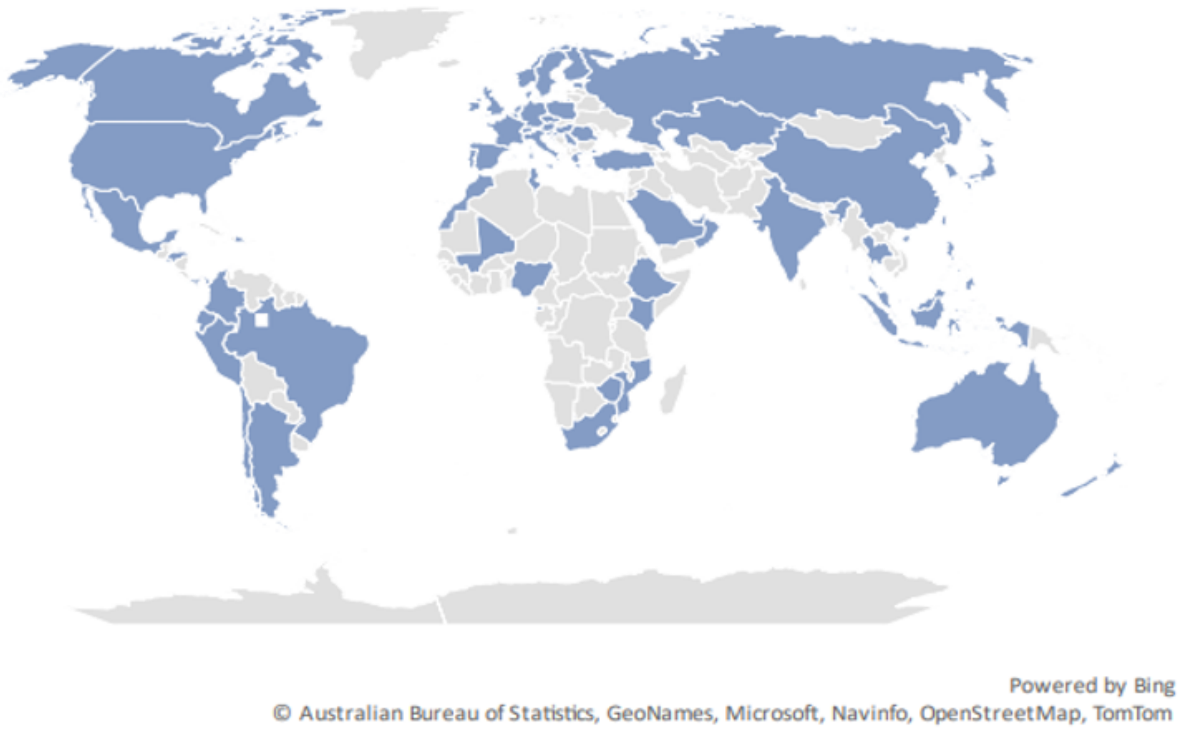

Figure 14 *GSA's countries deploying private mobile networks (June 2020)*

While LTE gets the lion's share of private mobile networks for which GSA has data, 5G is being deployed in 39.8% of these customers. The GSA notes that although the proportion of 5G deployments makes up a significant number of references, "this number skews toward long-term expensive trials and deployments within educational and testbed or validation facilities, with a limited number running real operation in industrial situations".

The technology breakdown for these private networks is as shown in **Figure 15**

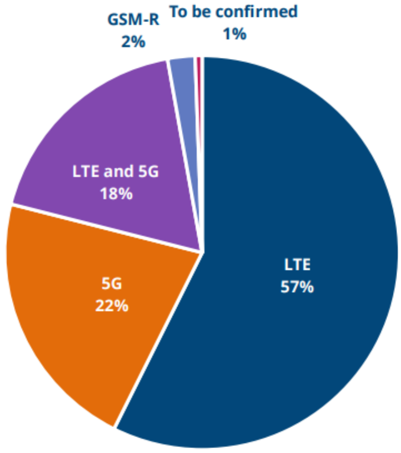

Figure 15 *GSA's private mobile network customers by technology (base: 889 catalogued customers)*

The GSA also analysed the breakdown of the customers using private mobile networks per sector as shown in **Figure 16**.

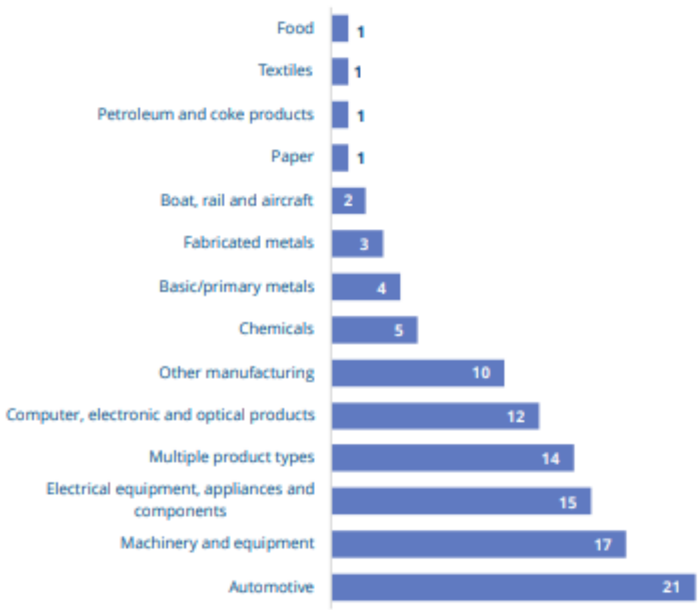

Figure 16 *GSA's breakdown of manufacturing private mobile networks*

The GSA's breakdown of the manufacturing sector is presented in **Figure 17**. The most common one is the manufacturing sector to which 5G-TIMBER belongs.

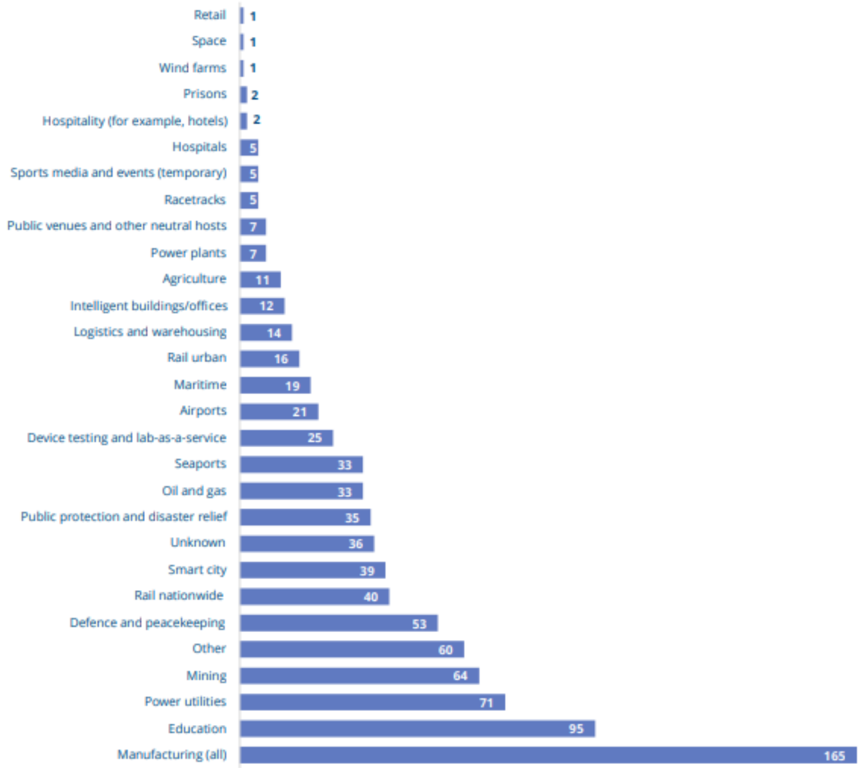

Figure 17 *GSA's number of private mobile networks in trials and commercially by sector*

As can be seen in GSA's enumeration of the bands used for private networks from **Figure 18**, the lion's share is taken by the C-band followed by the Citizens Broadband Radio Service (CBRS) (B48 and N48) bands. CBRS is further discussed in section 6.5.1. Even though there are some cases using FR2, this is still very uncommon, and the majority of bands belong to FR1 range.

According to GSA's latest report the following European countries have dedicated spectrum for industry: Czechia, Denmark, Netherlands, Australia, Sweden, France, Finland, UK and Germany. Poland is considering dedicating spectrum for industry and the Belgium regulator has a current consultation on spectrum for private network use.

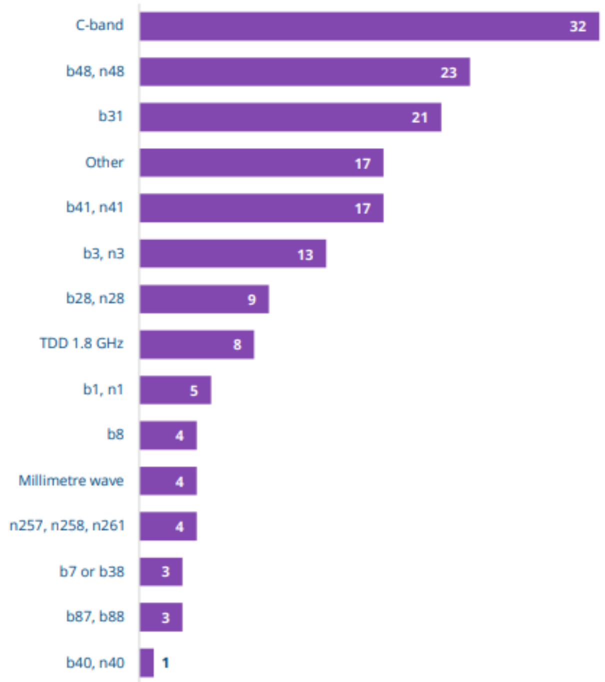

Figure 18 *GSA's breakdown of number of private mobile networks by band*

We will briefly describe some of the most interesting private spectrum use cases in the next section.

6.4. Regulatory spectrum approaches to private networks

As indicated in [9], there are different models under which private spectrum can be assigned: dedicated local licenses on areas/sites, sub-leasing from MNOs to enterprises, dynamic spectrum sharing, secondary licensing of MNO bands with no coverage in the area, indoor usage of MNO bands with no interference implications, etc....

Spurred on by the positive economic results of innovative spectrum access approaches elsewhere, such as CBRS in the US, regulators in Europe are increasingly engaging with the idea of enabling spectrum access for private use. Some are looking at the Ofcom case in the UK, on the upper n77 band while others are looking at the guard NATO radar band at the bottom of n78. The C-band in FR1 seems like a good option to target with regards to propagation characteristics with enough spectrum assets for both public and private purposes while the ecosystem gets ready for the FR2 bands bringing even wider spectrum assets into the game.

6.5. Regulatory examples enabling private network spectrum

6.5.1. USA Citizen's Broadband Radio Service (CBRS)

The Citizen's Broadband Radio Service (CBRS) defined in [10] is an innovative dynamic shared access spectrum regulatory and technological framework based on geographical coordination of database-based spectrum management systems which provides the ability to protect incumbents where the spectrum is already in use (Fixed Satellite Service, military radars) at the same time as enabling prioritised licensed spectrum usage and opportunistic general access spectrum (unlicensed) usage in different areas.

6.5.2. UK Local/Shared Access

In July 2019 Ofcom published the grounds to enable wireless innovation through local licensing [11], which resulted in the guidelines for "Shared Access Licence - Guidance document" and "Local Access Licence - Guidance document".

The Shared Access License uses are shown in **Figure 19**.

Uses	1800 MHz shared spectrum	2300 MHz shared spectrum	3.8-4.2 GHz	Lower 26 GHz band
Private network	✓ (narrowband)	✓	✓	✓ (indoor)
Mobile coverage (rural)	✓	certain locations[3]	×	×
Mobile coverage (indoor)	✓	✓	×	✓
Fixed wireless access[4]	×	×	✓	✓[5]

[3] Due to coexistence with other users, the availability of medium power licences in the 2300 MHz shared spectrum will be limited initially.
[4] Fixed wireless access (FWA) networks provide an alternative solution to traditional fixed broadband services. These networks use a wireless link for the final connection to a home or business, avoiding the installation of a line into the building.
[5] FWA is available through existing fixed links authorisation. However, we are not encouraging people to apply for new licences in the band. See paragraph 5.29 of our Statement for more information.

Figure 19 *Use of UK Shared Access Bands*

While the current implementation of the Shared Access licensing scheme is by manual application, Ofcom expects some future automatic enablement of license acquisition based on a centralized database like in TV Whitespace or CBRS.

There are 2 types of UK Shared Access licenses: low power or medium power with different EIRP limits and deployment conditions. The typical cost of a yearly license covering a particular area is £800 per year for 100 MHz. There is a growing ecosystem of 5GNR RU solutions covering the N77u FR1 band in particular.

The Local Access licence scheme is a mechanism that enables sharing spectrum already licensed on a national basis to MNOs in locations where a particular frequency is not being used by the MNO. It is therefore applicable to traditionally licensed spectrum.

6.5.3. German dedicated industrial license

In 2019 the German regulator opened up a total of 100 MHz of spectrum in 3700-3800 MHz (n78/n77) FR1 for 5G local private use and many of the industrial players in Germany applied for such licenses and are currently demonstrating 5G use cases for the industry such as Bosch, Siemens, BMW, Volkswagen, etc.

As of June 2021, a total of 243 licensees had been granted as indicated in [12]. This step in Germany is being used by other countries in Europe as example to explore and consult.

6.5.4. French industrial licenses

In October 2022 the French regulator had already awarded 13 private 5G licenses in 3800-4000 MHz (n77) FR1 for 5G industrial use as indicated in [13]. This was done in line with the recommendations done by the French government industrial 5G task force. Additionally, spectrum in 26 GHz is also enabled by the regulator in order to experiment with 5G.

6.5.5. Estonia

The Estonian regulator has allocated the n258 mmWave band (24.25 GHz to 27.5 GHz) for NPN use in Estonia.

7. 5G Core Network

The core network is one of the key elements of a mobile network and it oversees all network functionalities and processes that are not related to the RAN, like user authentication, subscriber data management, policy control, connectivity and mobility management, exposure of services towards application functions, and traffic forwarding between the radio access infrastructure and data networks.

In SA 5G deployments, the core network needs to fully comply with all relevant 3GPP standards. Accordingly, Athonet is providing 5G-TIMBER with a SA fully virtualised 5GC, tailored to the project's requirements to best serve the project's use cases. The virtual software architecture of Athonet's 5GC offers increased flexibility and adaptability. Its 3GPP-compliant Network Functions (NFs), fully developed and programmed in-house at Athonet, are implemented as containerized Virtual Network Functions (VNFs), with the separation of User Planes and Control Planes as required by 3GPP.

The separation of these planes gives the flexibility to deploy the User Plane Function (UPF) either locally or remotely, depending on the business and use case requirements.

At the time of writing, Athonet has already developed a working SA 5GC based on a minimum set of required functionalities, inherited (and evolved) from the legacy 4G/5G-NSA Software Mobile Core. The VNFs that compose it are:

- The Access and Mobility Management Function (AMF).
- The Session Management Function (SMF)
- The User Plane Function (UPF)
- The Unified Data Management (UDM)
- The Authentication Server Function (AUSF)
- The Unified Data Repository (UDR).
- The Policy Control Function (PCF).
- The Network Repository Function (NRF)
- The Network Slice Selection Function (NSSF)

Figure 1 shows the 5GC architecture. It also highlights the reference points towards the RAN, the UE, and the data network, labelled as per the 3GPP standard notation [14].

8. Overview of 5G UE ecosystem

8.1. 3GPP Services

The UE to be used in the 5G-TIMBER pilots is based on 3GPP Release 16. As shown in **Figure 20**, the primary focus of R16 UEs is eMBB (enhanced Mobile Broadband). Further details about eMBB, Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC) and their relevance to the 5G-TIMBER Use Cases, are presented in Section 9.5.

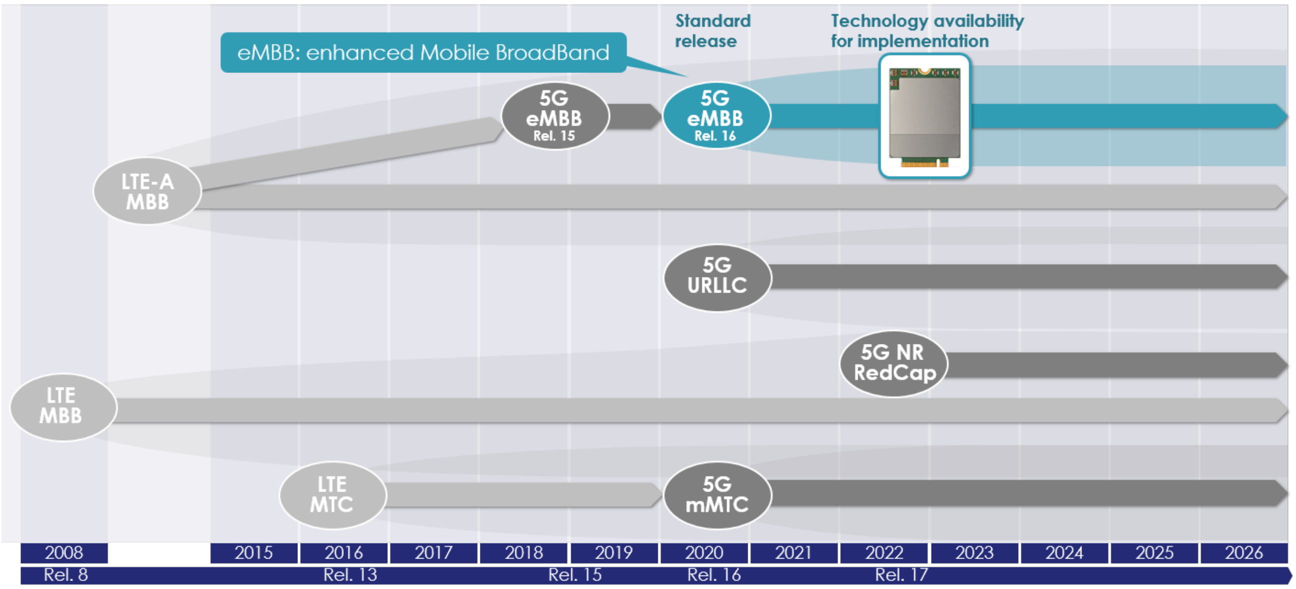

Figure 20 *Thales UE, Release 16 – Primary Focus eMBB*

8.2. Network Deployment Options

As detailed below, 5G networks can be deployed with a high level of flexibility depending on the available network infrastructure. For the 5G-TIMBER pilots, Option 2 (highlighted in grey in **Figure 21**) will be used. The other options are outlined for completeness. Note: The options are listed by EPC use and are therefore not in numerical order.

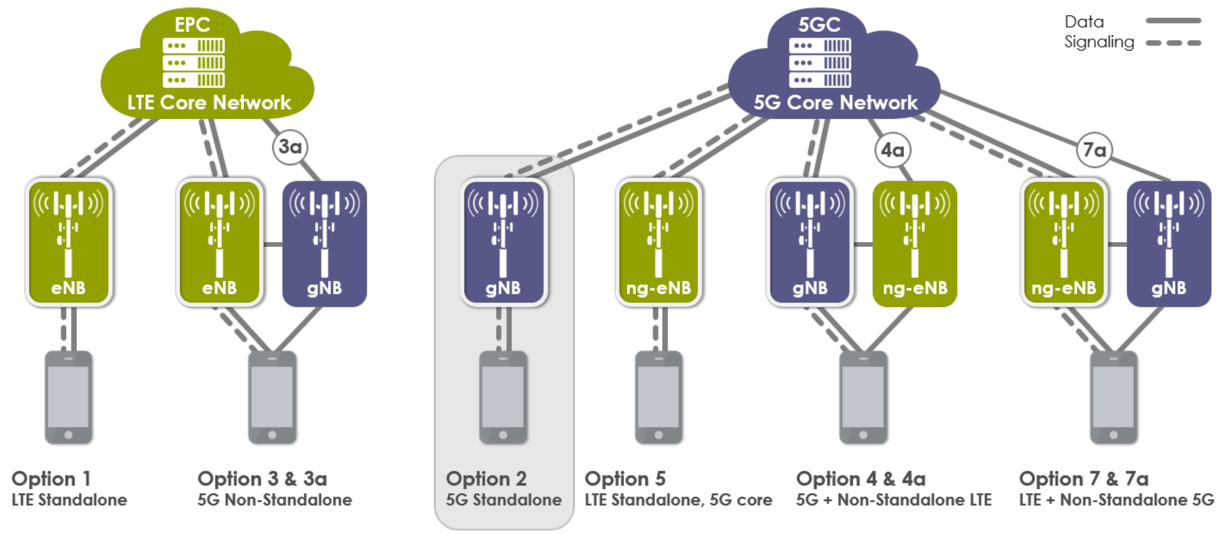

Figure 21 *UE Deployment Options – Highlighting Option selected for 5G-TIMBER*

Option 1 - LTE Standalone

•UE connected to LTE radio and core network only

•LTE Public and private network deployments

Option 2 - 5G Standalone(5G-TIMBER)

•UE connected to 5G radio and core network only

•5G Public and private network deployments

Option 3 & 3a - 5G non-Standalone

•Capacity extension via 5G

•No 5G Core functionalities

•Leveraging LTE and use 5G for capacity extension

Option 5 - LTE Standalone with 5GC

•Enabling 5GC services for LTE, leveraging LTE capacity

•Efficient way to maintain LTE

•Suitable for rural areas

Option 4 & 4a - 5G + Non-Standalone LTE

•5GC services

•5G NR control plane anchor

•Data aggregation with LTE

•Best for low band NR scenarios

Option 7 & 7a - LTE + Non-Standalone 5G

•Like option 5 with dual Connectivity

•Enabling 5GC services for LTE
•Leveraging 5G NR carriers
•Best for leveraging low band LTE

9. Considerations for an NPN deployment for 5G-TIMBER in Estonia

9.1. Background

As detailed in [29], earlier generations of wireless networks were largely focused on the needs of people and were mainly designed for business to customer/consumer (B2C) types of services e.g., voice calls, text messages and Web browsing.

The rationale for the development of the 5th generation of mobile communications (5G) was not only to expand the broadband capabilities of mobile networks, but also to provide advanced wireless connectivity for a wide variety of vertical industries, such as the manufacturing, automotive and agricultural sectors. To achieve this, 5G supports three primary use case families:

1. enhanced Mobile BroadBand (eMBB).
2. massive Machine-Type Communication (mMTC).
3. ultra-reliable low-latency communications (URLLC).

More details of these 5G use case families can be found in D1.1.

These 5G use case families foresee a widening in focus beyond B2C to also include business to Business (B2B) where new non-human users such as robots, machines and sensors in industrial verticals become the area of focus.

9.2. 5G Use Case Families and 3GPP Standardisation

It is important to view these 5G use case families in the context of the overall 3GPP release roadmap i.e., they are not fixed features that will be delivered by a specific date, rather they are features that will continue to evolve independently as the 3GPP standards evolve.

As described in [30], although these 5G use case families rely on the same or very similar underlying technology, they actually place significantly different requirements on the operating hardware and software that will be deployed in a network.

A network with a primary focus on eMBB is designed to cope with a moderate number of devices that communicate at high speed. eMBB requires wider

channel bandwidths, massive MIMO, advanced channel coding and other features.
In contrast, mMTC focuses on IoT applications where a much larger number of devices are connected to an access point or gateway. In these cases, sensors receive and transmit small amounts of data at low speeds and often operate for several years powered only by small batteries. The principle focus here is on achieving acceptable performance using simpler devices that consume very little power.
URLLC applications will typically have high data rates, but may only serve only a few devices rather than potentially millions. In order to reduce latency to the least possible amount, potentially a few milliseconds, it’s mission critical that these systems function properly.
By separating out the 5G use case families, 3GPP is enabling engineering companies to prioritise specific 5G use cases and accelerate early network deployments and trials.

As shown in **Figure 22** from ZVEI/5G-ACIA [29], different industrial use cases can typically be grouped by their basic service requirements (5G use case family).

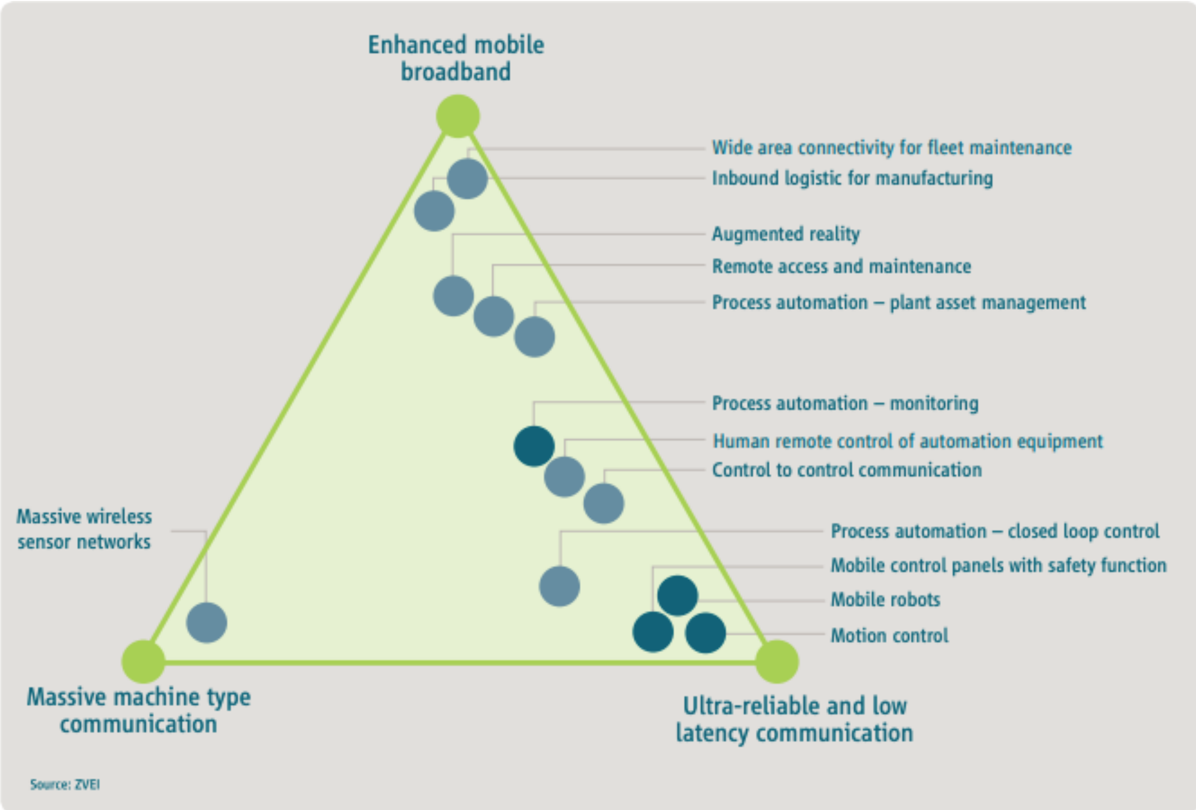

Figure 22 industrial use cases, arranged according to their basic service requirements

The fact that 3GPP has allowed for and foreseen the development and deployment of networks with an eMBB or URLLC focus, in reality it is not an either-or situation. It is certainly the case today, that industrial use cases with an extreme eMBB requirement are unlikely to be suited to a network geared towards URLLC deployments and vice-versa, a URLLC focused deployment will likely not support eMBB data rates or device numbers. However, most industrial use cases do not lie at the extreme ends of this diagram i.e., they require "a degree" of eMBB and a degree of URLLC.

In **Figure 22**, mMTC appears to sit an island of its own and to some degree this is true. As described in [31] and [32], mMTC standardisation actually predates the 3GPP 5G specifications. LTE-M (LTE for machine-type communications) and NB-IoT (narrowband IoT) were introduced as new cellular LPWA standards by 3GPP in Release 13 of the LTE standards in 2015. 3GPP has agreed that the LPWA use cases will continue to be addressed by evolving NB-IoT and LTE-M as part of the 5G specifications. As such, NB-IoT and LTE-M networks are considered to be forwards-compatible with 5G technologies.

Although NB-IoT and LTE-M devices are forwards-compatible with 5G, existing devices predate the 5G standards and as a consequence, current devices will not operate in the new bands defined for 5G NR. A complete list of bands that have currently been allocated for NB-IoT and LTE-M devices can be found in [33].

The only significant innovation in the IoT standards since Release 13 has been the addition of NR-Light (RedCap) in Release 17. Though this is aimed at medium throughput rich IoT and as such, is not really an NB-IoT replacement.

This indicates that to use NB-IoT and LTE-M devices in a 5G NR deployment a separate LTE spectrum allocation will be required or an IoT gateway will need to be used. The 5G-TIMBER Use Cases that require mMTC features will make use of an IoT Gateway.

The 5G-TIMBER Use Cases that rely on eMBB and/or URLLC functionality fall roughly in the middle of the eMBB and URLLC axis of **Figure 22** i.e., they have neither extreme eMBB nor URLLC requirements and the expectation is that the proposed deployment, described in Chapter 10, will be sufficient to meet the eMBB and URLLC requirements of these Use Cases.

9.3. 5G Positioning and 3GPP Standardisation

As with the 5G use case families, native support for positioning in 5G is under constant development. As **Figure 23**, below from Qualcomm [34] shows, Release 16 sets the foundation for 3GPP supported (RAT-dependent) positioning in 5G, with further enhancements expected in future releases.

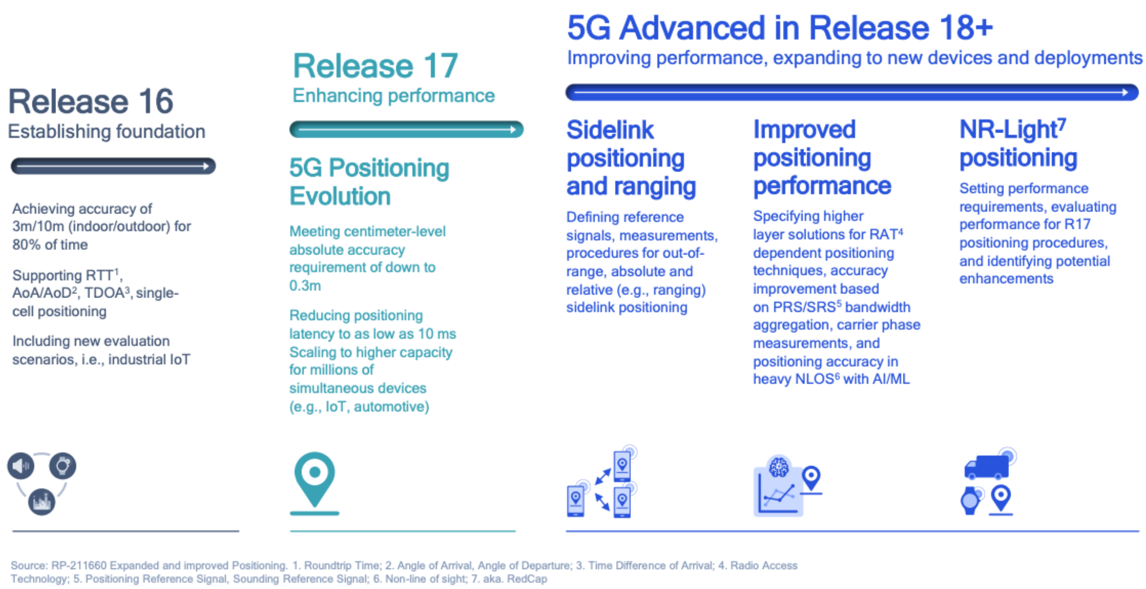

Figure 23 *Planned Evolution of 5G Positioning Technologies*

9.4. NPN Ecosystem and implications for 5G-TIMBER deployments

Unfortunately, it is not sufficient, when considering a NPN network deployment, to look at the 3GPP release of the various network elements and assume that all features will be supported. As mentioned in section 9.2 above for example, a network geared towards an eMBB deployment, may not be particularly suited towards URLLC or mMTC use cases.
A further confusing complication is that having a feature defined in a particular 3GPP release does not guarantee that that feature will be supported by release compliant network elements. This confusion can arise as not all features in any given release are deemed by 3GPP to be mandatory. A good example of this is RAT-dependent support for positioning.

Looking again at **Figure 23**, it would seem fair to assume that a Release 16 compliant network will support the positioning mechanisms identified there. However, these positioning techniques are actually optional. Indeed, even moving beyond Release 16, it would be reasonable to assume that all of the positioning techniques identified in **Figure 23** will also be deemed to be optional. A network being able to provide highly accurate positioning is pretty fundamental to industrial use cases, however, the ability of an MNO to track individuals to that level of accuracy, without their knowledge or consent, would raise serious privacy concerns.

Most UE devices incorporate a 5G modem or chipset from a small number of chipset vendors, typified by Qualcomm and their Snapdragon chipsets. These chipsets are driven by sales volume. Currently, this volume is generated by the B2C consumer smartphones that most people now carry with them. These B2C users don't currently require much beyond eMBB capabilities. So, while Carrier Aggregation and other eMBB related features are being prioritised, optional features that are more useful to Industrial B2B types of things like Positioning/LCS, Ethernet PDU sessions for native Layer 2 TSN LAN bridging, SA FR2 only, etc, are deemed to be of lower priority and are sometimes struggling to even make foreseeable roadmaps. The lack of recent innovation in the standards relating IoT (see Section 9.2) shows, we believe, that this is an industry-wide prioritization, including 3GPP and is not just limited to chipset vendors.

Over time, as NPN's become mainstream, the expectation is that B2B features will grow in importance, but 5G-TIMBER has to deal with the realities of the feature sets that are currently supported in 3GPP Release 15 and 16 equipment.

Drilling down a bit into the R16 RAT-dependent positioning mechanisms identified in **Figure 23**, **Figure 24** further details which network elements which need to support a particular method in order for that method to be supported end-to-end e.g., end-to-end support for UL-AoA (Uplink Angle of Arrival) would require that all the gNB elements (RU, DU and CU) support it along with the 5GC.

Method	UE Support	gNB Support	5GC Support
Multi RTT	Yes	Yes	Yes
DL-AoD	Yes	No	Yes
DL-TDOA	Yes	No	Yes
UL-TDOA	No	Yes	Yes
UL-AoA	No	Yes	Yes

Figure 24 *3GPP Release 16 Radio Access Technology (RAT) Positioning Mechanisms*

It is clear that precise localisation is fundamental to many industrial use cases [35] and as is indicated above, it is also clear, from a 5G-TIMBER Use

Case perspective, there are limitations on the accuracy that is achievable using the R16 RAT-dependent approaches.

At the time of writing, there is still uncertainty as to what degree these R16 mechanisms will be supported by the 5GS components that will be deployed as part of the 5G-TIMBER pilots but the expectation is that support will be very limited.

Furthermore, it is not anticipated that a R17 or beyond compliant 5GS NPN will be available in the course of the 5G-TIMBER project i.e., the later positioning mechanisms identified in **Figure 23** will likely not be available during the project timeline.

The limitations of relying solely on RAT-dependent localisation and the benefits of combining heterogeneous observations from RAT-dependent and RAT-independent technologies are detailed in [36].

Given the limitations identified above, it is not likely that the RAT-dependent telemetry that will be available, will be sufficient to achieve the positioning accuracy required by the 5G-TIMBER Use Cases. In this context, a novel solution that could be considered in 5G-TIMBER would be to look at the possibility of the real-time integration of data from multiple sources into the RIC thus enabling xAPPs/rAPPs to combine these heterogeneous observations to improve localisation accuracy.

9.5. 5G-TIMBER Use Case Considerations

D1.1 (Descriptions of use cases with expected outcomes and impact) outlines the dependencies between the 5G-TIMBER Use Cases and the 5G use case families (5G Scenarios). It also identifies the 5G-TIMBER Use Cases that have a localisation/positioning requirement (LCS).

In reality, for the RIC xApps/rApps intelligence, like RRM, Location zone alerts, Beamforming and Interference Management to work, the RIC just needs accurate information about the UE location; where that actual information comes from is of secondary importance.

9.5.1. eMBB

As discussed in [29] and [37], the primary focus of early 5G deployments has been on eMBB (largely to cater for commercially attractive B2C Use Cases). This focus has filtered down to the equipment that is currently available to support NPN deployments. It is not anticipated that the Use Cases that have higher eMBB requirements (1.2 and 3.1) will cause any issues for the proposed NPN deployment. Indeed, the biggest limitation on data rates is likely to be the amount of spectrum that is available for the project pilots rather than any inherent limitation in the deployed NPN 5GS.

9.5.2. URLLC

A key factor in determining overall network latency will be the location of the UPF i.e., the 5GS network termination of the user data. As the 3GPP 5G standards allow for deploying the UPF at the edge, it is expected that using this approach to deploy the UPF at the on-premises edge, should be sufficient to handle Use Cases that have higher URLLC requirements (1.2, 2.2, 2.3 and 3.1).

9.5.3. mMTC

The initial SNPN deployment for the 5G-TIMBER pilots will involve the use of SA n78 compatible equipment with a plan to migrate to a SNPN SA mmWave deployment (band n258) as compatible equipment becomes available.
As described in section 9.2, existing NB-IoT and LTE-M devices will not operate in either the n78 or n258 bands. This indicates that for the Use Cases where mMTC is important (1.1, 1,3 and 3,2), an IoT gateway will need to be deployed.

9.5.4.Positioning / LCS

Use Case 2.1 and, to a lesser degree, 2.2, have a dependency on high-accuracy positioning. As described in sections 9.3 and 9.4 above, this is likely to be the most challenging aspect of the NPN deployment in 5G-TIMBER. A combination of the maximum available 3GPP release (Release 16) in conjunction the uncertainty about the support for R16 positioning mechanisms suggests that the stated positioning accuracy for these Use Cases (10s of cm) is unlikely to be achieved by relying solely on whatever RAT-dependent localisation mechanisms that are available. Section 9.4 proposes the novel approach of supplying heterogenous measurements to the RIC to enable xApps/rApps achieve the accuracy levels required by the Use Cases.

9.6. 5G-TIMBER Non Use-Case Specific Considerations

As outlined in this document, there are multiple additional factors that need to be examined when looking to deploy a 5G NPN in an industrial environment. These considerations include:

- Spectrum availability
- Equipment availability
- Deployment environment

Many initial 5G networks deployments leverage existing 4G network infrastructure and operate in a manner termed non-standalone (NSA) mode. A 5G network that can operate independently of existing 4G network infrastructure is said to be operating in standalone (SA) mode. NSA is considered to be an interim steppingstone and the expectation is that most 5G deployments will ultimately be SA. For a greenfield 5G deployment, such as the 5G-TIMBER pilots, it does not make sense to deploy an NSA network as there is no existing 4G infrastructure to leverage.

As mentioned in Section 6.5.5, the Estonian regulator has allocated the n258 mmWave band for NPN use in Estonia. Unfortunately, at the time of writing, there are no commercially available UEs or RUs that can operate in Standalone mode in this band.

To circumvent this issue and to facilitate early 5G-TIMBER NPN deployments, the project consortium has been in discussions with local Estonian operators to gain temporary access to n78 band spectrum (3300 MHz to 3800 MHz). This document focuses on the equipment that can be deployed in this n78 band. The expectation is that UEs and RUs that can operate in SA mode in n258, will become available over the course of the project and that this initial n78 deployment could then be replaced by an n258 SA network.

To facilitate the project Use Cases and minimise external dependencies, the recommended deployment for 5G-TIMBER in Estonia is an O-RAN compliant SNPN (**Figure 3**).

This means that the consortium will take responsibility for selecting, deploying and operating all 5G software and equipment used during the course of the project.

An RF and network planning exercise will need to be completed at the Use Case sites before the deployment and network topology can be finalised.

9.7. 5G-TIMBER and Zero-Touch

A brief overview of “Zero-Touch” is provided in Section 3.9 and a more comprehensive presentation can be found in [4].

In D1.1, Use Cases 1.2 (DTs assisted assembly, remote operation and servicing of woodworking machinery) and 3.2 (Long term SHM of wooden construction using IoT and embedded AI) both identify Zero-Touch as an important factor (5G roles and benefits).

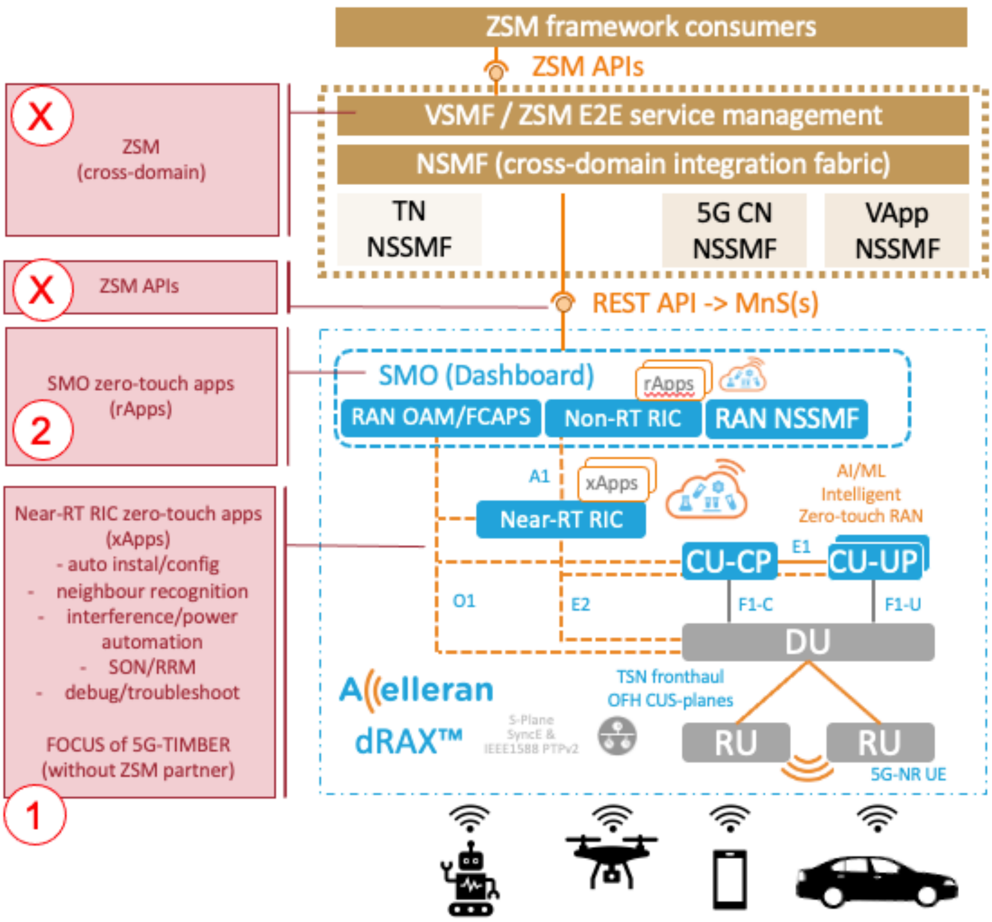

Figure 25 ETSI ZSM and 5G-TIMBER

As there are no ETSI ZSM partners in the 5G-TIMBER project, the scope of Zero-Touch will exclude ETSI ZSM interfacing (**Figure 25**). Rather, the scope of Zero-Touch in 5G-TIMBER will be limited to RIC (RAN Intelligent Controller) capabilities as enabled by xApps/rApps.

xApps under active consideration in 5G-TIMBER, include:

- Neighbour Recognition
- Interference Management
- Power Automation
- SON/RRM

10. NPN deployment strategy for 5G-TIMBER in Estonia

10.1. Background

In 5G-TIMBER, three use case categories of have been identified:

1. Data driven sawmill and woodworking machine setup
2. Modular wood-house factory
3. Construction and renovation with wooden elements, valorisation of composite waste

Each category is further subdivided into three individual use cases. The use cases are fully detailed in D1.1.

An SNPN operating in band n78 will be deployed to cover the requirements of the category 1 and category 2 use cases. The same 5G network equipment will be used in both the category 1 and 2 use cases and this equipment is described later in this Chapter. This Chapter provides further details on the proposed NPN deployments.
The deployment of an NPN does not make sense for the Category 3 use cases. The Category 3 use cases will instead, be handled through the deployment of IoT devices and an IoT gateway in an existing public MNO network.

10.2. Use Case Category 1 - Data driven sawmill and woodworking machine setup

The proposed location for the pilot deployments is a Nordwood sawmill in Viiratsi Saeveski in Estonia. A band n78 SNPN will be deployed on site. The use case descriptions in D1.1 indicate that mMTC, eMBB and URLLC are all important considerations for this use case category. Accurate positioning is not an important factor for these use cases.
As accurate positioning is not an important aspect of these use cases, it will be sufficient to deploy a single base station (no triangulation is required). To cover the URLLC requirements of the use cases, the Core Network will also be deployed locally, on-site. Sufficient bandwidth will be available in the n78 band to cover the eMBB requirements of the use cases. mMTC aspects will be covered by the deployment of IoT sensors in conjunction with an IoT gateway. The IoT traffic will be routed “over the top” of the 5G SNPN Network i.e., no specific traffic routing or scheduling is applied or required. The deployment is indoors so a site inspection will be required to determine if a

GPS antenna can be connected to the RU to ensure accurate timing synchronization can be provided. If this is not feasible then it will be necessary to also deploy a PTP grandmaster clock, as described below.
D1.9 will contain more specific network topology details of the final NPN deployment at the Nordwood site.

10.3. Use Case Category 2 - Modular wood-house factory

The proposed location for the pilot deployments is the Harmet production facility in Kumna in Estonia. A band 78 SNPN will be deployed on site. The use case descriptions in D1.1 indicate that URLLC and accurate positioning are important considerations for this use case category. eMBB and mMTC are not deemed to be of significant importance. An analysis of the Harmet production facility site plans in conjunction with the positioning requirements of these use cases indicates that three base stations should be deployed at the Harmet facility.
This deployment is also indoors. The plan is to deploy the network RUs in the ceiling space at the Harmet plant and for timing synchronization reasons, connect a GPS antenna to each RU. If this is not feasible then it will be necessary to also deploy a PTP grandmaster clock, as described below.
D1.9 will contain more specific network topology details of the final NPN deployment at the Harmet Kumna site.

10.4. Use Case Category 3 Construction and renovation with wooden elements, valorisation of composite waste

The use case category 3 pilots cover wooden house construction and use. Candidate sites for the category 3 use cases will be identified as part of task 4.1 (M13-M27). D1.1 indicates that both eMBB and mMTC are relevant to the category 3 use cases. For reasons detailed in D1.1, an NPN will not be deployed at the category 3 construction sites. Instead, a public network operated by an MNO will be used for comparison reasons. IoT devices, in conjunction with an IoT gateway will be deployed at the chosen construction sites. In this case, all IoT traffic will be routed “over the top” of the public MNO network.

10.5. Network Software

In terms of the software components required to deploy the 5G SNPN networks of the category 1 and category 2 use cases, Athonet will provide the Release 16 5GC software and Accelleran will provide RAN components; the CU (CU-UP and CU-CP) and RIC software (see **Figure 2**). As the consortium does not have a partner who can provide DU software, a 3rd-party commercial provider will be used. Accelleran will integrate this 3rd-party DU into the overall SNPN network. Accelleran will provide an xApps/rApps development framework to the project. Any xApps/rApps developed to support the individual project Use Cases will be the responsibility of the individual Use Case partners.

10.6. Network Hardware

This section describes the hardware that will need to be deployed to support the 5G-TIMBER Use Cases. Example specifications of the hardware described here can be found in the Appendix in Chapter 13.

10.6.1.UEs

The UEs used in the project will be provided by Thales. As mentioned in section 9.6, the initial 5G-TIMBER deployment will be in band n78 with a plan to migrate to band n258 when suitable radio equipment becomes available. The n78 UEs that are available today are R16 compliant. More details of the Thales-provided UEs can be found in the Appendix in Chapter 13.

10.6.2. RU.

The RUs used in the initial deployment will be the Benetel 650. The Benetel 650 is designed for outdoor use but can be used indoors. The Benetel 550 which is designed for indoor use, was also considered but given nature of the deployment sites (factory/sawmill), it was determined that the higher IP rating for the 650 made it more suitable for the 5G-TIMBER Use Cases. (The 650 has an IP65 rating versus an IP30 rating for the 550). More details of the Benetel 650 can be found in the Appendix in Chapter 13.

10.6.3. COTS Server for DU, CU-CP, CU-UP and RIC.

A representative specification for a COTS Server for hosting the DU, CU and RIC software can be found in the Appendix in Section 13.3.

10.6.4. COTS Server for hosting the 5GC.

A representative specification for a COTS Server for hosting the 5GC software including the UPF can be found in the Appendix in Section 13.4.

10.6.5. Server for hosting edge applications.

As the performance requirements for the Edge Applications are not yet known, no suggested server specification is provided here. However, the working assumption is that a COTS Server, similar to the ones described in Sections 13.3 and 13.4 will suffice for this purpose.

10.6.6. Timing Provision hardware.

A 5G network has strict timing requirements both in terms of synchronising frequency and phase across different gNBs. Typically for an outdoor deployment, a GNSS signal can be used to provide a timing source to the individual gNBs. As the category 1 and category 2 5G-TIMBER deployments will be indoors, it might not be possible to get a GNSS signal to every gNB. In this case an alternative solution will need to be found e.g. A grandmaster clock providing a PTP signal.

10.6.7. Network Accessories.

A representative network accessories list is provided in the Appendix in Chapter 13.

10.7. Network Component Connectivity

The plan is to deploy the Benetel 650 RUs in the ceiling spaces at the Nordwood and Harmet sites. If possible, a GPS antenna will be fed directly to each deployed RU. If this is not feasible (the GPS antennas will not have line-of-sight to GNSS satellites) then the RUs will need to synchronise using PTPv2. This would require the deployment of a grandmaster clock on site. The RUs need to be individually powered.

Fibre cabling (SFP+ single mode, 10 Gbps) is required to link every deployed RU back to the COTS Server hosting the DU (and CU and RIC). If GPS connectivity is not possible then a PTP signal can be fed to the RUs using this fibre link.

It is foreseen that the COTS Servers hosting the RAN software, the 5GC and the Edge Applications, will be deployed in local IT rooms. The maximum distance between RU and DU is in the region of 10 km so the precise location of the server room is not deemed to be critical.

All COTS Servers should be networked together with cabling that supports a 10Gbps data rate i.e., a minimum of Cat6 interconnect cabling.

A network backhaul to the Internet is not a strict requirement so, whether this is necessary or not, is more dependent on the individual Use Cases and whether remote access to the deployed equipment is required/desirable.

11. Conclusions

The vast majority of 5G networks in existence today are deployed by Mobile Network Operators and are designed to provide high data rates (eMBB) to the public. However, as 5G-ACIA states, the use of 5G NPNs in commercial and industrial scenarios is in its infancy [38].

5G technology and standards continue to evolve and the technology that is commercially available today (R16) is mature enough to support many industrial use cases but there are still gaps between industry expectations and current technology capabilities.

In particular, in a 5G-TIMBER context, use cases with a focus on high-accuracy positioning and mMTC, are proving to be more complex to deliver. In the former case as the 3GPP defined RAT-dependent positioning mechanisms are not currently supported, or are only minimally supported, in the equipment that is commercially available today (UE, RAN, 5GC). In the latter case, there are no IoT devices available today that operate natively in 5G-NR frequencies. This necessitates the use of IoT gateways so that the IoT devices that are available today, can be used without the need to deploy a parallel 4G network.
Conversely, the 5G-TIMBER use cases that have a focus on eMBB and URLLC are not expected to be problematic in terms of current technology availability i.e., the equipment available to the consortium should be capable of meeting the eMBB and URLLC use case requirements specified in D1.1.
It is not clear however, that the 5G network equipment and software that is commercially available today would be capable of supporting use cases that have more extreme eMBB or URLLC requirements e.g., closed-loop-control process automation.

Nevertheless, as stated above, the standards and technology continue to evolve so industrial use cases that might still prove challenging today will likely be manageable within the scope of future technology evolutions.

Given the areas of expertise of the consortium partners with a 5G focus (Thales, Athonet and Accelleran), it was not unreasonable that an O-RAN compliant SNPN would be the network type chosen for deployment in the 5G-TIMBER trials. However, it is clear that there is no “one size fits all” when it comes to deploying 5G Networks in an industrial environment.

Some topics that need to be taken into consideration when looking to deploy an NPN are mentioned in Section 3.1 and alternative NPN deployment options are presented in Section 3.4. These topics will be further addressed in D1.9

12. References

[1] 3GPP, "5G Non-Public Networks. Types of Deployment," [Online]. Available: https://www.3gpp.org/news-events/3gpp-news/tsn-v-lan.

[2] O-RAN Alliance, "The O-RAN Alliance Homepage," [Online]. Available: https://www.o-ran.org/.

[3] Cisco, "5G Automation Framework," 23 September 2020. [Online]. Available: https://accelleran.atlassian.net/wiki/spaces/GRANTS/pages/2238578689/ETSI+ZSM+Zero-touch+network+Service+Management.

[4] ETSI, "Zero touch network & Service Management (ZSM)," [Online]. Available: https://www.etsi.org/technologies/zero-touch-network-service-management. [Accessed 24 11 2022].

[5] 3GPP, "TS 38.104 – NR; Base Station (BS) radio transmission and reception. V17.7.0," 2022.

[6] KEYSIGHT, "5G Flexible Numerology – What is it? Why should you care?," [Online]. Available: https://edadocs.software.keysight.com/kkbopen/5g-flexible-numerology-what-is-it-why-should-you-care-598781627.html. [Accessed December 2022].

[7] Global Mobile Suppliers Association, "5G - NTS Statistics October 2022," 10 2022. [Online]. Available: https://gsacom.com/paper/nts-statistics-october-2022/.

[8] Global Mobile Suppliers Association, "Private Mobile Networks August 2022 Summary," [Online]. Available: https://gsacom.com/paper/private-mobile-networks-august-2022-summary/.

[9] "Private LTE Networks & CBRS," [Online]. Available: https://www.ibwave.com/Marketing/Download/ebook-private-LTE-CBRS.pdf.

[10] FCC, "3.5 GHz Order on Recon and 2nd R&O," 02 05 2016. [Online]. Available: https://www.fcc.gov/document/35-ghz-order-recon-and-2nd-ro.

[11] Ofcom, “Enabling wireless innovation through local licensing,” 12 03 2019. [Online]. Available: https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation.

[12] Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, 15 09 2022. [Online]. Available: https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/LokaleNetze/Zuteilungsinhaber3,7GHz.pdf?__blob=publicationFile&v=9. .

[13] enterpriseiotinsights.com, “French regulator Arcep awards 13 private 5G licences in 3.8-4.0 GHz band,” 13 10 2022. [Online]. Available: French regulator Arcep awards 13 private 5G licences in 3.8-4.0 GHz band.

[14] 3GPP, “Technical Specification Group Services and System Aspects; System architecture for the 5G System (5GS); Stage 2 (Release 15), 3GPP TS 23.501 V15.12.0,” 2020.

[15] 3GPP, “TS 38.300 - version 16.2.0 Release 16: "NR; NR and NG-RAN Overall Description,” 2020.

[16] 3GPP, “TS 38.401; Technical Specification Group Radio Access Network; NG-RAN; Architecture description (Release 16),” 2021.

[17] 3GPP, “TS 38.425; 5G; NG-RAN; NR user plane protocol, v15.3.0,” 2018.

[18] 3GPP, “TS 38.470; “5G; NG-RAN; F1 general aspects and principles”, v15.5.0,” 2019.

[19] 3GPP, “TS 38.473; 5G; NG-RAN; F1 Application Protocol (F1AP), v16.3.1,” 2020.

[20] Benetel Limited, “RAN650,” [Online]. Available: https://benetel.com/ran650/.

[21] 3GPP, “TS 23.501; System architecture for the 5G System (5GS), v16.11.0,” 2021.

[22] 3GPP, “3GPP TS 38.460: "NG-RAN; E1 general aspects and principles".”.

[23] O-RAN Alliance, “ORAN-WG3.E2GAP.0-v02.02 “O-RAN Working Group 3; Near-Real-time RAN Intelligent Controller Architecture & E2 General Aspects and Principles v02.02”.”.

[24] O-RAN Alliance, “O-RAN-WG10.O1-Interface-v07.00: “O-RAN Operations and Maintenance Interface Specification v07.00””.

[25] O-RAN Alliance, “O-RAN-WG6.CAD-v03.00: “Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN v03.00”.”.

[26] O-RAN Alliance, “O-RAN-WG2.A1GAP-v02.03: “O-RAN Working Group 2; A1 interface: General Aspects and Principles v02.03”.”.

[27] O-RAN Alliance, “O-RAN-WG4.MP.0-v09.00: “O-RAN Alliance Working Group 4; Management Plane Specification v09.00”.”.

[28] O-RAN Alliance, “O-RAN-WG6.CAD-v03.00: “Cloud Architecture and Deployment Scenarios for O-RAN Virtualized RAN v03.00”.”.

[29] ZVEI / 5GACIA, “www.5g-acia.org,” February 2019. [Online]. Available: https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2019/Maerz/5G_for_Connected_Industries_and_Automation/WP_5G_for_Connected_Industries_and_Automation_Download_19.03.19.pdf.

[30] SKYWORKS SOLUTIONS, “5G-Expands-Beyond-Cellular-What-You-Need-to-Know,” July 2018. [Online]. Available: https://www.skyworksinc.com/-/media/SkyWorks/Documents/Articles/5G-Expands-Beyond-Cellular-What-You-Need-to-Know.pdf.

[31] Enterprise IoT Insights, “What is mMTC in 5G NR, and how does it impact NB-IoT and LTE-M,” October 2019. [Online]. Available: https://enterpriseiotinsights.com/20191016/channels/fundamentals/what-is-mmtc-in-5g-nr-and-how-does-it-impact-nb-iot-and-lte-m.

[32] GSMA, “gsma-5g-mobile-iot,” April 2018. [Online]. Available: https://www.ericsson.com/assets/local/reports-papers/5g/doc/gsma-5g-mobile-iot.pdf.

[33] 4G LTE Networks, “What are NB-IoT and LTE-M,” 22 May 2020. [Online]. Available: https://www.4g-lte.net/lte/what-are-nb-iot-and-lte-m/.

[34] Qualcomm, “5G: Bringing precise positioning to the Connected Intelligent Edge,” 7 December 2021. [Online]. Available: https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/5g_positioning_for_the_connected_intelligent_edge.pdf.

[35] Ericsson, “5G positioning: What you need to know,” 18 December 2020. [Online]. Available:

https://www.ericsson.com/en/blog/2020/12/5g-positioning--what-you-need-to-know.

[36] ANDREA CONTI, SANTIAGO MAZUELAS, STEFANIA BARTOLETTI, WILLIAM C. LINDSEY , MOE Z. WIN, "Soft Information for Localization-of-Things," IEEE, 2019.

[37] ZVEI / 5GACIA, "5G for Connected Industries and Automation (White Paper - Second Editon)," February 2019. [Online]. Available: https://www.zvei.org/en/press-media/publications/5g-for-connected-industries-and-automation-white-paper-second-editon.

[38] ZVEI/5GACIA, "Service-Level Specifications (SLSs) for 5G Technology-Enabled Connected Industries," September 2021. [Online]. Available: https://5g-acia.org/wp-content/uploads/5G-ACIA_Guaranteed-Service-Level-Specification-SLS-for-5G-technology-enabled-connected-industries_2021.pdf.

[39] Benetel, "Benetel 650," [Online]. Available: https://benetel.com/ran650/.

[40] G2 Digital, "2U NANO C9395L," [Online]. Available: https://g2digital.co.uk/rack-pc/2unano-rackpc/2u-nano-ryzen-9-3950x-2-pcie-slots/.

[41] Creo Server, "Dell PowerEdge R630 SFF Generation 13," [Online]. Available: https://www.creoserver.com/dell-r630-e5-2603v3-16ghz-6-core-32gb-ram.

[42] Supermicro, "SuperServer E300-9A-16CN8TP," [Online]. Available: https://www.supermicro.com/en/products/system/Mini-ITX/SYS-E300-9A-16CN8TP.cfm.

[43] O-RAN Alliance, "O-RAN Architecture Description 7.0. O-RAN.WG1.O-RAN-Architecture-Description-v07.00,," 2022.

[44] Directorate-General for Communications Networks, Content and Technology (European Commission) , LS telcom AG , Policy Tracker , Valdani Vicari & Associat, "Study on spectrum assignment in the European Union," 05 10 2017. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/865c787b-aa42-11e7-837e-01aa75ed71a1/language-en.

[45] FCC, “Auction 105: 3.5 GHz Band,” [Online]. Available: https://www.fcc.gov/auction/105.

13. Appendix I

13.1. UEs

13.1.1. Technical characteristics and band support:

Feature	Implementation
Device Type	5G eMBB
Category	3GPP Release 16 256 QAM UL/DL
Bands	FDD: n1, n2, n3, n5, n7, n8, n12, n13, n14, n18, n20, n25, n26, n28, n30, n66, n70, n71 TDD: n38, n40, n41, n48, n53, n77, n78, n79 SDL: n75, n76
SIM/UICC	Dual SIM with eUICC on board, Dual SIM Single Active (DSSA/DSDA)
Form factor	M.2 3042 S3 Key B
Connector	PCI Express® M.2 Card system (75 pin golden finger, Key ID B)
USB	USB 2.0 (for debug/factory mode only) USB 3.1 Gen.2 SuperSpeed+ (10Gbps) USB configuration supported: Windows (TM) 11: MBIM, GNSS Linux: DIAG, MBIM, Modem, NMEA
Antenna	4 MHF4 type connectors for UMTS/LTE/5G (Sub 6G) main antenna and UMTS/LTE/5G (Sub 6G) Diversity/MIMO antennas

Figure 26 *UE Technical Characteristics and Band Support*

13.1.2. Antenna Interfaces

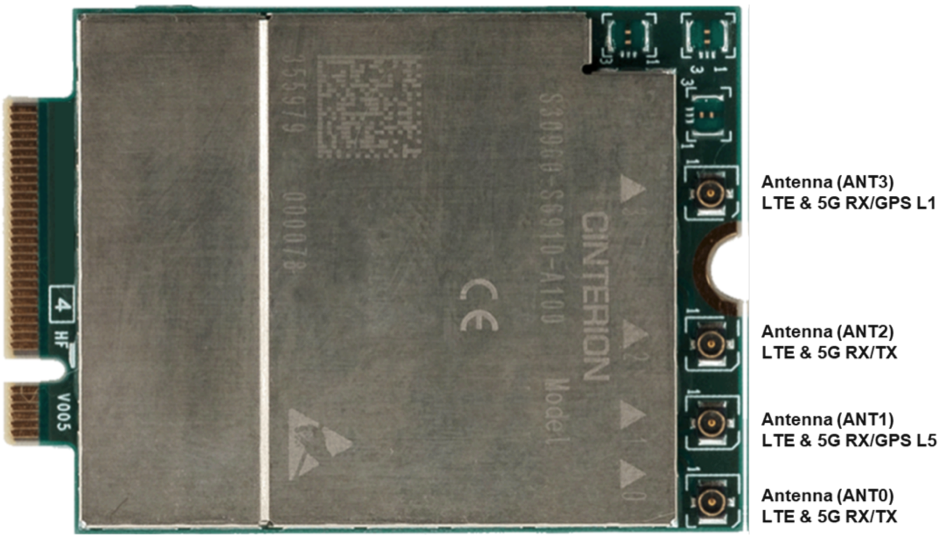

Figure 27 *UE Antenna Interfaces*

13.1.3. UE System Overview

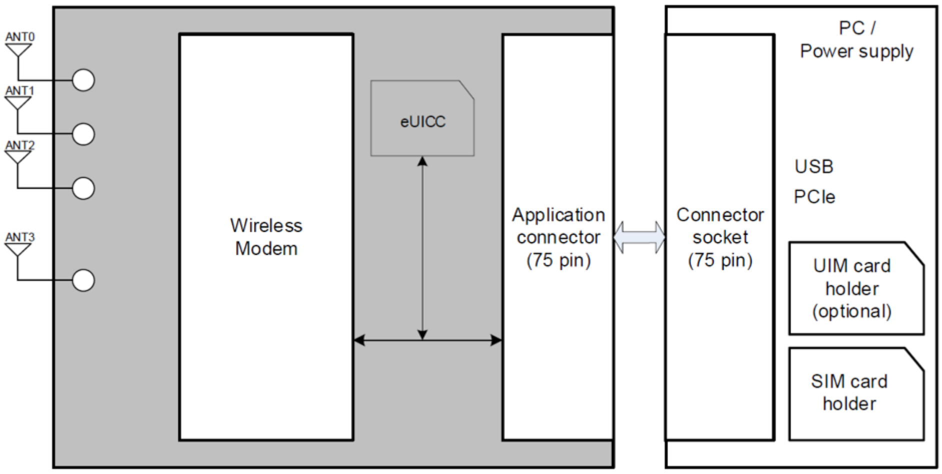

Figure 28 *UE System Overview*

13.2. RUs

The specification of the Benetel 650 RU can be downloaded from [39]. Additional accessories that are required for the RU and are not supplied by default e.g., antennas power supply units etc., are listed in section 13.5.

13.3. COTS for DU, CU and RIC

Representative specifications for a COTS Server for hosting the Accelleran RAN software (and 3rd-Party DU) can be found in [40] and [41] with a minimum specification of 4 CPUs, 32 GB of RAM and 256 GB of permanent storage. Note: An Intel X520 NIC card with compatible (Intel-approved) SFP+ transceiver is required for a direct connection to the DU server using 10G fibre (no switches in between).

13.4. COTS for 5GC

A representative specification for a COTS Server for hosting the Athonet 5GC can be found in [42] with a minimum configuration of 4 CPUs and 8 GB of RAM.

13.5. Accessories

13.5.1. GPS Antenna

The RU has a GNSS (GPS) input from the external mounted antenna via RG174 coaxial cable, this will typically have an N Type connector on the GPS antenna itself and an SMA connector into the RU. The GPS receiver is included in the Benetel 650 but an external GPS antenna and its cable needs to be mounted and are not part of the kit provided.

13.5.2. RU Power Supply Unit

No Power Supply Unit (PSU) is supplied with Benetel RAN650 RU. Just cable the RU to -48v/0 with standard 2 coloured 3A power cable as specified in the Benetel installation manual.

For lab environments a standard Lab PSU can be used. For non-lab deployment scenarios, a remote controllable PSU can be considered, as it will allow to power-cycle the RU to recover from any unexpected failure conditions. An additional cable to connect the RU to the PSU is required.

13.5.3. RU Attenuator

Attenuators are not needed since RU can be configured to max Tx power/attenuation based on antenna to be used, so that max EIRP conditions of the shared access spectrum license for indoor use are respected. It might be required to use a HW attenuator to comply with the licence conditions so that the Radio can never send out more power then allowed. For Lab use 30dBm Attenuators are recommended. One Attenuator is needed for each Antenna port. The 650 RU uses N-type connectors. Depending on the antenna connected, different attenuator or cable connector types might be needed.

13.5.4. RU SFP+

An SFP+ that works with the Intel X520 Nic card is recommended. The SFP+ module needs to be compatible with the Fibre type used i.e., Multi-Mode or Single-Mode.

13.5.5. RU Fibre

For distances over 300 metres Single-Mode fibre is recommended. For shorter distances Multi-Mode fibre can be used.

13.5.6. RU Antennas

The type of antennas to be used will be determined as part of final Radio planning.