5G Rural Dorset WP6 Task 3: O-RAN and Neutral Host

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Abbreviations

BBU	Baseband Unit
O-CU	O-RAN Central Unit
O-CU-CP	O-RAN Central Unit – Control Plane
O-CU-UP	O-RAN Central Unit – User Plane
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
near-RT RIC	O-RAN near-real-time RAN Intelligent Controller
non-RT RIC	O-RAN non-real-time RAN Intelligent Controller
eNB	E-UTRAN Node B
O-eNB	O-RAN eNB
gNB	gNodeB
MORAN	Multi-operator radio access network
MOCN	Multi-operator Core Network
MIMO	multiple-input, multiple-output
NSA	NonStand Alone
RIC	RAN Intelligent Controller
RRU	Remote Radiohead Unit
RAN	Radio Access Networks
xAPP	Near-RT RIC Applications
rApp	Non-RT RIC Applications
SMO	Service Management and Orchestration Network
NH	Neutral Host
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
5GC	5G Core
AMF	Access Mobility Function
UPF	User Plane Function
LLS	Lower Layer Split
SDN	Software Defined Networking
QoS	Quality of Service

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Introduction

Satellite Applications Catapult is leading this Work Package 6, where it is responsible for the scope, delivery (design, build and test), validation and acceptance of work. This work package utilises Network Functions Virtualisation so as to allow network operators to significantly reduce costs and the maturation cycle. Virtualisation caters for any future production, test and integration efficiently and allows for the customised services which can be rapidly scaled up/down as required. In addition, service velocity is improved by remote provisioning and the enablement of a wide variety of multivendor/multi-tenant systems bringing new services and new revenue streams at a lower risk. It also allows for network configuration optimisation on a near real time basis. The analysis undertaken here is based on OpenRAN specifications and the interfaces.

This report includes (a) ORAN Architecture (b) ORAN Interfaces and (c) an assessment of how ORAN fit alongside the Neutral Host architecture options.

The O-RAN Alliance

O-RAN ALLIANCE was established in 2018 by AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO and Orange and has grown to 237 mobile operators, network equipment providers, and research and academic institutions operating in the Radio Access Network (RAN) industry. O-RAN has two membership categories: Members and Contributors or Academic Contributors. The Board is consisting of up to 15 Members; there are 5 founding Members and up to 10 elected Members. The operators now represented on the board for 2020-2022 are (as per [1]):

Company	Type
AT&T	Founding Member
China Mobile	Founding Member
Deutsche Telekom	Founding Member
NTT DOCOMO	Founding Member
Orange	Founding Member
Bharti Airtel	Elected Member
KDDI	Elected Member
Rakuten Mobile	Elected Member
Reliance Jio	Elected Member
Singtel	Elected Member
TIM	Elected Member
Telefonica	Elected Member
Telstra	Elected Member
Verizon	Elected Member
Vodafone	Elected Member

O-RAN ALLIANCE aims to drive new levels of openness in the Radio Access Network. The new O-RAN standards will enable a more competitive RAN supplier ecosystem thanks to the open, multi-vendor interfaces. This increase of competition will result in faster innovation and service optimisation. To achieve this, O-RAN ALLIANCE publishes new specifications standards for open, intelligent and big data and AI enabled RAN, releases open software development for the RAN and supports member companies in testing and integration of their O-RAN implementations.

The Open RAN Concept

In RAN deployments until now, the software, the interfaces and the underlying hardware are proprietary of one vendor and are all tied together. On the other hand, the key concept of Open RAN is based on openness of interfaces and infrastructure between the various building blocks in the RAN. Open RAN targets to achieve open, interoperable interfaces non-proprietary of a closed vendor environment but a standardized, multi-vendor one which maximizes the use of common-off-the-shelf hardware. An open, vendor-neutral hardware and software-defined technology with open interfaces between all the components, environment like this, aims to expand the ecosystem and increase the competition. It is also expected to stimulate innovation and service optimisation since more vendors are involved and provide the building blocks of a RAN.

The Open RAN Architecture

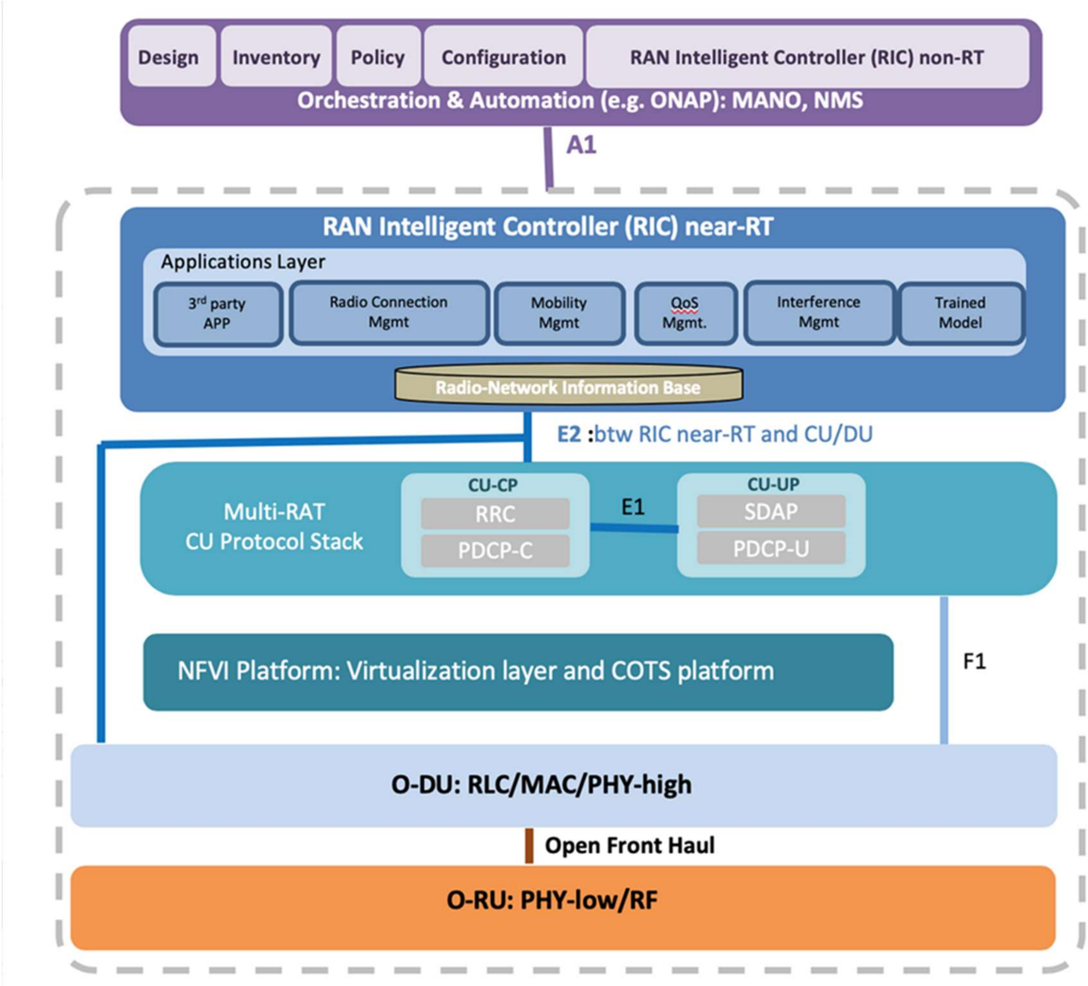

Figure 1. ORAN Architecture, source [1]

The Open RAN Architecture [2] is designed with standardized interfaces to support existing and next generation 5G RAN infrastructures. It is based on open, inter-operable, virtualized cloud-centric hardware for enhanced collaborations between multiple suppliers and network vendors. Such collaborative efforts require flexibility, robustness, and interoperability to cater for the multitude of varied implementations. The O-RAN Alliance have nine working groups (See Appendix) which specify the functionalities of each module and its interfaces.

Typically, the ORAN can be configured with the following modules: Near-RT RIC, Non-RT RIC, O-CU-CP, O-CU-UP, O-DU and O-RU; also, the management side includes Service Management and Orchestration Framework. Those modules use ORAN O1, O1*, A1, F1, E1, E2 interfaces to communicate; X2, Xn interface for communication between RAN nodes; and interface to the Core Network via the NG interfaces as illustrated in Figure 2. An important observation here is the separation of RU, DU and CU, contrary to previous deployments in 4G and early generations in 5G. In an Open RAN environment, the RAN is disaggregated into three main building blocks, the Radio Unit (RU), the Distributed Unit (DU) and the Centralised Unit (CU). In a nutshell, the RU is where the radio frequency signals are received and transmitted, where analog to digital conversion and power amplification is happening. The DU and CU are the computation parts of the base station, where digital processing is happening including signal modulation, encoding, scheduling, and finally sending this digitalized radio signal into the core network.

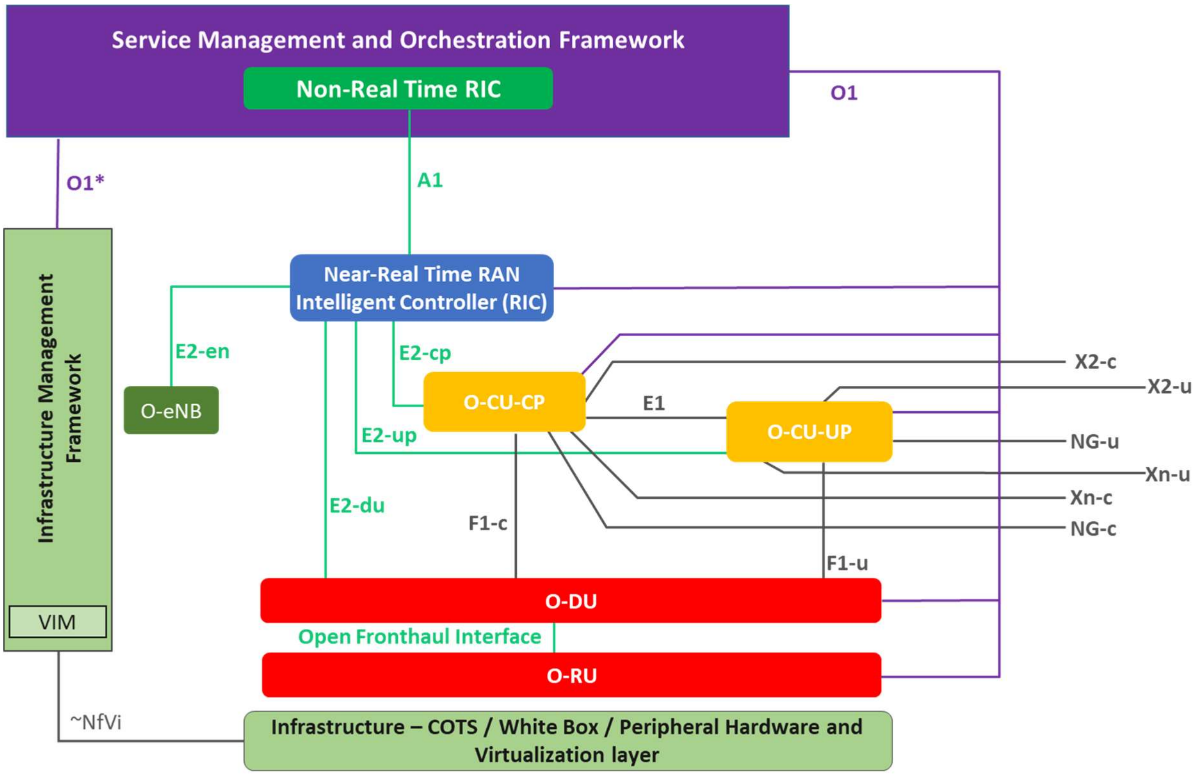

Figure 2. ORAN Architecture, source [14]

Specifically, the modules and associated interfaces can be defined in more detail as follows:

One of the main functional blocks is the RIC which enables SDN functionalities in open RAN networks and is responsible for all RAN operation procedures such as radio resource control, mobility, QoS management, edge services, and interference management, higher layer procedure optimization, policy optimization in RAN, that applies policies based on AI/ML models for optimising the network operation. In general RIC handles configuration, management and analytics functionality which makes it the key element to enable Open RAN to support interoperability across different hardware (RU, servers) and software (DU/CU) components, as well as ideal resource optimization for the best subscriber quality of service. There two types of RIC in ORAN as shown in Figure 2, namely Near Real-Time RIC (near-RT RIC) and Non-Real Time RIC (non-RT RIC). In detail:

near-RT RIC: It stands for O-RAN near-real-time RAN Intelligent Controller which is a logical function that enables near-real-time control and optimization of O-RAN elements and resources. Near-RT RIC, through one or more xApps that hosts, collects near-RT information using E2 interface on a UE or a cell basis and through A1 and O1 interfaces communicates with the Non-RT RIC which works, as described below, for the management and optimization of the RAN. xAPP is an application, independent of the Near-RT RIC which can be provided by any third party, a software plug-in which provides functional extensibility to the RAN. near-Real Time RIC is communicating with the RAN nodes through E2 interface. In detail, E2 is a standard interface between the near-RT RIC and one or more O-CU-CPs, one or more O-CU-UPs, one or more O-DUs, and one or more O-eNBs, for monitoring, suspension or stopping, overriding or control in the context of an O-RAN architecture. The RAN shall be able to function independently of the RIC and continue to function properly in case the E2 interface or the RIC fails. Hence this makes the E2 interface an optional interface.

non-RT RIC: This is the O-RAN non-real-time RAN Intelligent Controller, a logical function that, as defined by O-RAN Alliance [1], supports non-real-time control and radio resource management. Non-RT RIC, which as shown in Figure 2 lays in Service Management and Orchestration Network, is there to support intelligent RAN optimization by retrieving metrics from the network and then providing policy-based guidance, model management and enrichment information to the near-RT RIC function so that the RAN can be optimized. This is achieved by AI/ML policies and models that generate messages in non-RT RIC which are then conveyed, via the A1/O1 interfaces, to the near-RT RIC to support its operations. Like the near-RT RIC, here also non-RT RIC hosts applications named rApps, which can extend the functionalities and services of their host regarding RAN optimization; rApp examples include functions such as operation data analytics, AI/ML training etc. The A1 Interface is the standard interface that enables non-RT RIC and near-RT RIC to exchange messages, as defined by the WG2 ORAN alliance, that contains this information regarding policy management, enrichment information and ML model management service functionalities as specified in [8].

O-CU: O-RAN Central Unit is a logical node hosting RRC, SDAP and PDCP protocols, responsible for non-real time, higher L2 and L3 scheduling functions. RRC messages are responsible for functions such as connection, establishment and release, broadcast of system information, radio bearer establishment, reconfiguration, and release, RRC connection mobility procedures, etc [4]. This Unit is split in O-CU-CP for Control Plane which hosts the RRC and the control plane part of the PDCP protocol and O-CU-UP which hosts the user plane part of the PDCP protocol and the SDAP protocol. E1 is the interface between CU-CP and CU-UP. The E1 Interface contains error handling, configuration update functions in the gNB-CU-UP or gNB-CU-CP which allows the setup, exchange, and information data from gNB-CU-UP and gNB-CU-CP to inform NR CGI(s), S-NSSAI(s), PLMN-ID(s) and QoS information supported by the gNB-CU-UP. Additionally, it contains a reset function for initializing peer entities after a failure event occurred. Further E1 functionalities have been specified in [9]. The F1 interface acts as a midhaul interface between DU and CU that supports the exchange of signalling information between the logical end nodes points and separates Radio Network and Transport Network layers for data transmission as specified in [10]. It consists of both control plane and user plane via F1-C and F1-U interfaces. F1 need to be interoperable across different vendors to deliver the true promise of Open RAN. X2/Xn interfaces are defined as the interfaces between RAN nodes. The X2 is the interface between eNBs in LTE or between RAN nodes in 5G non-standalone operation. The X2-c interface is defined in 3GPP for transmitting control plane while the X2-u for transmitting user plane [3][11]. The Xn is the interface between RAN nodes in 5G standalone operation. Again here, Xn-c interface is defined in 3GPP for transmitting control plane information while Xn-u transmits user plane [12][3]. Finally, NG interface lies between RAN and the Core Network; NG-c interface, as defined by 3GPP, is between the gNB-CU-CP and the AMF in the 5GC and the NG-u interface, as defined by 3GPP, is between the gNB-CU-UP and the UPF in the 5GC [3]. In O-RAN, it reuses the principles and protocol stack defined by 3GPP but is adopted for the O-RAN specifications.

O-DU: O-RAN Distributed Unit which is a logical node hosting the RLC, MAC, and parts of the PHY layer of the radio interface towards the UE. DU is located between the O-RU and O-CU and performs real-time L1 and L2 functions, baseband processing and radio frequency processing. At O-DU terminate the E2 and F1 Interfaces, which were described above. O1 interface between O-DU and SMO is used for supporting the management features such as software management, configuration management, performance management, fault management and file management towards the O-DU as specified in [6]. Finally, O-DU is connected to O-RU through the Open Fronthaul Interface. A Lower Layer Split (LLS) Option 7-2x based architecture defining the open fronthaul interface, for functional splitting between O-DU and O-RU, is adopted by O-RAN [13]. An overview of Functional Split Architecture is shown in chapter below “Functional Split Architecture”.

O-RU: O-RAN Radio Unit, a logical node hosting Low-PHY layer and RF processing based on a lower layer functional split. O-RU functions as a termination to both Open Fronthaul Interface and any O1 interface towards the SMO as specified in [7].

Service Management and Orchestration Network: At the highest level, the Service Management and Orchestration functional block provides network functionalities such as Core Management, Transport Management, End to End Slice Management. O1 Interface connects the management entities in Service Management and Orchestration Framework and O-RAN managed elements, for operation and management, by which FCAPS (fault, configuration, accounting, performance, security) management, Software management, File management shall be achieved. O1* Interface between Service Management and Orchestration Framework and Infrastructure Management Framework supporting O-RAN virtual network functions.

Functional Split Architecture

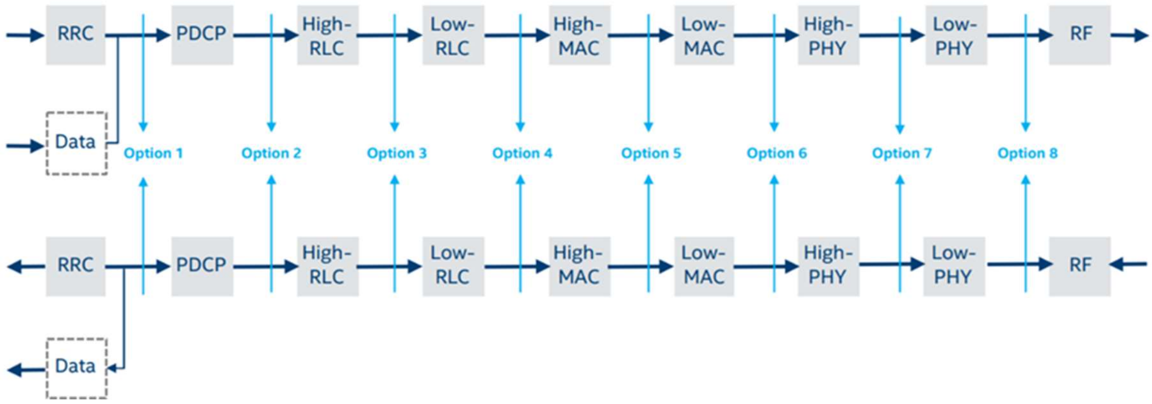

Figure 3. Functional Split Options. Source : [15]

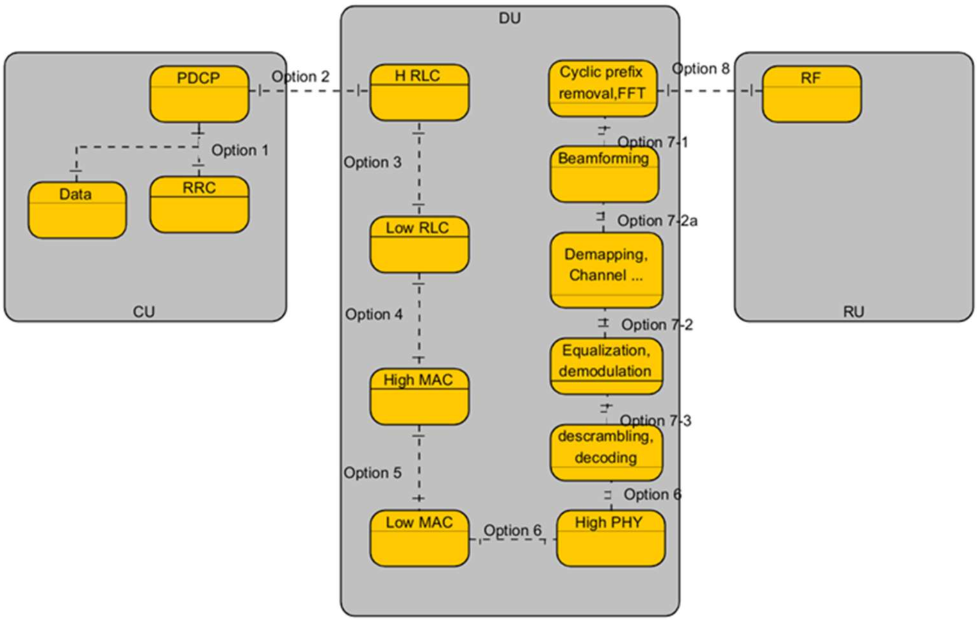

Figure 4. Functional Split Architecture

In the functional split architecture, fronthaul and backhaul are optimised for bandwidth and efficiency. The backhaul would either connect the wireless and/or wired networks through either cable or optical fibre to the fronthaul. Such a split architecture as shown in Figure 3 and 4, provides the customisation for user devices, access networks and the core networks of various combinations such as the split between the CU and DU (High Layer Split) and the DU and RU (Low Layer Split). For instance, one possible configuration is the BBU functionality being split into a centralized unit (CU), a distributed unit (DU) and a remote radio unit (RRH). A list of the functionalities associated with the various options is provided in Table 1. The DU is hosted in an Edge cloud while CU can be collocated with the DU in a regional cloud for a centralised RAN configuration. In a distributed scenario, the DU would reside with the radio unit (RU). The actual functionality supported in the CU, DU and RU as defined in 3GPP include IP related user plane and control plane separation within key elements. Information from the Radio Resource Control (RRC), Packet Data Convergence Protocol (PDCP), Medium Access Control (MAC) and Physical Layer (PHY) for both uplink and downlink are extracted from various components.

Options	Logical functions	Purpose
1	RRC/PDCP	
2	PDCP/RLC	F1 interface
3	Intra RLC	All ARQ and RT in RU
4	RLC/MAC	
5	Intra MAC	High level scheduling
6	PDCP/RLC/MAC	
7-1	MAC/Low PHY	IFFT and CP insertion/removal
7-2 and 7-2a	MAC/High PHY	Precoding and beamforming
8	PHY/RF	

Table 1: Functional Split Options

OpenRAN and Neutral Host

The term neutral host (NH) architecture is used to describe a network which resources are shared by multiple mobile network operators (MNOs) and mobile virtual network operators (MVNOs). The NH concept is growing fast with many vendors developing solutions considering the significant advantages Neutral Host has to offer, such as reduced costs for MNOs and MVNOs via Network Sharing in terms of capital investment in physical infrastructure, operational costs, and maintenance of equipment as well as deployment of new technologies much faster, maximisation of use of available resources, with minimal environmental impact.

There are different methods to manage this multi-operator environment. Examples are:

- a single operator owns the resources and provides access to these resources to others;
- two or more operators own resources and mutually provide to each other access to their resources;
- an independent network provider owns the resources and provides a service to any operator customer.

The case of NH solution using an OpenRAN combines the advantages of both OpenRAN and NH. In this use case the shared network includes the open radio access network. Specifically, a shared OpenRAN is configured to advertise multiple PLMNs for selection by UEs, each PLMN to be used by a single operator and when selected by a user will route the UE to the respective core network of this specific operator in order to be registered and have access to MNO's core network's resources and services. In this use case it can be either 4G or 5G systems that can share common OpenRAN resources. A 5G enabled Node B (gNB) [5] neutral host networks have been carried in Lucca illustrating [16] the use of NH platforms for new media services and managing connectivity from edge to cloud.

OpenRAN-based Neutral Host Architecture

A possible architecture for combining the OpenRAN framework within the NH concept is illustrated in Figure 5. In this architecture, a multi-band RRU can receive multiple connectivity requests from UEs belonging to different mobile operators. For simplicity, and without loss of generality, two MNOs operating in different bands are being considered in this exemplary scenario. However, a similar topology could be deployed in the case where operators are utilizing spectrum sharing agreements (i.e. the case of Multi Operator Core Network -MOCN)

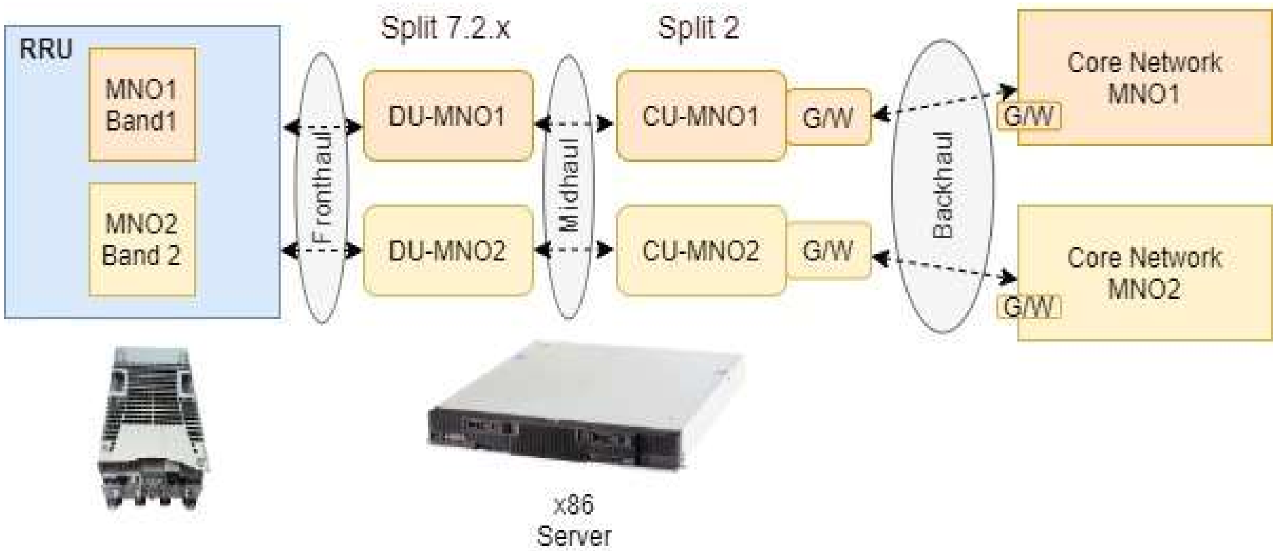

Figure 5. NH architecture based on OpenRAN interfaces.

Assuming a connection takes place from a UE subscribed to MNO-1, the UP/CP is transferred from the RRU to the corresponding distributed unit (DU1), through eCPRI that is an open fronthaul interface.

Split 7.2x implies FFT/IFFT, Cyclix Prefix insertion/removal, pre-coding and digital beamforming, modulation and demodulation or parts of it, are performed at the DU. Compared to option 8 (i.e. legacy C-RAN), only the samples related to occupied sub-carriers need to be processed at the RRU, instead of time domain samples reflecting the whole system bandwidth. Further , for 7.2x splitting, fronthaul requirements scale with number of MIMO layers and not number of antenna ports, as it is the case in option 7.1.

The link from DU to CU (Midhaul) is based on a split 2, splitting Radio Link Control (RLC) and Packet Data Convergence Control (PDCP). PDCP and RRC (Radio resource layer) are then logically located in the CU. This split corresponds to F1 interface in 3GPP Release 15. Finally, through a secure gateway, the communication is established to the core network of the respective operator.

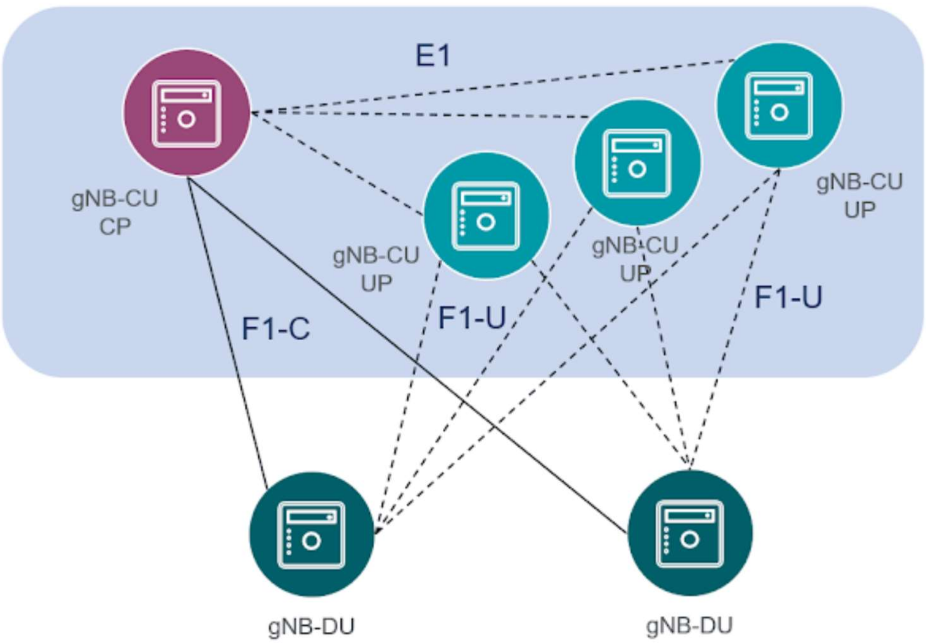

Figure 6. 5G DU-CU Connectivity in virtualized RAN

The benefits from the virtualized open radio access can be inferred from Figure 6. The figure demonstrates a single gNB-CU CP in charge of controlling several gNB-CU UPs and gNB-DUs. In a live network deployment, a single gNB-CU CP will control hundreds of gNB-DUs and maybe several gNB-CU Us [17]. These logical units will be deployed on commercial off the self hardware platforms, significantly reducing deployment and operational cost, whereas creating the required flexibility on the use of available resources, based on the network requirements.

More specifically, this centralized architecture implies that in a rural environment, based on appropriate radio planning, multiple NH RRH units can be deployed, whereas commercial off the shelf servers can host the respective DU and CU functions for each of the mobile operators under a single CU-CP reference point. In other words, the decoupling of RAN functionality into hardware and software layers, provides the possibility for the deployment of multiple high-level split NH RRUs, which in turn are associated with each of the operators' DUs and CU units, that can be hosted under the umbrella of a centralized infrastructure.

Market Research & Real-World Platforms

This report is mostly related to the underlying technology governing the OpenRAN ecosystem, as well as the use of NH use case which could essentially be part of the OpenRAN advancements. Going through the milestone deliverables of WP6, there is a specific task (Task 6) related to market/product research that will report and analyse the state of the art of current platforms and services available in the market.

This study is to be conducted with respect to product/platform maturity, flexibility, openness, as well as its deployment and operational cost. For instance, OpenRAN based NH platforms from major industrial players such as Mavenir and Airspan will be thoroughly reviewed and assessed. In addition, suggestions for improvement and a set of requirements will be shaped towards more flexible and cost-effective solutions that fully comply with the O-RAN alliance and the OpenRAN concepts.

Conclusions

This report details the concept of OpenRAN and its association with the Neutral Host paradigm. Empowered by principles of intelligence and openness, the OpenRAN architecture is the foundation for building the virtualized RAN on open hardware and software, with embedded AI-powered radio control. Inspired by the O-RAN alliance, the OpenRAN infrastructure combined with increasing RAN virtualization and data-driven intelligence, will allow complexity reduction, faster innovation and significant reduction on deployment and operational cost.

The report begins with an introduction to O-RAN alliance, whereas the OpenRAN architecture and the corresponding standardized interfaces are demonstrated in detail. Thereafter, RT and non-RIC components are described together with the service management and orchestration functional block. Next, the functional splitting points are discussed for the fronthaul, midhaul and transport data layers. Finally, an architecture for combining the OpenRAN framework within the NH concept is provided, emphasizing on the capabilities and benefits of deploying OpenRAN-based platforms for the NH use case.

Appendix

O-RAN Working Groups

W1	Use Cases and Overall Architecture Workgroup. It has overall responsibility for the O-RAN Architecture and Use Cases. Work Group 1 identifies tasks to be completed within the scope of the Architecture and Use Cases and assigns task group leads to drive these tasks to completion while working across other O-RAN work groups.
W2	The Non-real-time RAN Intelligent Controller and A1 Interface Workgroup. The primary goal of Non-RT RIC is to support non-real-time intelligent radio resource management, higher layer procedure optimization, policy optimization in RAN, and providing AI/ML models to near-RT RIC.
W3	The Near-real-time RIC and E2 Interface Workgroup. The focus of this workgroup is to define an architecture based on Near-Real-Time Radio Intelligent Controller (RIC), which enables near-real-time control and optimization of RAN elements and resources via fine-grained data collection and actions over E2 interface.
W4	The Open Fronthaul Interfaces Workgroup. The objective of this work is to deliver truly open fronthaul interfaces, in which multi-vendor DU-RRU interoperability can be realized.
W5	The Open F1/W1/E1/X2/Xn Interface Workgroup. The objective of this work is to provide fully operable multi-vendor profile specifications (which shall be compliant with 3GPP specification) for F1/W1/E1/X2/Xn interfaces and in some cases will propose 3GPP specification enhancements.
W6	The Cloudification and Orchestration Workgroup. The cloudification and orchestration workgroup seeks to drive the decoupling of RAN software from the underlying hardware platforms and to produce technology and reference designs that would allow commodity hardware platforms to be leveraged for all parts of a RAN deployment including the CU and the DU.
W7	The White-box Hardware Workgroup. The promotion of white box hardware is a potential way to reduce the cost of 5G deployment that will benefit both the operators and vendors. The objective of this working group is to specify and release a complete reference design to foster a decoupled software and hardware platform.
W8	Stack Reference Design Workgroup. The aim of this workgroup is to develop the software architecture, design, and release plan for the O-RAN Central Unit (O-CU) and O-RAN Distributed Unit (O-DU) based on O-RAN and 3GPP specifications for the NR protocol stack.
W9	Open X-haul Transport Work Group. This workgroup focuses on the transport domain, consisting of transport equipment, physical media and control/management protocols associated with the transport network.

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