Horizon Europe Framework Programme

OPTI-6G

OPTICAL 6G CELL FREE NETWORKS

D3.1 Near IR Cell Free Communication System Design

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ABSTRACT

This deliverable follows the use cases analysis document (OPTI-6G Deliverable D2.1) and provides the near infra-red and cell-free network system overall architecture design. It underlines the requirements and detailed specifications for the main building blocks to ensure feasibility of the design.

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Executive summary

This document covers the overall design specification. It contains detailed description of the system architecture of Optical Wireless Communication (OWC) and Cell Free Network (CFN), as well as the interfaces required in order to provide a fully functional communication system to respond to the targeted use cases.

It provides

- detailed use case specification and requirements
- general OWC/CFN system architecture
- detailed OWC/CFN system architecture and building blocks
- detailed system design
- detailed hardware interface
- detailed software interface and protocols
- preliminary testing methods and KPIs

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Company	Author	Contribution
OLEDCOMM	LARTIGUE Clément	Document structure, initial inputs for OWC and general architecture
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Document History

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5	03/02/2025	KAPOVITS Adam	Final editing and submission

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Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
5G-EIR	5G Equipment Identity Register
5QI	5G QoS Identifier
AC	Alternating Current
AFE	Analogue Front End
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AoA	Angle of Arrival
AP	Access Point
API	Application Programming Interface
AR	Augmented Reality
AUSF	Authentication Server Function
BW	Bandwidth
BWP	(5G NR) Bandwidth Part
CFN	Cell-Free Network
CMAS	Commercial Mobile Alert Service
CSI-RS	Channel Start Information Reference Signal
CU	Centralised Unit
DAS	Distributed Antenna System
DC	Direct Current
DCI	Downlink Control Information.
DIMM	Dual In-line Memory Module
DL	Downlink
DMRS	De-Modulation Reference Signal
DRB	Data Radio Bearer
DRX	Discontinuous Reception
DSS	Dynamic Spectrum Sharing
eDRX	extended Discontinuous Reception
EN-DC	(5G) Evolved Non-standalone Dual Connectivity
EPS	Evolved Packet System
ETWS	Earthquake and Tsunami Warning System
EUTRA	Evolved Universal Terrestrial Radio Access
FDD	Frequency Division Duplex
FoV	Field-of-View
FPGA	Field-Programmable Gate Array

FR1	Frequency Range 1
FR2	Frequency Range 2
GPS	Global Positioning System
GTP-U	GPRS Tunnelling Protocol User
IF	Intermediate Frequency
IM	Information Model
IMS	IP Multimedia Subsystem
IoT	Internet of Things
IP	Internet Protocol
IR	Infrared
ISAC	Integrated Sensing and Communication
ITU	International Telecommunications Union
IPR	Intellectual Property Right
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCM	Life-Cycle Management
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
LO	Local Oscillator
LoS	Line of Sight
LS	Location Server
MAC	Media Access Control
MANO	Management and Orchestration
MEC	Multiaccess Edge Computing
MIMO	Multiple-Input Multiple Output
ML	Machine Learning
mMIMO	Massive Multiple-Input Multiple-Output
mmWave	Millimeter Wave
MSG3	Message 3
NAT	Network Address Translation
NF	Network Function
NFV	Network Function Virtualisation
NFVI	Network Function Virtualisation Infrastructure
NGAP	Next Generation Application Protocol
NIB	Network In a Box
NIC	Network Interface Connection
NR	(5G) New Radio

NR-DC	NR Dual Connectivity
NS	Network Service
NSA	Non-Stand Alone
NSD	Network Service Descriptor
NTN	Non-Terrestrial Networks
NVMe	Non-Volatile Memory express
O-RAN	Open-Radio Access Network
O-RU	O-RAN compliant Remote Unit
OFDMA	Orthogonal Frequency-Division Multiple Access
OFE	Optical Front End
OSM	Open Source MANO (Management and Orchestration)
OVS	Open Virtual Switch
OWC	Optical Wireless Communication
PCB	Printed Circuit Board
PD	Photo-Detector or Photo-Diode
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PLC	Programmable Logic Controller
PRACH	Physical Random-Access Channel
PRS	Positioning Reference Signal
PTRS	Phase Tracking Reference Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	Quality of Service Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RADAR	Radio Detection and Ranging
REST	Representational State Transfer
RF	Radio Frequency
RRC	Radio Resource Control
RSS	Received Signal Strength
Rx	Receiver
SA	Stand Alone
SATA	Serial Advanced Technology Attachment

SDN	Software Defined Network/Networking
SDR	Software Defined Radio
SDT	Small Data Transmission
SMF	Session Management Function
SNR	Signal to Noise Ratio
SNS	Smart Networks and Services
SONAR	Sound Navigation and Ranging
SR	Scheduling Request
SSB	Synchronization Signal Block
SSD	Solid State Drive
SQL	Structured Query Language
SUL	(5G) Supplementary Uplink
TDD	Time Division Duplex
TDoA	Time Difference of Arrival
ToA	Time of Arrival
TRS	(5G) Tracking Reference Signal
Tx	Transmitter
UE	User Equipment
UDM	Unified Data Management
UL	Uplink
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communication
VCSEL	Vertical Cavity Surface Emitting Laser
VIM	Virtual Infrastructure Manager
VLC	Visible Light Communication
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	Virtual Network Function Descriptor
VR	Virtual Reality
WP	Work Package
XR	Extended Reality

1 Introduction and Objectives

1.1 Objectives of This Document

This document covers the general specification for the OWC cell free network system. It provides general architecture and detailed building blocks structure which are required to provide a technical solution for the different use cases. This specification and architecture phase will help in the design and development of the product and will lead to the detailed description of the solution.

1.2 Structure of This Document

Section 2 will outline the general requirements and specifications derived from the use cases, as well as the building block specifications.

Section 3 will primarily focus on the system architecture, from the high-level overview to the detailed building block architecture. Network protocols, interfaces, and the Cell Free implementation method will also be described in this section.

Section 4 will provide a detailed implementation of the solution, including OWC, CFN, and the required radio-to-optical interfaces.

Section 5 will cover network and protocol setup.

Section 6 will conclude the document by offering insights for preliminary test planning and validation of the solution.

2 Use Cases Analysis (requirements & specification)

2.1 Communication and UE Localization Use Cases

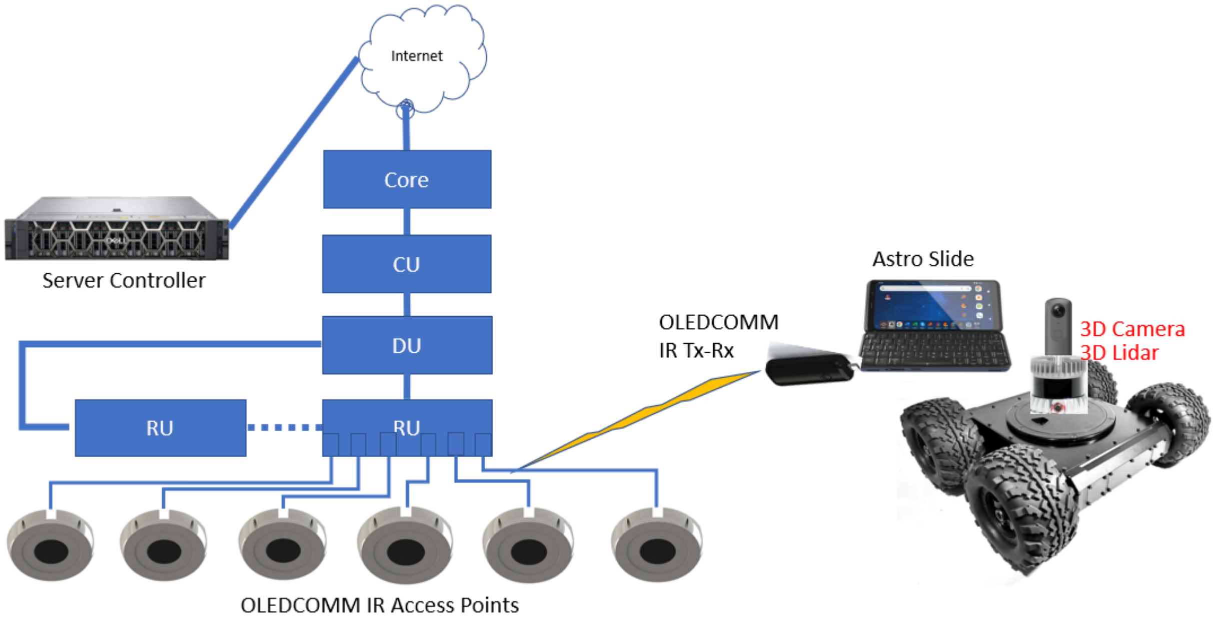

Figure 1 – AGV navigation - localisation and image processing offloading for collision avoidance

The position of a user equipment on an automated guided vehicle (AGV) will be estimated by measuring the distance and angle of the user equipment (UE) from photodiode (PD) at an Optical Wireless Communication (OWC) access point or by measuring the distance of the user equipment (UE) from four PDs at four Optical Wireless Communication (OWC) access points.

The angle is estimated by rotating the PD receiver at the OWC access point using a gimbal so that the Received Signal Strength (RSS) is at a maximum.

The distance is estimated by measuring the Received Signal Strength (RSS) and/or Time of Arrival (ToA) at the OWC access point from an IR emitter at the UE.

The combination of distance and angle obtains position or of four distances obtains position. This will be used for navigating the AGV in its environment on predefined routes.

A measurement campaign will be performed to measure accuracy in a coverage area.

A LIDAR will be installed on the AGV to capture a point cloud image of its environment for the purposes of collision avoidance using object detection. Alternatively, a camera and SONAR or RADAR will be used for the same purposes.

2.2 System Requirements and Specifications

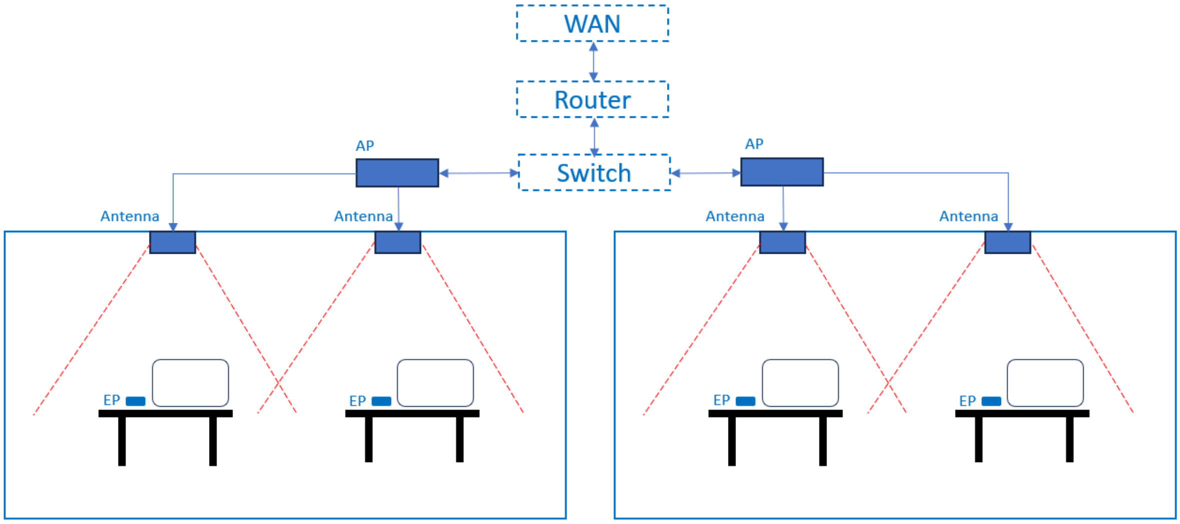

Figure 2 – Standard OWC implementation

As part of OPTI-6G the OWC system should be integrated with 5G radio system. This implies that the OWC Access Point and its Antenna have to be redesigned to interface with RF environment and be able to transport signals at a high frequency – around 3.3 GHz.

The OWC system should be able to interface with the 5G network using appropriate interfaces.

The Interface with the RU and UE side should be identical and compatible to allow flexibility in system integration phase.

On the UE side a commercial smartphone will be used to connect with the OPTI-6G OWC system. Integration with the smartphone requires access to the antenna to connect the RF to the OWC. In case integration is too complex or the phone manufacturer does not provide enough information to accomplish the interconnection, standard 5G modem connected to a laptop with easy access to the antennas can be used to emulate the user equipment.

Preliminary use of beam-steering techniques for communication and sensing (localization use cases) as part of the OPTI-6G project will allow to improve overall coverage and localization precision. By focusing the light beam on the receiver, beam-steering significantly increases the signal-to-noise ratio, leading to higher data rates and/or longer transmission distances. Additionally, it enables proper control over the coverage area, reducing interference and improving security. It can also be used to dynamically adjust the beam pattern to track moving receivers or adapt to changing environmental conditions, ensuring optimal performance in various scenarios. Beam-steering is a key technology that enhances the efficiency, reliability, and capacity of LiFi systems. Requirements to the OWC in order to use it with beam-steering tools will also be taken into account in the specification of Deliverable 3.1. More information on the use of beam-steering system will be describe in the deliverables of Work Package 4 of OPTI-6G.

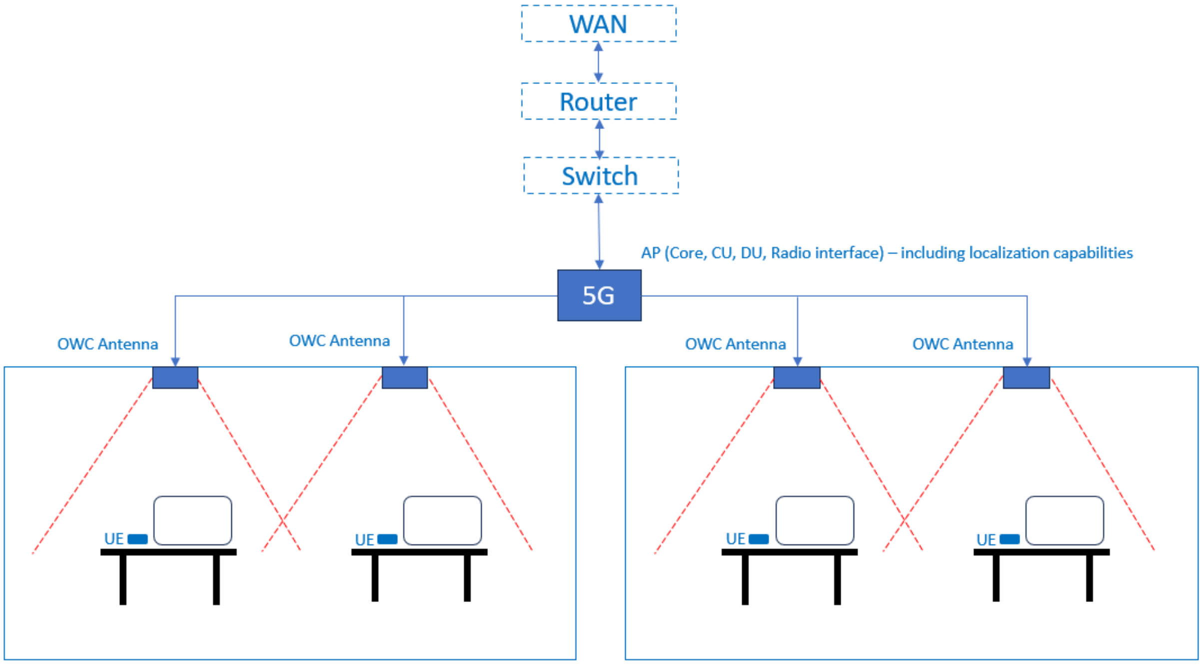

Figure 3 – Targeted implementation of hybrid Radio and OWC cell free network

The implementation of a CFN deployment will reduce the number of required equipment elements. In the above specific case, only one AP will be needed instead of two. Performances of the communication system will remain unchanged. Additionally, the 6G implementation will provide enhanced localization capabilities, opening innovative possibilities for integration and usage as promoted by the OPTI-6G consortium. This will benefit to the whole so-called Industry 4.0 and its use cases.

2.2.1 Requirements for the Radio system

RunEL's RU provides a flexible, 5G outdoor and indoor network deployment solutions where increased capacity and coverage is required.

The RU is designed for coverage flexibility: depending on the required scenario, the same ORU can be configured to cover more sectors with relatively sparse concurrent user requirements or fewer sectors with higher needs.

Sparq-2025-ORU-3.5G ORUs provide adaptable solutions,

- 5G Radio for several Spectrum bands
- Optimized for Ultra Reliable Low Latency Communications URLCC

- Adaptable solution, O-RAN compatible (CAT. A and B) with PHY split (7.2) and standardized fronthaul, allowing interoperability with other vendors O-RAN 5G devices.
- HW Accelerated (FPGA based), based on 16 nm technology
- Includes novel (patented) technology for 1cm range accurate positioning of air linked devices
- 0pen and standardized interfaces
- Adequate for Indoor and Outdoor deployment
- Support for internal GPS receiver for TDD synchronization
- IEEE-1588 synchronization
- Small footprint, single-handed quick installation and simple provisioning
- Excellent sustainability with efficient energy consumption

2.2.2 RU Specifications

[RU-RQ001] Meets 3GPP Release 16 STAND ALONE- SA

[RU-RQ002] Duplexing Mode: TDD (All configurations)

[RU-RQ003] Sub Carrier Spacing 30 kHz

[RU-RQ004] Channel BW: Up to 100 MHz

[RU-RQ005] RF Antenna Gain – 17 dB

[RU-RQ006] Frequency: 3.3-3.8 GHz (Band N78)

[RU-RQ007] Modulation: QPSK, 16 QAM, 64 QAM, 256 QAM

[RU-RQ008] Beam width – 30 deg., 18 deg. Average +/- 5 deg.

[RU-RQ009] Polarization Dual Slant

[RU-RQ010] TTI spacing – 500 µsec

[RU-RQ011] Support CSI-RS, PTRS, DMRS

[RU-RQ012] Synchronization: GPS, Local clock, external input clock

[RU-RQ013] Meets O-RAN Split 7.2 requirements

[RU-RQ014] Meets O-RAN Cat. A and B

[RU-RQ015] Fronthaul port - Ethernet x10G SPF

[RU-RQ016] 1 x O-RAN SPF+

[RU-RQ017] Includes a USB port to control 4 UARTS (a for CPU, b for CPU, c for FPGA, d for GPS)

[RU-RQ018] Power input - -48 V DC (-35 to -75 V DC)

[RU-RQ019] Weight – 5 kg,

[RU-RQ020] Physical Dimensions – 40 x 24 x 12 cm

[RU-RQ021] Includes a minimum of 4 RX ports and 1 TX ports

[RU-RQ022] Each port should include a circulator in order to have a unidirectional signal ether emission of reception.

[RU-RQ023] Output ports should be SMA instead of existing N-type ports

The following figure depicts the RU including its assemblies. The antenna assembly will be replaced by connections to circulators and SMA output ports.

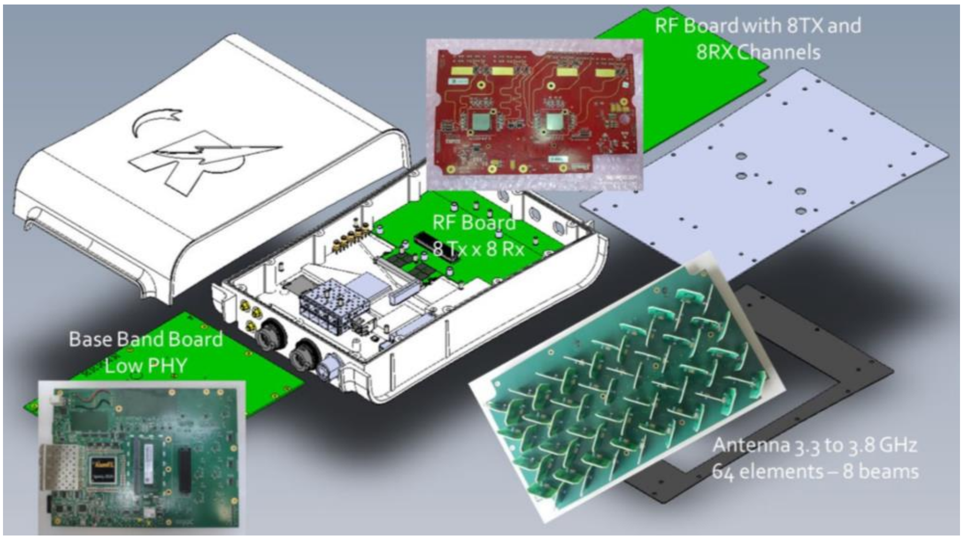

Figure 4 – RU assembly

In the following figure a CU/DU server along with two RUs configuration is shown.

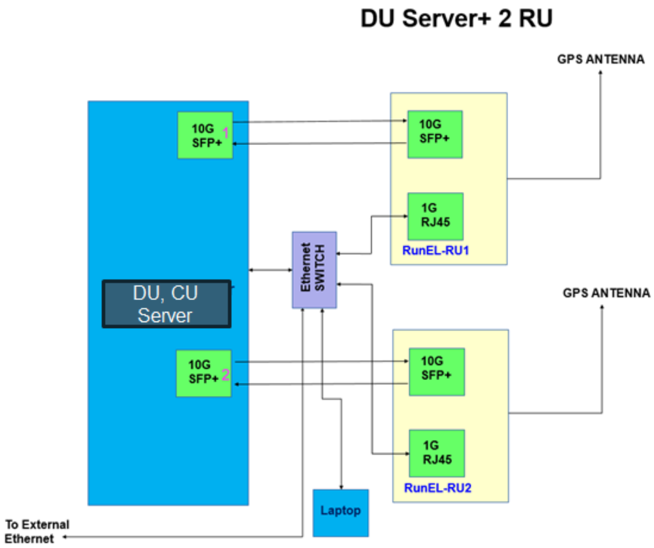

Figure 5 – CU/DU Server and 2 RUs Configuration

The diagram above depicts a basic cell free 5G Network where two access points (RUs) are connected to a single central processor unit called Network In a Box (NIB). The NIB includes a 5G core (NgCore) a Control Unit (CU) ad a Distributed Unit (DU) protocol stack installed on a high-end server which is connected to the two RUs via the O-RAN PHY Split option 7.2.

This diagram will be converted to an OWC cell free 5G Network by replacing the 3.5 GHz transmitter and receiver units with optical transmitters and detectors using 5G numerology (OFDMA).

The motivation to use this architecture is to test the benefits of the cell free 5G network operating at the optical domain rather than the traditional microwave domain (usually at 3.5 GHz (n78 band). Improvements are expected in the coverage area, throughput to and from (Downlink and Uplink) the UE, as well as the handover time from cell to cell.

2.2.3 Requirements for the OWC system

OWC system should be designed in such a way that each of its antenna covers a minimum of 5 m^2. This represents 64° of FOV based on belt plotter scenario and the considered communication distance of 2 meters.

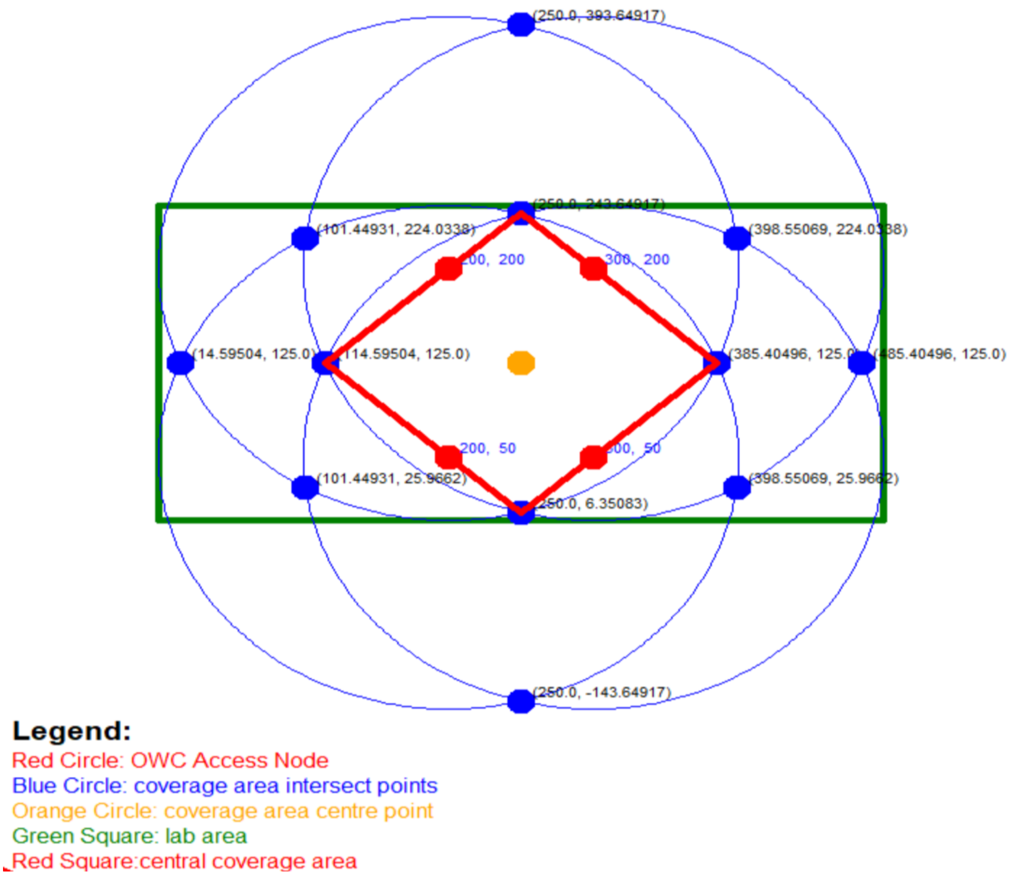

Figure 6 – Projection of the minimum required coverage of each OWC antenna

The position of the OWC Access Nodes were estimated by eye but there is no easy closed form mathematical solution to compute the optimum position of the access nodes so in order to estimate their optimum position an AI machine learning search algorithm is needed to be applied. The green square denotes the laboratory working area with each OWC access node antenna denoted by red circle. Lines in blue represent the coverage of each antenna in reception and blue circles the intersection points of these coverage areas. The red zone represents the minimum coverage required in emission for a single emitter placed in the centre of the targeted area [FRE24]. The orange circle denotes the centre point of the coverage area. In this configuration placing UE in the red area ensures sufficient overlap of the receivers for the implementation of localization technics.

An AI Genetic Algorithm (GA) will be used to find the best location of indoor OWC transmitters to maximise overlap of their coverage areas and coverage area in Python. GAs are a meta-heuristic search technique inspired by natural evolution [HOL92][TAL09]. They have been successfully applied to a wide range of real-world problems of significant complexity, too complex for exact methods. A GA operates on a population of often randomly generated solution representations known as chromosome(s). Each chromosome represents a solution to a problem and has a fitness (returned by the objective function), a real number which is a measure of how good a solution it is to addressing the particular optimisation problem. Starting from the generated population of chromosomes, a GA carries out a process of fitness-based selection and recombination to produce a successor population, referred to as the next generation. During recombination, parent chromosomes are selected and their genetic material (solution components) combined based a crossover method to produce child chromosomes. These then pass into the successor population. As this process is iterated, a sequence of successive generations evolves and the average fitness of the chromosomes tends to improve until some stopping criterion is reached (often a maximum number of iterations). The fittest (i.e. the solution with the best objective value) chromosome in ultimate population is returned as the optimal solution to the problem. In this way, a GA "evolves" a best solution to a given problem.

Emitters and receivers should be made of matrix of emitters and receivers, if possible, to allow future use of beam-steering or beam-switching technics and adaptative behaviour of the OFE and OWC system. This is not an official requirement as part of the OPTI-6G project but it would be an interesting setup to put in place. Feasibility will be confirmed in implementation phase.

[OWC-RQ001] OWC should have an emission coverage of at least 64° in order establish the link in the 5sqm surface pointed in figure 4

[OWC-RQ002] OWC should have a reception coverage of 90° to make sure there is sufficient overlap between the different receivers for localization method that will be implemented as part of WP4

[OWC-RQ003] OWC system should provide 200 Mbps connectivity in physical layer in the defined coverage area of 5 sqm. Speed of the link could be reduced when interfacing OWC system with 5G. Impact still needs to be calculated during the integration phase.

[OWC-RQ004] OWC system should be able to interface with 5G system meaning that 3.3GHz should be exploitable form the physical interface of the OWC system

[OWC-RQ005] OWC system should be connected to 5G network through SMA connectors - 2 separated connectors for emission and reception

[OWC-RQ006] OWC should be supplied through standard DC connector independent from radio unit power

[OWC-RQ007] OWC system should be powered with 5 to 28 V DC. Exact DC range will be defined in implementation phase

[OWC-RQ007] Power consumption of the OWC system should not be greater than 15W.

[OWC-RQ008] OWC modules with the mechanical enclosure should be mounted via a hook or a loop on the demonstrator. Alternatively, holes/screws placed on the PCB (electronic board) should allow direct mounting on the demonstrator without mechanical enclosure to match with all partners constraints.

[OWC-RQ009] OWC modules including mechanical enclosure should be 140x140x40mm maximum with total weight of maximum 800 grams.

[OWC-RQ010] OWC modules should include an extra SMA port to retrieve RSS

[OWC-RQ011] OWC modules should be provided as 2 separated modules: 1 module for the emission and 1 module for the reception

3 System Architecture Overview

3.1 General Architecture

The OPTI-6G End-to-End Cell Free network to be developed and tested in the project is depicted in the Figure 5 below. the System consist of a Central Unit Server that includes the Core Network (5GCore), The Control Unit (CU) and the distributed Unit (DU). The Central Unite Server is connected via Standard O-RAN Protocol (Option 7.2) to two RUs that have been modified to operate in the optical domain instead of sub 6GHz bands by use of circulators and Up/Down Converters to transfer the RF signal to Zero IF that drives the Optical Transmitters (Tx) and Detectors (Rx). The two RUs are connected simultaneously to the User Equipment that was also modified to operate in the optical domain via same implementation of a circulator and Up/Down converter. The fact that the uplink signal transmitted by UE and detected by two different RUs and processed and combined at the DU to obtain a single optimized up link stream represents the performance of the Cell Free Network.

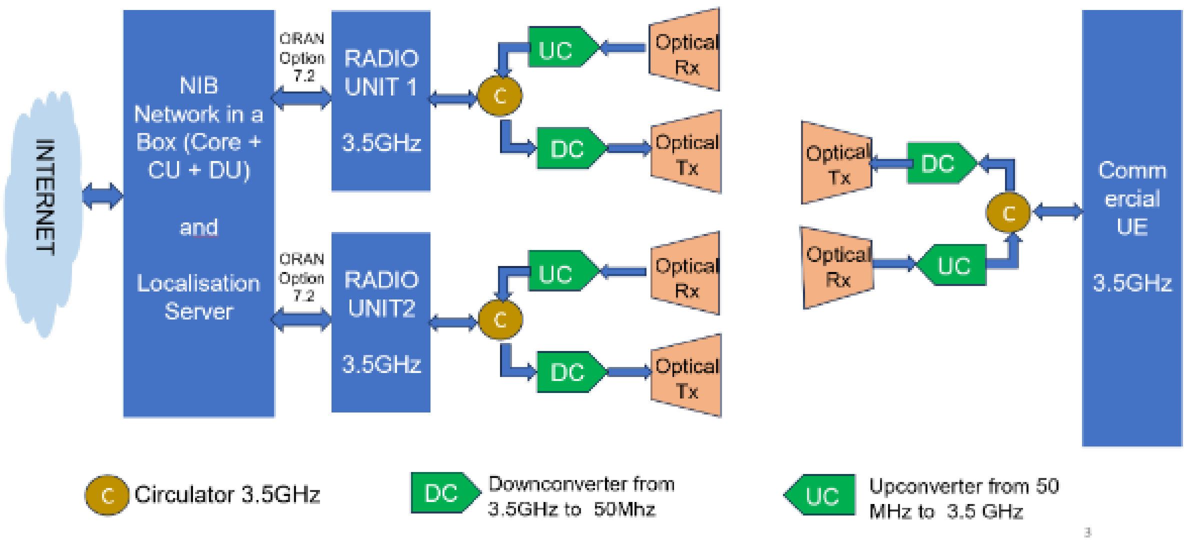

Figure 7 – General Architecture of Radio to OWC system for OPTI-6G

The OWC link performance KPIs such as Throughput, latency, capacity, Bit Error Rate, Coverage range will be compared between the Cell Free network and the regular 5G OWC network that connects the UE to only one RU.

3.2 Building Blocks (Core, CU, DU, RU, OWC and UE) Description

3.2.1 RU building blocks

The RU building block is described and specified above (chapter 2.2).

RAN upper layers building blocks – The DU, CU and the Core are provisioned by Amarisoft software package which runs over Dell xr11 server.

Amarisoft software technology caters to 5G RAN requirements.

Amarisoft provides software to the wireless industry, compatible with readily available off-the-shelf hardware, including the physical layer.

3.2.2 Key Features of Amarisoft's 5G DU

The DU Manages real-time functions, including parts of the Physical (PHY) layer and the Medium Access Control (MAC) layer. The DU is responsible for tasks that require low latency, such as scheduling and signal processing. Its main features include:

- Software-Defined Radio (SDR) Integration: Amarisoft 5G DU operates seamlessly with various SDR platforms, enabling flexible deployments.
- Various Configurations support: These include standalone (SA) and non-standalone (NSA) modes. Facilitates carrier aggregation and MIMO configurations, enhancing network capacity and performance.
- High Performance and Scalability: Designed to handle up to 1,000 active UEs, the DU ensures robust performance for both public and private network deployments. Scalable architecture.
- Advanced Features: The DU includes support for features such as Dynamic Spectrum Sharing (DSS), Non-Terrestrial Networks (NTN), and Reduced Capability (RedCap) devices, aligning with the latest 3GPP Release 17 specifications.

3.2.3 Key Features of Amarisoft's 5G CU

Amarisoft 5G software suite includes the Centralized Unit (CU) as part of its virtualized Radio Access Network (vRAN) architecture. In 5G networks the gNodeB (gNB) is divided into two main components:

a. Centralized Unit (CU): Handles non-real-time functions such as the Radio Resource Control (RRC) and:
b. Packet Data Convergence Protocol (PDCP) layers.

The CU manages tasks like mobility control, session management, and Quality of Service (QoS) enforcement.

Amarisoft's vRAN package integrates the CU and DU functionalities into a software-based gNB, which can be deployed on standard Linux distributions running on x86 (or ARM general-purpose) servers. This architecture offers flexibility and scalability for a diversity of deployment scenarios.

The CU communicates with the DU via the F1 standardized interface, allowing for centralized management of multiple DU units. This architecture enables efficient resource allocation and supports advanced features like carrier aggregation and handovers.

3.2.4 Amarisoft 5G Core Features

The 5G Core Network is fully compliant with 3GPP Release 17 standards. This software package integrates several key network functions:

- Access and Mobility Management Function (AMF)
- Authentication Server Function (AUSF)
- Session Management Function (SMF)
- User Plane Function (UPF)
- Unified Data Management (UDM)
- 5G Equipment Identity Register (5G-EIR)

These functions collectively manage essential tasks such as mobility, session handling, authentication, and user data management.

For seamless integration, the 5G Core provides multiple network interfaces, part of these interfaces are listed below:

- NG Interface: Connects to gNodeBs, ng-eNodeBs, or N3IWFs using NGAP and GTP-U protocols.
- Rx and N5 Interfaces: Link to external IMS servers.

Overall, Amarisoft's 5G Core Network provides a robust, flexible, and fully integrated platform for deploying and managing the network 5G.

3.2.5 The vRAN software package

The vRAN software package is integrated with the RU by using standardized split 7.2 O-RAN interface.

The vRAN package includes Layer 3 and Layer 2 functionalities, and upper Physical layer functions. It connects via the split 7.2 to the RU.

The vRAN package supports a standard NG interface to connect with a 5G core network also provided by Amarisoft.

The vRAN package is configured through a plurality of parameters in a text file in JSON format. It has a WebSocket API for automation, and a command line interface.

Following is the vRAN package features and main specifications:

- NR release 17 compliant
- Supports FDD/TDD at FR1 (<= 7.125 GHz) and FR2 (>= 24.25 GHz)
- Bandwidth: 3 to 100 MHz

- Subcarriers Spacing - Data subcarrier spacing: 15, 30, 60 or 120 kHz. SSB (Synchronization Signal Block) subcarrier spacing: 15, 30, 120 or 240 kHz. All SSB/data subcarrier spacing combinations are supported
- MIMO - supports up to 4-layer downlink MIMO
- Up to 4-layer uplink MIMO.
- Supports up to 256 QAM (DL/UL) and 1024 QAM (DL)
- All PUCCH and PRACH formats
- Two steps RACH procedure
- PDCCH order PRACH procedure.
- Contention-free RACH procedure for PDCCH order and handover
- PUSCH with and without transform precoding. PUSCH and PDSCH with user configurable DMRS, PT-RS and number of symbols.
- PUSCH codebook and non-codebook TX configuration.
- Uplink Tx Switching in CA and SUL.
- User configurable TDD UL/DL pattern. Automatic or custom setting for k0, k1 and k2 values
- PDCCH with DCI 0_0, 0_1, 1_0 and 1_1 formats.
- CSI-RS and TRS support with automatic configuration available
- SRS support with automatic configuration available
- UL Configured Grant Type1 and Type2 support
- Scheduling Request support
- DSS support
- PHY test mode: support for continuous PDSCH and PUSCH transmission
- EN-DC support with dynamic activation/deactivation based on events
- FR1-FR1 and FR1-FR2 NR-DC support with dynamic activation/deactivation based on events
- Dynamic NR DRB configuration
- User selectable DRB configuration for each QCI/5QI
- DRX support
- RRC measurement with measurement gap support

- PScell (Primary Secondary) change support
- Standalone mode support
- Intra gNodeB, NG, Xn or 5GS to EPS handovers support
- Public Warning System (CMAS/ETWS) support.
- Carrier aggregation support, both in NSA and SA operation.
- Multi-BWP support with RRC and DCI BWP switching.
- Supplementary Uplink support.
- RRC release with redirection to EUTRA cell support.
- RRC Inactive mode support.
- EPS fallback support.
- Network slicing support.
- Positioning Reference Signals (PRS) support.
- eDRX support
- FDD, HD-FDD, TDD (e)RedCap support
- NTN support in FR1 and FR2
- PDSCH and PUSCH repetition support, including MSG3 repetitions
- Small Data Transmission support (4-steps and 2-steps RA SDT)

3.2.6 The gNB Server

The xr11 platform is a rugged, and compact 1U server. Its front view is depicted below.

Figure 8 – Dell rg11 Server

The server is designed for telecommunication, retail, restaurants, government, and military systems.

Compact design, measuring only 16 inches (400 mm) in depth, allows for installation in space-constrained areas.

Processor - a single 3rd Generation Intel® Xeon® Scalable processor with up to 36 cores.

Memory - Accommodates up to 1 TB of DDR4 memory across eight DIMM slots, with speeds up to 3200 MT/s. Additionally, it supports Intel Optane Persistent Memory 200 series, enhancing data handling capabilities.

Storage - Features four 2.5-inch drive bays compatible with SATA, SAS, or NVMe SSDs, with a maximum storage capacity of 61.44 TB. Universal backplane design allowing flexibility in storage configurations.

Networking - quad-port 25 GbE SFP28 LAN on Motherboard (LOM), providing high-speed network connectivity suitable for data-intensive applications.

Expansion - Includes three PCIe Gen4 slots, enables adding accelerators or other expansion cards to meet special workload requirements.

Power Supply - Supports various power supply options, including 700 W, 800 W, 1100 W, and 1400 W units, configurable for both AC and DC inputs ds.

Management - Incorporates Dell's iDRAC9 with Lifecycle Controller, facilitating comprehensive remote management and monitoring capabilities.

The XR11 is engineered to withstand harsh conditions ensuring reliable operation in rough environments exposed to dust, extreme temperatures, shock, and vibration. Dell xr11 server specifications are detailed in the next figure.

Feature	Technical Specifications
Processor	One 3rd Generation Intel Xeon Scalable processor with up to 36 cores
Memory	• Eight DDR4 DIMM slots, supports RDIMM 512 GB max or LRDIMM 1 TB max, speeds up to 3200 MT/s • Up to four Intel Optane PMem 200 Series slots, 512 GB max • Supports registered ECC DDR4 DIMMs only
Storage controllers	• Internal controllers (RAID): PERC H755, S150 • Internal Boot: Boot Optimized Storage Subsystem (BOSS-S1): HWRAID 2 x M.2 SSDs or USB • External PERC (RAID): PERC H840 • 12 Gbps SAS HBAs (non-RAID): internal- HBA355i, external-HBA355e
Drive bays	4 x 2.5-inch SATA/SAS/NVMe (SSDs) max 61.44 TB
Power supplies	• 1400 W Platinum AC/240 HVDC • 1100 W DC/-48 - (-60) V • 800 W Platinum AC/240 HVDC
Cooling options	Air cooling
Fans	Very High Performance fans • Six cold swap fans
Dimension	Rear Accessed configuration • Height: 42.8 mm (1.68 inches) • Width: 482.6 mm (19 inches) • Depth: 400 mm (15.74 inches) Ear to rear wall 477 mm (18.77 inches) with bezel 463 mm (18.22 inches) without bezel Front Accessed configuration • Height: 42.8 mm (1.68 inches) • Width: 482.6 mm (19 inches) • Depth: 400 mm (15.74 inches) Ear to rear wall • Bezel is not supported • 463 mm (18.22 inches) without bezel
Form Factor	1U rack server
Embedded management	• iDRAC9 • iDRAC Direct • iDRAC Service Module
Bezel	Optional bezel or security bezel
OpenManage Software	• OpenManage Enterprise • OpenManage Power Manager plugin • OpenManage SupportAssist plugin • OpenManage Update Manager plugin
Mobility	OpenManage Mobile
Integrations and Connections	OpenManage Integrations • BMC Truesight • Microsoft System Center • Red Hat Ansible Modules • VMware vCenter and vRealize Operations Manager OpenManage Connections • IBM Tivoli Netcool/OMNIbus • IBM Tivoli Network Manager IP Edition • Micro Focus Operations Manager • Nagios Core • Nagios XI
Security	• Cryptographically signed firmware • Secure Boot • Secure Erase • Silicon Root of Trust • System Lockdown (requires iDRAC9 Enterprise or Datacenter) • TPM 2.0 FIPS, CC-TCG certified, TPM 2.0 China NationZ
Embedded NIC	4 x 25 GbE SFP+ LOM
GPU options	2 x 70 W SW
Ports	For Rear Accessed configuration Front Ports • 1 x iDRAC Direct (Micro-AB USB) port • 1 x USB 2.0 Internal Ports • 1 x USB 3.0 Rear Ports • 1 x USB 2.0 • 1 x iDRAC dedicated port • 1 x USB 3.0 • 1 x Serial port • 1 x VGA For Front Accessed configuration Front Ports • 1 x USB 2.0 • 1 x iDRAC dedicated port • 1 x USB 3.0 • 1 x Serial port • 1 x VGA • 1 x iDRAC Direct (Micro-AB USB) port Rear Ports N/A Internal Ports • 1 x USB 3.0
PCIe	3 x PCIe Gen4 slots
Operating System and Hypervisors	• Canonical Ubuntu Server LTS • Citrix Hypervisor • Microsoft Windows Server with Hyper-V • Red Hat Enterprise Linux • SUSE Linux Enterprise Server • VMware ESXi • RHEL Realtime For specifications and interoperability details, see Dell.com/OSsupport.
OEM-ready version available	From bezel to BIOS to packaging, your servers can look and feel as if they were designed and built by you. For more information, visit Dell.com/OEM.

Figure 9 – Dell xr11 Server Specifications

3.2.7 OWC system building blocks

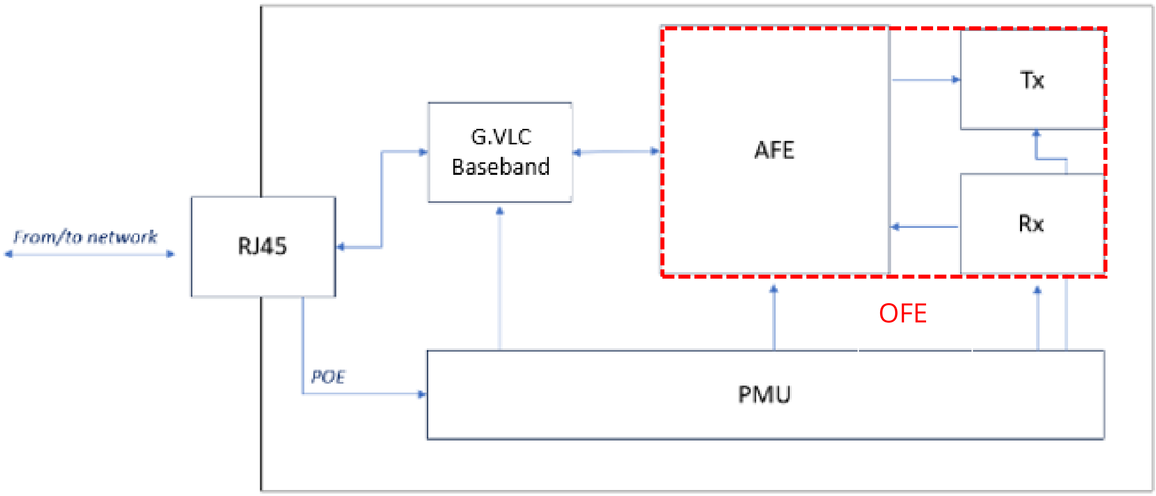

Figure 10 – Standard OWC building blocks

For OPTI-6G, the G.vlc baseband and the PHY Ethernet will be replaced by an up/down converter to allow using OWC in interface with 5G network leading to the following modification in the building blocks.

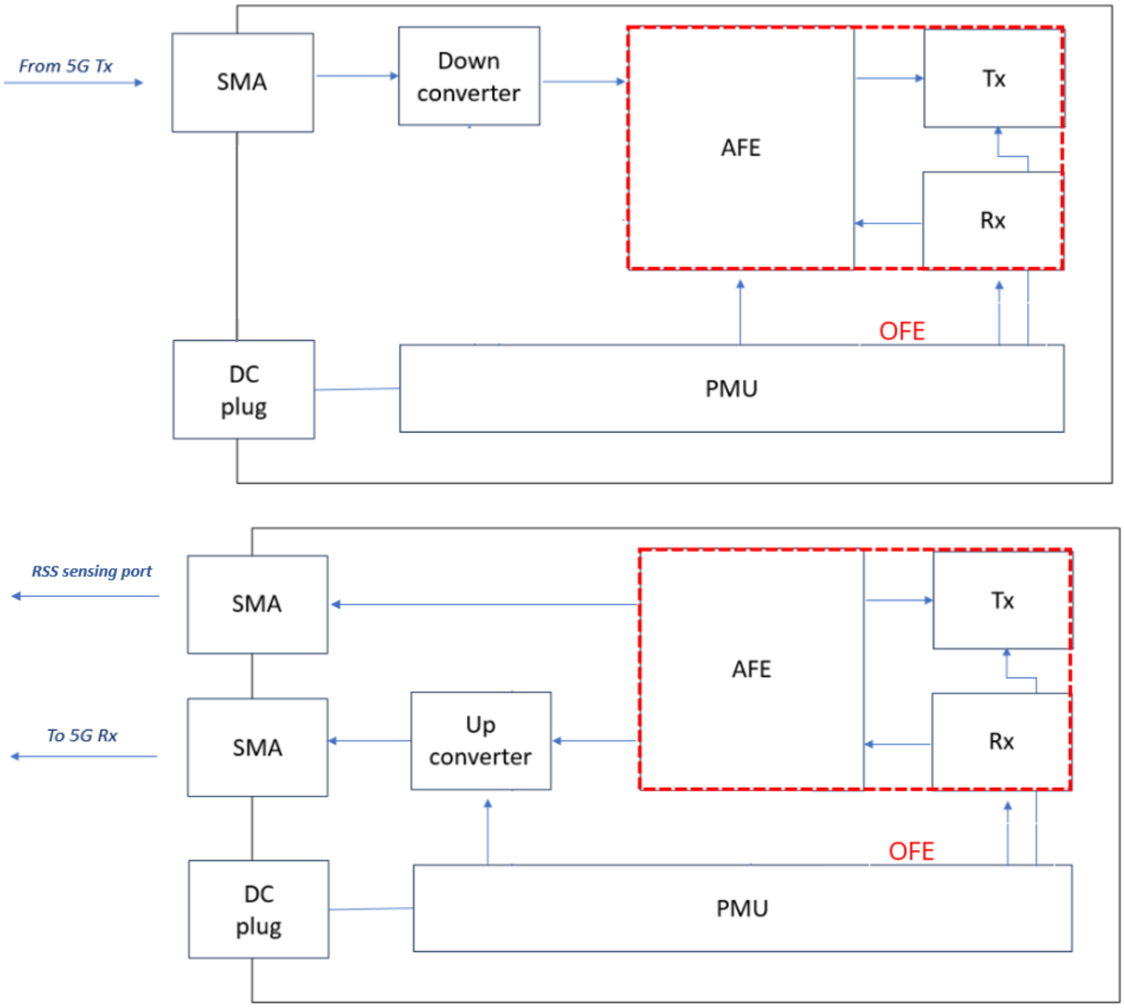

Figure 11 – OWC building blocks for the OPTI-6G TX and RX modules

OFE: The Optical front end is composed of the analogue front end (AFE), light sources and photo detectors. The field of view of the OFE should be designed to optimize coverage of the testing area. FOV should be minimum 64° as shown in system specifications. 90° FOV will be implemented in order to cover potential other use-cases. Emitters will be composed of a matrix of several light sources and photo-diodes to anticipate future beam-steering capabilities of the system. A minimum of 2 emitters and 2 receivers will be implemented. With 90° FOV expected throughput is 200 Mbps.

Up/down converter: the stage will allow conversion of the RF 5G signal in baseband for the OWC system. This means down converting the emitted 5G signal to 100 MHz to be used in the OWC on one hand. On the other hand, received signal will be up converted from baseband (0 to 100 MHz) to frequency centred around 3.3 GHz (5G).

PMU - the power management unit will provide will provide power with required DC voltage level for each of the core bricks

Connector: OWC communication system will be provided with 2 coax connectors (type SMA) with 1 connector for emission and the 2nd for reception. An additional DC plug will be used to power the system.

3.3 Networking, Protocols and Interfaces

The initial system diagram illustrates the architecture of the Open Radio Access Network (O-RAN) and its connection to the server, which plays a crucial role in delivering fast and reliable information. In this setup, the O-RAN serves as a flexible and efficient framework that enhances communication between various network components, ensuring that data transmission remains seamless and responsive.

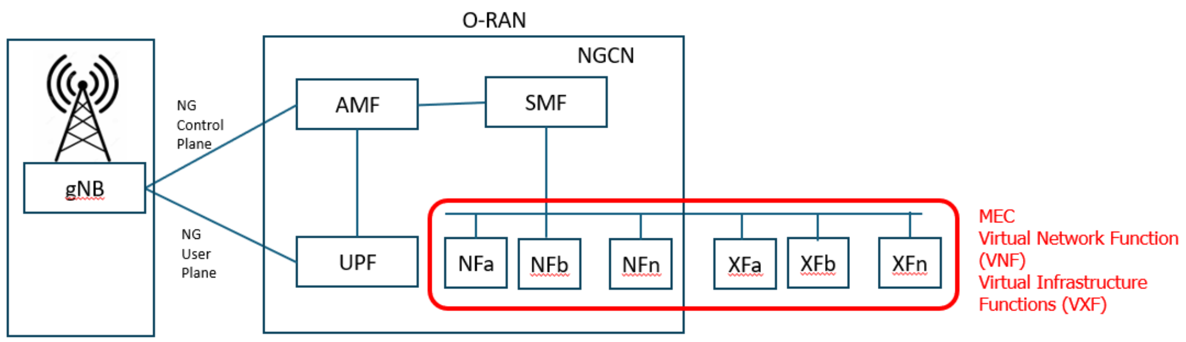

Figure 12 – Network protocols and interfaces

The diagram highlights the various elements involved in this connection, including the network interface, the Network Function (NF) and Infrastructure Function (XF) data processing units, and the server itself. The server acts as a central hub that processes incoming data with the NFs and XFs from the O-RAN, enabling real-time analytics and swift decision-making. This synergy between the O-RAN and server not only optimizes network performance but also improves user experience by reducing latency and increasing the reliability of data delivery.

Furthermore, the integration of advanced technologies within the O-RAN architecture allows for dynamic adjustments to network conditions, ensuring that users receive consistent and high-quality service. This initial system diagram serves as a foundational representation of how O-RAN effectively connects with the server to foster an environment of rapid and dependable information exchange.

3.4 Cell Free Method

Cell free cellular networks represent an innovative approach to wireless communication technology, diverging from traditional cellular network structures. These networks aim to improve connectivity, reduce latency, and enhance user experience by utilizing distributed antennas rather than relying on a centralized cell tower. In the following we provide an outline technical description of a cell free solution.

3.4.1 Architecture and Implementation

Distributed Antenna Systems (DAS): Unlike traditional networks with large, centralized antenna towers, cell-free networks deploy numerous small antennas distributed over a wide geographical area. These antennas work together to provide service, creating a seamless network blanket.

The figure 8 below describes a typical Cell free network that consist of a Central Unit (CPU) that controls several Access Points (AP) clusters in the coverage area. Each AP cluster includes several Radio Units (RUs) that are synchronized to simultaneously communicate with the UEs in the cluster coverage area

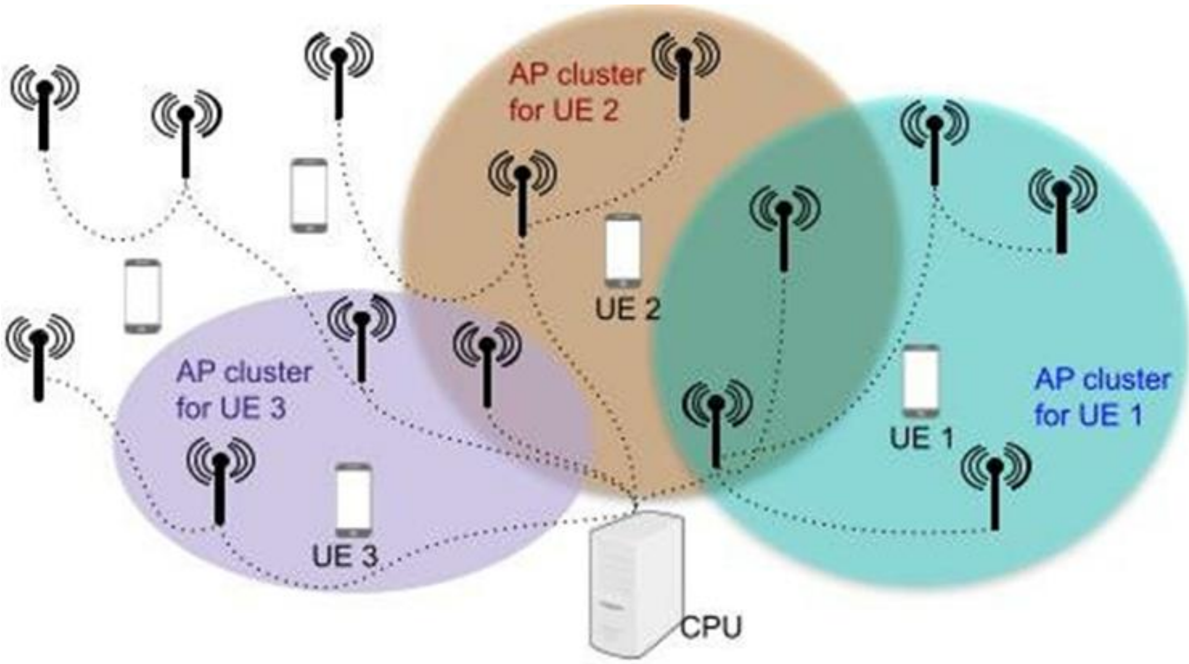

Figure 13 – Cell-free network concept

Coordination and Synchronization: Enhanced software algorithms are crucial for coordinating among these distributed antennas, ensuring data is transmitted and received efficiently. This process requires highly accurate timing and synchronization.

Backhaul Infrastructure: To connect all remote antennas to a central processing unit, robust backhaul links, typically fibre or high-capacity wireless, are necessary. This ensures the delivery of traffic from the antennas to the network's core.

3.4.2 Key Technologies

Massive MIMO (Multiple Input Multiple Output): An essential technology for cell-free networks, massive MIMO uses multiple antennas at both the transmitter and receiver to improve communication performance.

Beamforming: This technique helps in directing signals towards specific users rather than over a large area, thus improving signal quality and reducing interference.

3.4.3 Advantages of cell free

Enhanced Coverage and Capacity: Due to the distributed nature of antennas, cell-free networks can provide broader and more consistent coverage, particularly in urban areas with high user density.

Reduced Interference: Advanced techniques like beamforming can effectively minimize co-channel interference between users, improving overall network throughput.

Improved Energy Efficiency: Distributed antennas can tailor their power output specifically for each user, leading to overall energy savings.

Lower Latency: With more localized processing capabilities, data does not need to traverse long distances to reach core networks, thereby reducing latency.

No Handover: The Cell free network coverage area consist of the aggregation of several Access Points Clusters (AP Clusters). One the RUs are moving within a cluster there is no need to do Handovers between the Base Stations that cover this cluster and the latency is substantially reduced

3.4.4 Disadvantages of cell free

Complex Coordination: The distributed nature requires complex algorithms for coordination and management, introducing potential points of failure if not properly implemented.

High Infrastructure Costs: The deployment of numerous antennas and the accompanying backhaul infrastructure can be costly, necessitating significant initial investments.

Scalability Issues: Ensuring that the network can scale effectively without degradation in performance poses both a technical and economic challenge.

Potential Security Vulnerabilities: A wider array of access points can increase the potential vectors for security breaches if not adequately secured.

In conclusion, while cell-free cellular networks offer significant advantages in terms of coverage, capacity, and efficiency, they come with challenges related to coordination, cost, and security that need to be meticulously addressed.

4 System Design

4.1 CU, DU and RU design and implementation

The CU and DU are based on Amarisoft software package which is tailored and configured to meet OPTI-6G requirements.

Amarisoft package is running on an off the shelf Dell xr11 server.

Interfaces - Standard interfaces were configured to interconnect the system elements.

These interfaces include:

- O-RAN 7.2 split to backhaul the RU via the gNB
- F1 to connect the CU with the DU is internal within the gNB software package
- NG interface to connect the 5G core with the CU/DU gNB

The RU includes converter modules to convert the RU RF output to optical LEDS.

Zero IF conversion is used in the interface with the OWC (Optical wireless Communication) PD (Photo Diode) module.

4.2 OWC system design and implementation

OWC system design as part of OPTI-6G is unique in a sense that the interface between radio and optical system is currently not implemented at high TRL levels, and it is currently not in use as an industrial solution. The combination of the two technologies is a big step forward to the integration of OWC and location-based services as part of the 6G and industry 4.0 use-cases. However, this integration also comes with a number of challenges in the system design.

So the OPTI-6G specific OWC system design is as follows.

4.2.1 LED selection

VCSELs are the preferred light source for optical wireless communication (LiFi) systems due to their numerous advantages. Their high modulation bandwidth enables high-speed data transmission, while their low power consumption and high efficiency make them energy-efficient. VCSELs are also compact and inexpensive to manufacture, facilitating their integration into various devices. Additionally, their eye-safe operation and ability to form 2D arrays make them suitable for a wide range of applications, from indoor communication to outdoor wireless networks.

VCSEL manufacturers offer a wide range of power, wavelength and opening angles.

Table 1: Example of different VCSEL Diffuser types and FoVs available

Part number VD-0850I-004W-1C-5A(X)	Diffuser types	Description (Horizontal×Vertical)
VD-0850I-004W-1C-5A1	6045	60° × 45 °
VD-0850I-004W-1C-5A2	7258	72° × 58 °
VD-0850I-004W-1C-5A3	9070	90° × 70 °
VD-0850I-004W-1C-5A4	B085	110° × 85 °
VD-0850I-004W-1C-5A5	C090	120° × 90 °
VD-0850I-004W-1C-5A6	4234	42°× 34 °
VD-0850I-004W-1C-5A7	5040	50°× 40 °

The light source will be selected in order to match the minimum 64° FOV in emission. At least 2 VCSEL will be used to have a symmetric pattern of light and optimize performances. A "2x1 VCSEL configuration will also allow to potentially reuse the design in future beam-steering integrations. The VCSELs will be driver by the Oledcomm chipset "Keren" for preamplification amplification and automatic gain control implementation.

2x VD-0850I-004W-1C-5A2
90° oriented
FOV = 72° total

2x VD-0850I-004W-1C-5A3
90° oriented
FOV = 90° total

Figure 14 – Possible Emission configurations

For OPTI-6G, 850nm will be used to optimize the sensing capabilities of the photodiode, which has its peak spectral response at this wavelength.

4.2.2 Receiver selection

PIN photodiodes are well-suited for optical wireless communication due to their high sensitivity, low noise, and fast response time. They offer a good balance between performance and cost, making them a popular choice for LiFi systems. Additionally, PIN photodiodes are relatively simple to manufacture and operate, contributing to their widespread use in various optical communication applications.

Oledcomm will use well known Hamamatsu photodiodes that offer the best compromise between:

- Size of sensing area
- Sensitivity at 850 nm
- Bandwidth

– Thermal performances

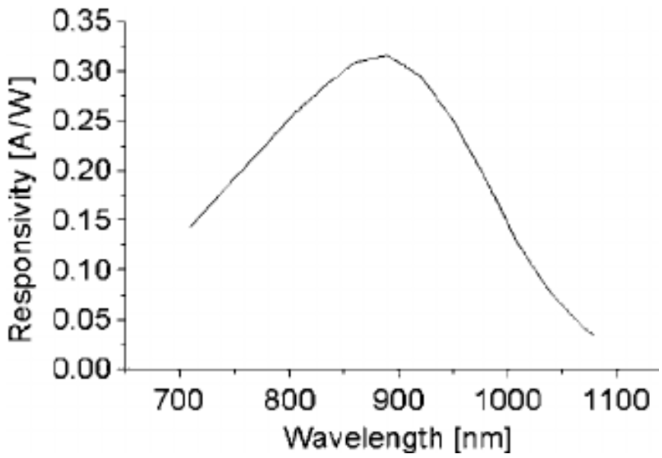

Figure 15 – Standard spectral responsivity of a PIN photo-diode

Table 2: Photo-detector characteristic parameters

Characteristic	Value
Sensing Area	26.4 mm^2
Peak Sensitivity	900 nm
Photosensitivity	0.55 A/W
Cutoff frequency	100 MHz
Operating temperature	-25 to +85 °C

4.2.3 Optical system

In some cases an additional optical system might be necessary to reach the targeted performances. Expected throughput in this case is 200 Mbps in a 5 m^2 area at 2 m. Based on several years of engineering Oledcomm has developed a model to help calculating the power budget in order to reach the required quality of service and expected performances. Based on the model. No optical system is required. This means that the system will be very compact. This might not be a key factor in this use case but this will be a competitive advantages for future implementation of the solution in industrial use-cases where system sizing is critical to the integration of the solution.

Based on experimental results received power threshold for 200 Mbps communication is 2,20 μW. By using the light propagation model developed by Oledcomm it is possible to verify if connectivity will be at the required level of performances

Table 3: Input parameters to light propagation model and expected performance

Tx parameters				Rx parameters		
P_t (W)	d (m)	Phi_1/2 (°)	phi (°)	A_r (m²)	psi (°)	gamma (A/W)
0.8	2	45	0	2.60E-05	0	0.55

Calculated parameters			
m	H_0	P_r (W)	I_p
2	3.10E-06	2.48E-06	1.37E-06

Where:

P_T *is the emitted power*

d *is the distance of communication*

Phi_1/2 *is the half FOV of the light source*

A_r *is the sensing area surface*

Gamma *is the sensitivity*

The outcome of the model gives a received power P_r = 2,48 µW, which is greater than the 200 Mbps threshold. This confirms in a first approach that a PD with 26 mm² surface is sufficient to reach the targeted performances.

No misalignment (psi) in Tx or Rx is considered at the stage for the performance's evaluation

4.2.4 UP/DOWN conversion

Up/down converters are essential components in radio frequency systems that allow for frequency translation. They shift a signal from one frequency band to another, enabling efficient transmission and reception of information.

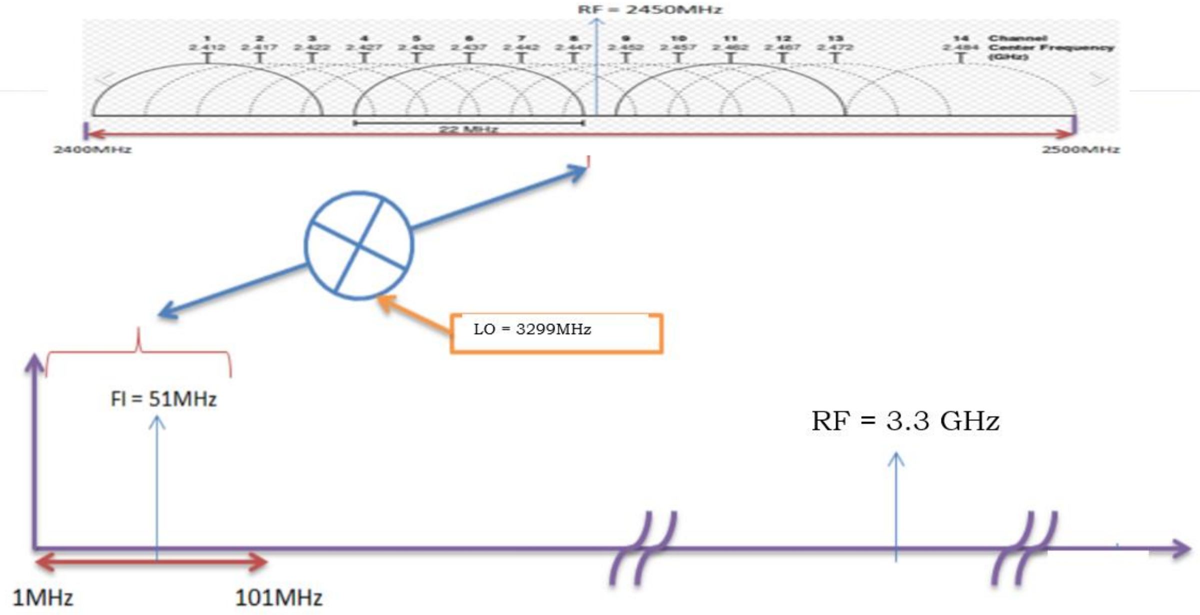

Figure 16 – Up/Down converter principle

An up/down converter essentially multiplies the input signal with a local oscillator (LO) signal. This multiplication results in two new signals: the sum frequency and the difference frequency.

- Up conversion: When the input signal frequency is lower than the LO frequency, the difference frequency is the desired output.
- Down conversion: When the input signal frequency is higher than the LO frequency, the difference frequency is the desired output.

The following are the key components of up/down converters:

- Mixer: The core component of an up/down converter, responsible for multiplying the input signal with the LO signal.
- Local Oscillator (LO): Generates the frequency used for mixing.
- Filters: Bandpass filters are used to select the desired output frequency and reject unwanted harmonics.
- Amplifiers: Can be used to boost the output signal if necessary.

On one hand, down conversion is necessary to translate RF signals coming from the RU (Radio Unit) or UE (User Equipment) at 3.3 GHz to a signal between 1 and 101 MHz. This allows for direct transmission with the light source of the OWC (Optical Wireless Communication) system due to the limited bandwidth of standard LED light sources, which can reach up to 30 MHz. However, VCSELs (Vertical-Cavity Surface-Emitting Lasers) can achieve higher frequencies, such as 300 to 400 MHz.

On the other hand, the signal received by the photodetector is a baseband signal (typically 1 to 101 MHz) that needs to be upconverted to the 5G frequency range for transmission to the RU or UE.

4.3 Interfaces and SW design and implementation

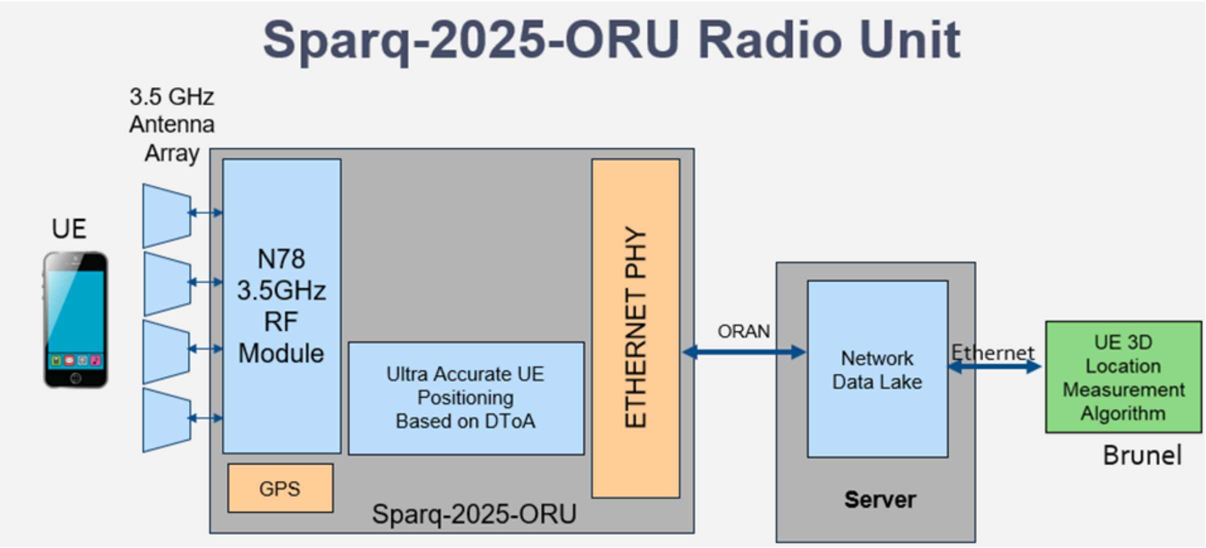

Figure 17 – Radio unit description

The RU will measure every millisecond the 4 x DToAs of the signal transmitted by the UE and received by 4 antennas.

The RU will calculate the 4 x Distances between the UE and the 4 antennas.

The calculated distances will be transferred to be stored in a Data Lake in a Server via the O-RAN Interface.

Brunel will be able to extract the data from the Data Lake via an Ethernet interface in order to calculate the 3D position of the UE.

Another option is to locate the Brunel 3D UE Location SW inside the server and extract the data from the Data Lake internally.

4.4 Cell Free Access design and implementation

Optical Wireless Communication (OWC) technologies are emerging as viable alternatives to Radio Frequency (RF) based systems. OWC based systems offer unlicensed, interference-free spectrum by utilizing the visible and invisible light spectrum. Inherently OWC systems enhance security and privacy in communications, making them suitable for a variety of applications, including Industry 4.0.

On the other hand, OWC systems coverage is limited due to its short range and inability to penetrate walls and more. To handle these issues, integrating OWC with RF networks is explored, creating hybrid architectures that leverage the strengths of both technologies.

Cell-free massive Multiple Input Multiple Output (MIMO) technology is aimed at improving wireless communication. Unlike traditional cellular networks, cell-free massive MIMO eliminates the concept of cells by distributing plurality of Access Points (AP) over the target area, all AP are connected to a central processing unit. This innovative configuration provides uniform service quality and reduces interference.

Combining OWC with cell-free massive MIMO leads to significant advancements in wireless communication. OWC offers high-capacity links with low interference, while cell-free massive MIMO ensures seamless connectivity and uniform service quality. Integrating these technologies presents challenges, such as managing the OWC line-of-sight requirements of and coordinating the numerous distributed access points in cell-free systems.

In OPTI-6G we exploit the benefits of augmenting cell-free access methods with OWC technology.

5 Networking, Protocols and Network Functions (NF) Setup

5.1 Networking Protocols and Interfaces

5.1.1 OpenStack Multiaccess Edge Computing Cloud Server

An overview about the concept and the implementation of the OpenStack Multiaccess Edge Computing (MEC) server is given, to establish a better understanding of the designed industrial cell system.

5.1.1.1 SDN – NFV platform concepts

The purpose of creating the MEC cloud server, is to enable industrial cell system to offer intelligent services to its users. Therefore, the system design leverages SDN/NFV technologies to enable flexible, adaptive and reconfigurable services. The platform enables third party service providers to utilize system information to customize the offered services. The next section will present the platform implementation.

5.1.1.2 Development of the SDN/NFV Home Environment – Platform, Concepts and Implementation

On the technical part, the MEC cloud architecture is realized by an SDN/NFV platform, implemented on a physical DELL R740 server (**Error! Reference source not found.**Figure 18).

The server basic specifications are as following:

- CPU: 2x Intel(R) Xeon(R) CPU E5-2620 v3 @ 2.40GHz
- Memory (RAM): 192 GB
- 2x Drives: 240GB SSD and 1TB
- Network Interface: 2x 10GbE and 1x GbE

Dell 730 Server

Figure 18 – Actual picture of the Dell R730 server at Brunel University

The SDN/NFV platform server is running on Ubuntu Linux 20.04, while OpenStack (Queens version) [OPE24] is used as the cloud operating system and NFVI enabler. OpenStack is currently the prevailing open-source cloud controller with a wide ecosystem of services and plug-ins. It is also the most widely used controller for NFV platforms, also a part of the OPNFV (Open Platform for NFV) suite. The services will be deployed on Virtual Machines (VMs), and as Virtual Network Functions (VNFs). Figure 19 depicts the dashboard of the OpenStack Virtualized Infrastructure Manager (VIM), giving an overview of the cloud infrastructure that implements the Intelligent Home IP Gateway. The OpenStack VIM is responsible for controlling and managing the (Network Function Virtualisation Infrastructure) NFVI compute, storage and network.

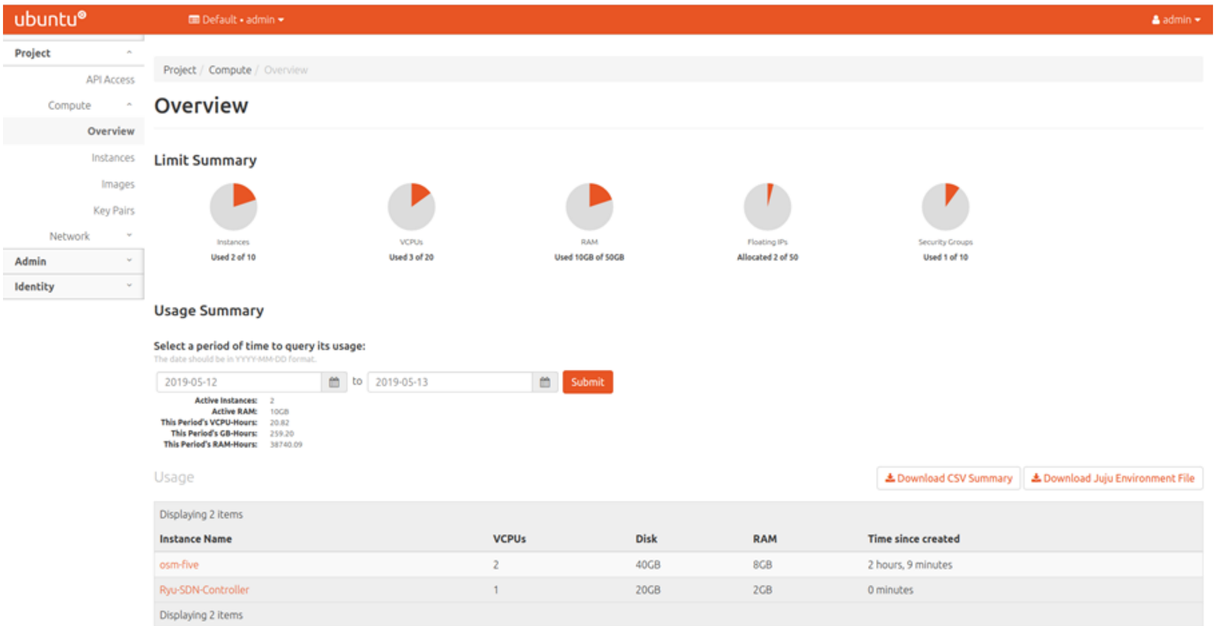

Figure 19 – Snapshot of the OpenStack Dashboard

The SDN/NFV platform includes three physical network interfaces, each connected to an external Layer 2 network. In addition to those, two more virtual networks (tenant networks in OpenStack terminology) are created on the NFV Infrastructure, in order to host some Management and Orchestration (MANO) Layer instances, as well as the VNFs that are instantiated on the platform. Figure 20 depicts the detailed Network Architecture, including the IP segments used for each network, while Figure 21 provides an overview of the Network Topology from the OpenStack Dashboard.

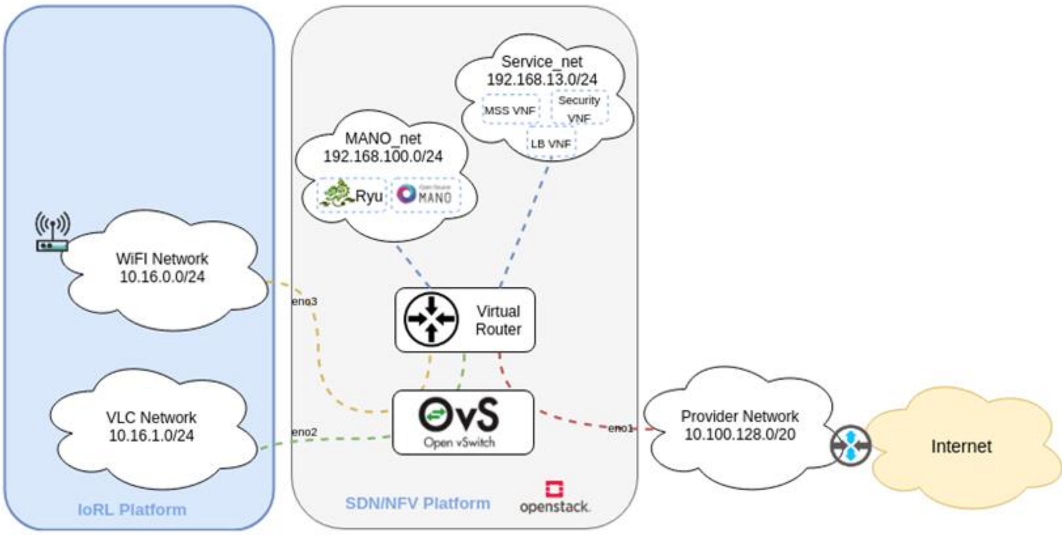

Figure 20 – Illustration of the network architecture

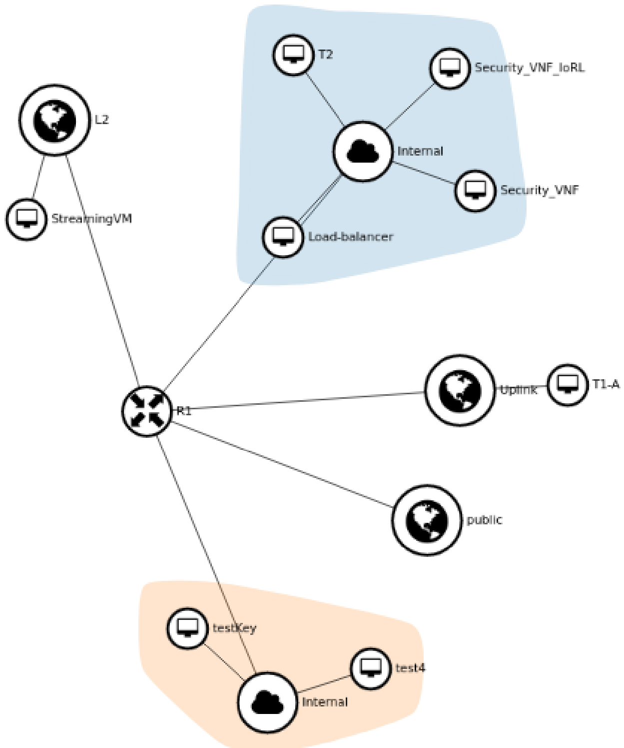

Figure 21 – Snapshot of the network topology at the OpenStack dashboard

The SDN/NFV platform acts as a Layer 3 router for the physical and virtual networks. In more details, each network is connected to an OpenStack virtual router **Error! Reference source not found.**. The router's role is to route the traffic between the networks, as well as to act as a gateway for the internal access networks (VLC network, Wi-Fi Network). An SDN Forwarding Device (SDN switch), on which OpenFlow v1.3 rules can be applied, is also part of the SDN/NFV platform. This SDN Forwarding Device is implemented by an Open Virtual Switch (OVS) on the server, being controlled by a Ryu SDN Controller running as an instance on the NFV Infrastructure.

5.1.1.2.1 Provider Network

"Provider" network is a sub 6 GHz physical Layer 2 network, which is responsible for realising the connection to the Internet. The IP segment used for this network is 10.100.128.0/20. The SDN/NFV platform is connected to this network via a 10 Gigabit Ethernet network interface connection (NIC). The interface is mapped to an OVS switch port inside OpenStack, which is then connected to the virtual router.

5.1.1.2.2 OWC Network

"OWC" network is another IR physical Layer 2 network, which implements the IR access network. The SDN/NFV server is connected to it via a second 10 Gigabit network interface, which is also mapped to an OVS switch port. The virtual router acts as a gateway to the Internet and NAT point for the "OWC" network. Finally, the IP segment used here is 10.16.1.0/24.

5.1.1.2.3 SDN controller

Ryu **Error! Reference source not found.** is the solution that implements the SDN controller on the SDN/NFV platform. It is deployed on a Virtual Machine on the NFV Infrastructure attached to the MANO_net. Ryu is responsible for controlling the OVS in the server, by installing, updating and deleting SDN rules. It supports OpenFlow version 1.3 for managing network devices and provides software components with well-defined REST APIs that implement the controller's North Bound Interface (NBI). Various application running as VNFs on the NFV Infrastructure, such as the Load Balancer and the security VNF, can use these REST APIs to create, update or delete SDN rules on the OVS switch. Finally, Ryu offers a graphical topology viewer that can be accessed using any web browser.

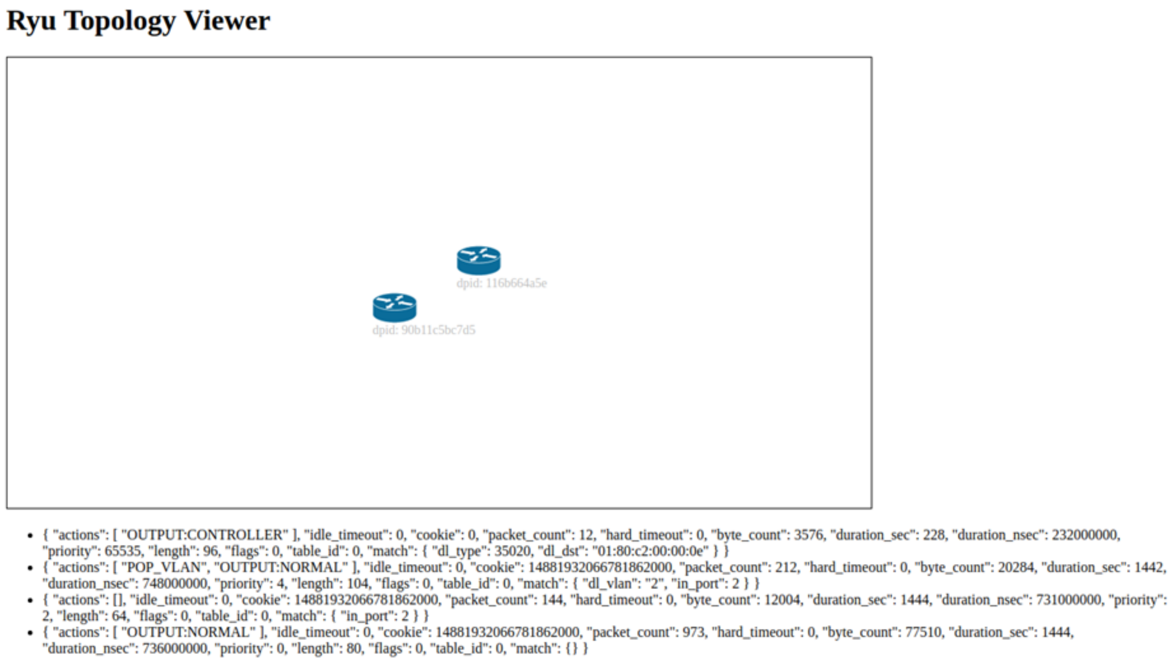

Figure 22 – Snapshot of OSM's for network service instantiation

5.1.1.2.4 VNFs

Virtual Network Functions are Virtual Machines, hosted in the SDN/NFV server, that run specific services. They are designed, implemented and distributed in the form of VM image files (e.g., img, raw, qcow2, etc.) by various partners of the project.

Onboarding the VM image to the OpenStack's image repository on the SDN/NFV server, is the first step for the deployment of a VNF. The next step is to create the VNF Descriptor (VNFD) for each VNF and upload it to the OSM VNF repository. VNFD is part of the OSM Information Model (IM), based on the YANG model, that is used to describe various parameters of the VNF to be deployed, such as the VM Image, compute, memory and disk resources, network connection points, etc. The last step is to create the Network Service Descriptor (NSD) and upload it to the repository. NSD is also part of the OSM IM and may include one or multiple VNFs, describing the way they are connected over one or more networks.

After NSD and the referenced VNFDs have been onboarded to the OSM Repository, we can instantiate the Network Service using the OSM Web Interface. Figure 22 illustrates the instantiation of a Network Service (NS). On the top-right, we can see the creation of the NS called "opti_uc1" on the OSM dashboard. This service is described in the "opti_uc_nsd" NSD and includes three VNFs, Load Balancer (LB), Multiple Source Streaming (MSS) and Transcoder, which we can see on the bottom-right part of the figure. Finally, on the left part of the figure, we see the creation of three new VMs on OpenStack dashboard, one for each VNF.

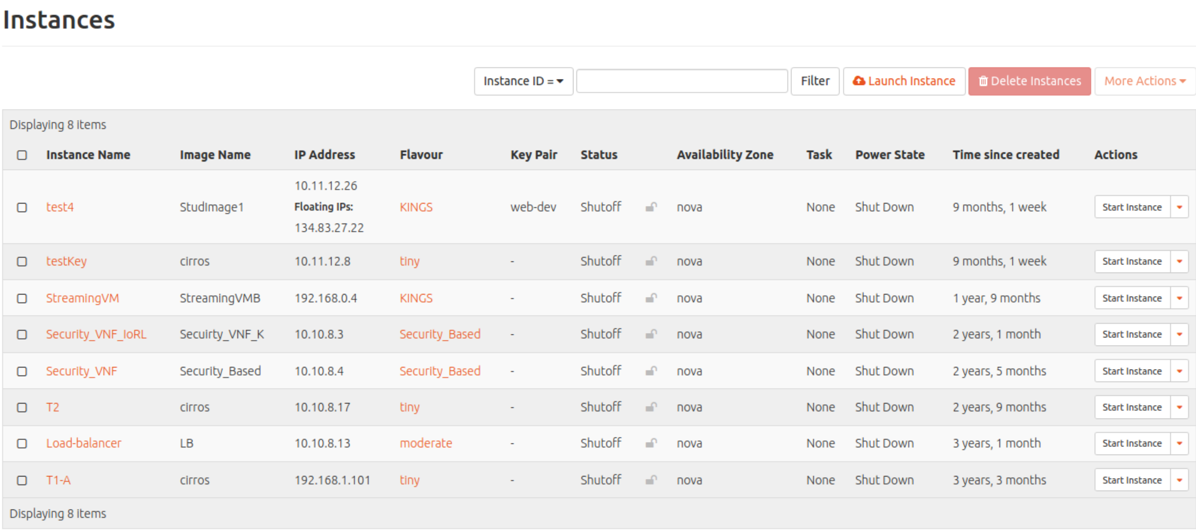

Figure 23 - Snapshot of OpenStack's dashboard for network service instantiation

In the OpenStack SDN/NFV platform we use the OSM to instantiate a Network Service (NS) with one or multiple VNFs and perform Lifecycle Management (LCM) actions on these VNFs. In addition to that, OSM acts as a VNF repository, where VNFs are stored.

5.1.2 Structure of Localisation Database

First the Anchor locations of the OWC emitter-receivers or the sub 6GHz antennas and the measurement test locations need to be recorded on the Location Database (LD). Then the raw Time Difference of Arrival (TDoA) data from the O-RAN Compliant Remote Unit (O-RU) needs to be recorded on LD. Furthermore, the data from the LIDAR and 360° camera can also recorded on LD. Then the Anchor locations and the data (raw TDoA, LIDAR and 360° camera) need to be processed on the Location Server (LS) and stored the UE data on LD. This process is shown in Figure 24.

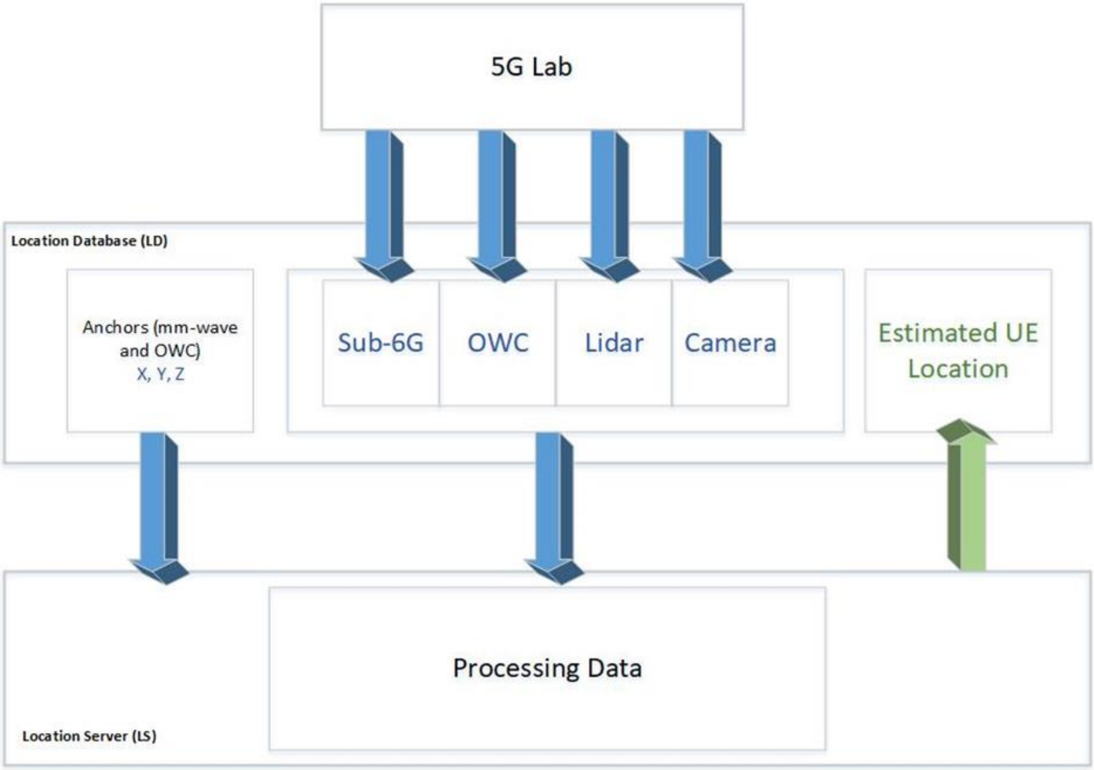

Figure 24 – Process Flow of Data in the MEC Cloud

Table 4: OWC and Sub 6 GHz antennas' locations

UE RNTI	x (cm)	Y (cm)	Z (cm)
MA1	50.25	20.5	40.35
MA2			
MA3			
MA4			
IF1			
IF2			
IF3			
IF4			
IF5			
IF6			

Table 5: OWC and Sub 6 GHz data SNR, TOA ...

UE RNTI	Frame	Slot	sect	Time-tics (0.3 ps or 0.1 mm)	SNR (dBmW)	RSSI (dBmV)
MA1	20	5	2	1040	30	20

Table 6: Estimated UE's location by using OWC and sub 6 GHz

UE RNTI	X (cm)	Y (cm)	Z (cm)
OW1	50.8	19.5	41.8

Table 7: OWC data and Reference location of UE

UE RNTI	RSS1 (dBmV)	RSS2 (dBmV)	RSS3 (dBmV)	RSS4 (dBmV)	RSS5 (dBmV)	RSS6 (dBmV)	X (cm)	Y (cm)	Z (cm)	Time (ms)
OW1	30.1	50.5	20.2	35.3	40.1	28.3	50.8	19.5	41.8	Start +33

Table 8: Estimated UE's location by using OWC

UE RNTI	X (cm)	Y (cm)	Z (cm)
IF1	101.9	54.2	33.7

Table 9: Camera data and actual location

UE RNTI	File location	X (cm)	Y (cm)	Z (cm)	Time (ms)
CAM1	C:\cam_name.jpg	101.4	54.3	33.7	Start + 300

Table 10: LIDAR data and actual location

UE RNTI	File1	File2	X (cm)	Y (cm)	Z (cm)	Time
LID01	C:\Lid_name1.pcap	C:\Lid_name2.pcap	101.3	54.1	33.8	Start + 300

Firstly, MySQL workbench was installed on the Dell R740 Server, which hosts Ubuntu 20.04

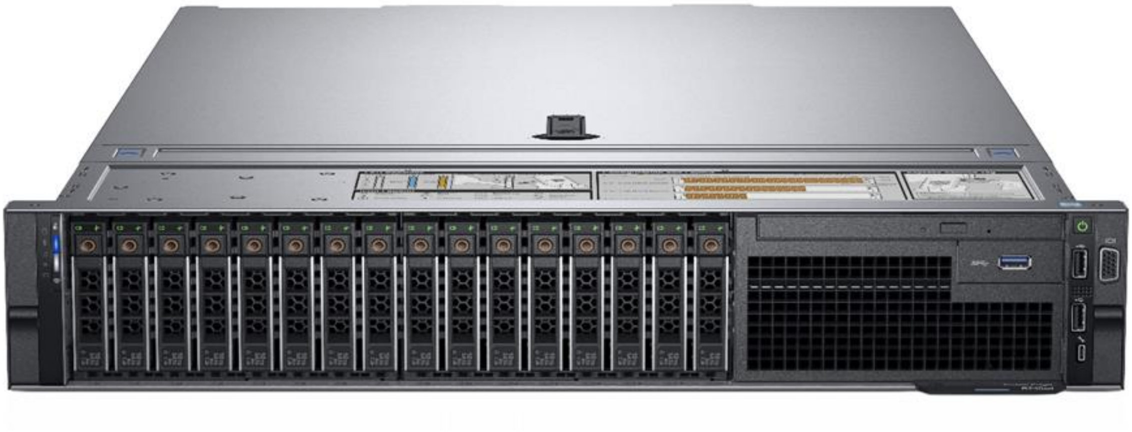

Figure 25 – Dell R740 Server

Then a database was set on the MySQL workbench so the packet data can be imported to the database.

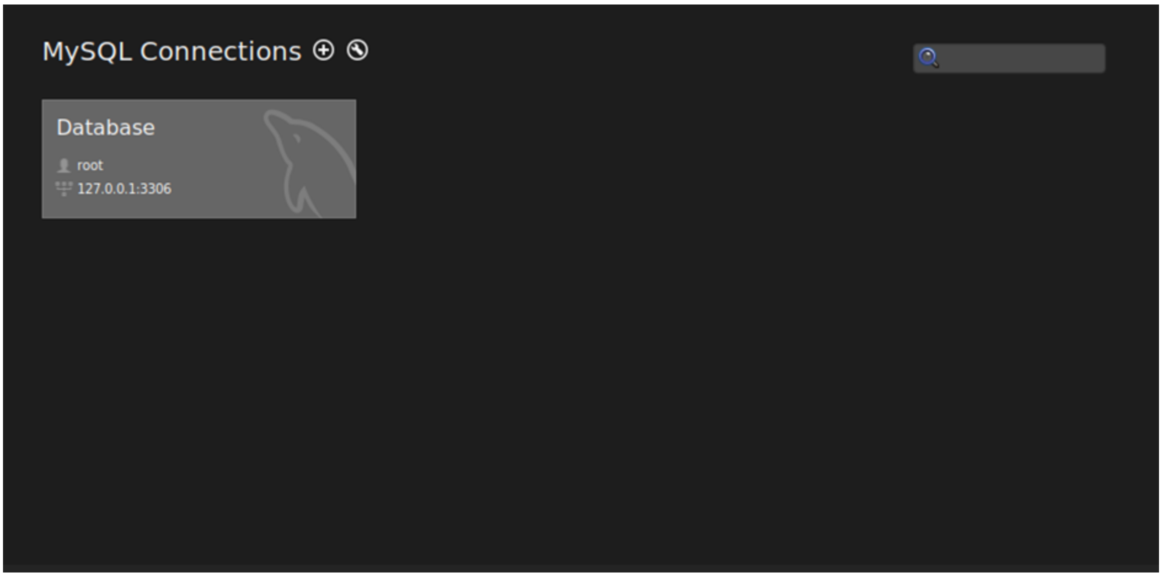

Figure 26 – MySQL Database Connector

A schema is a collection of tables with rows and columns and a separate query can be written for the schemas like databases. Figure 26 presents the MySQL connector that initiates the connection to the database.

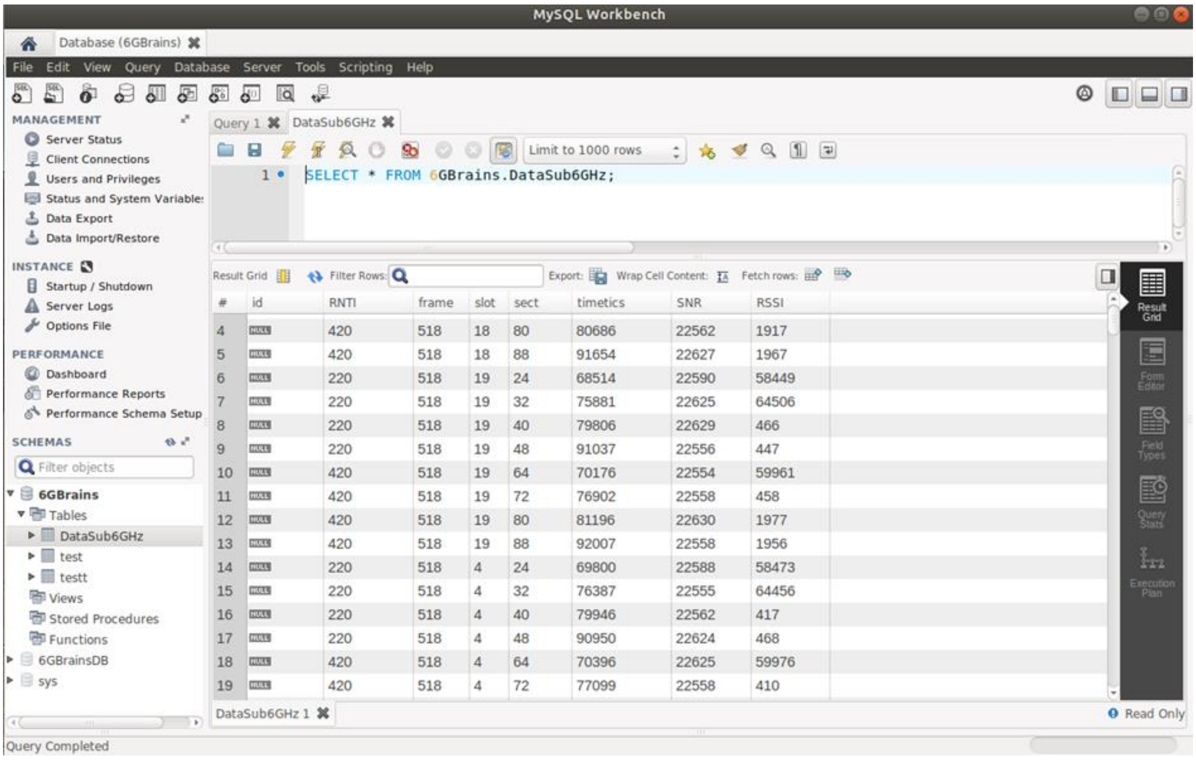

Figure 27 – MySQL database table

The other tables were created for the rest of the data for the IoT devices. However, it is still work in progress. Screenshots of the other tables are to be found for Figure 28 to Figure 32.

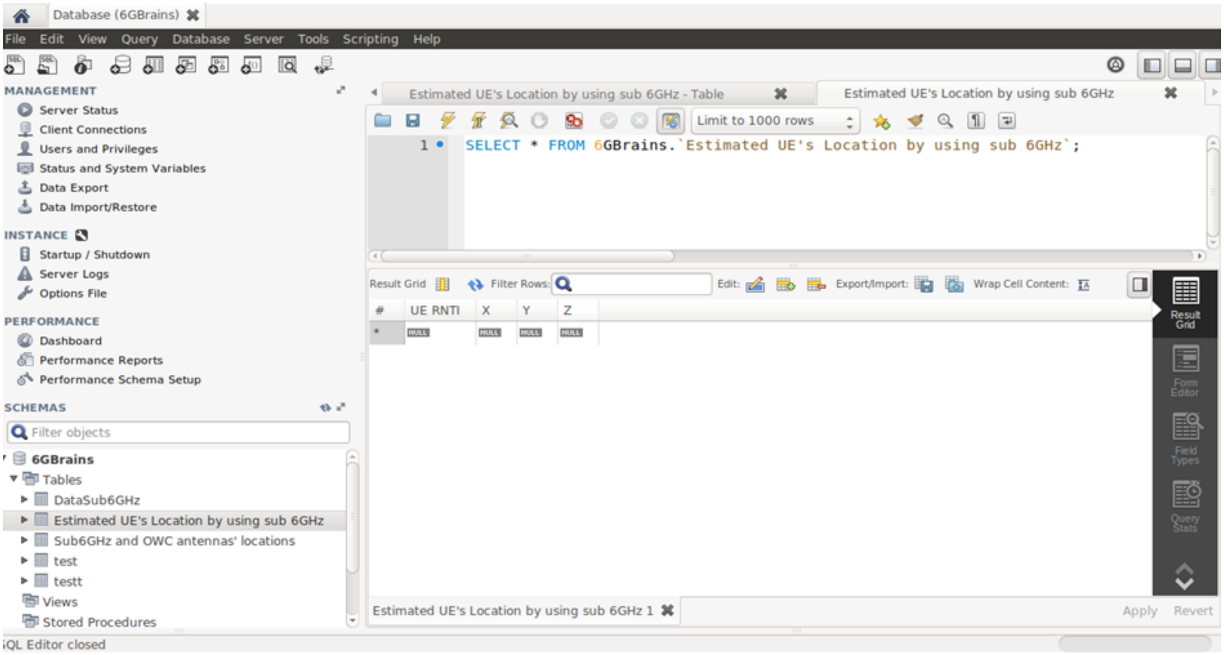

Figure 28 – UE Location using Sub-6 GHz database

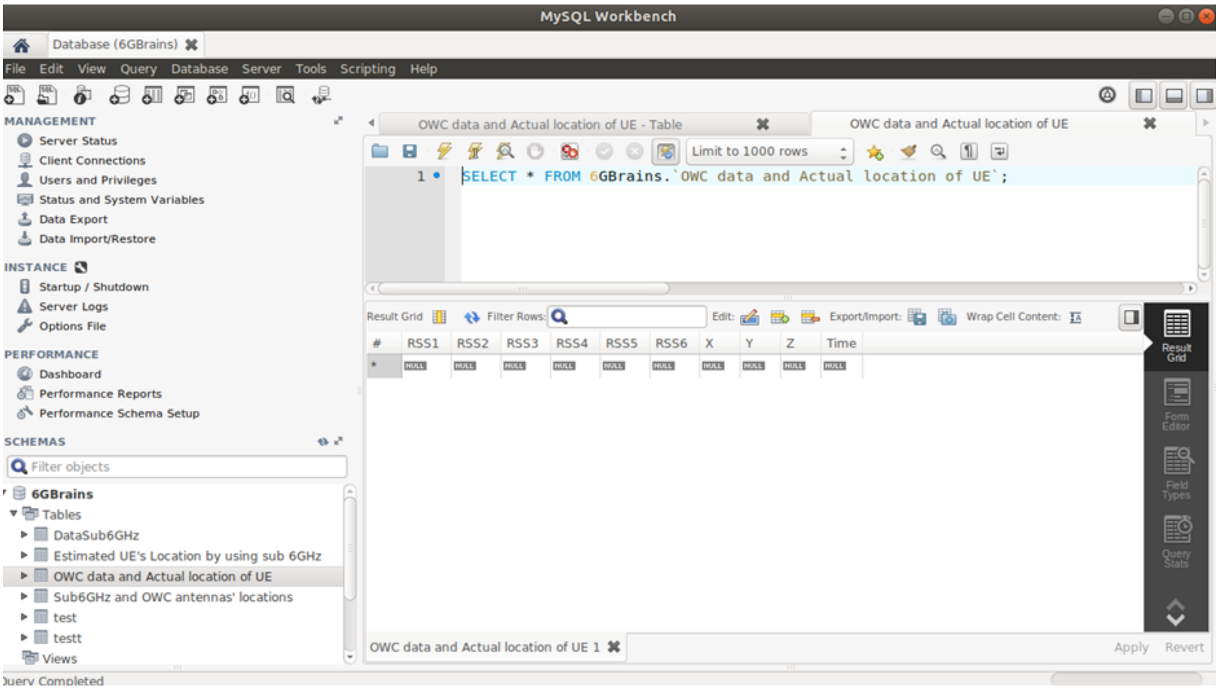

Figure 29 – OWC data and UE Location

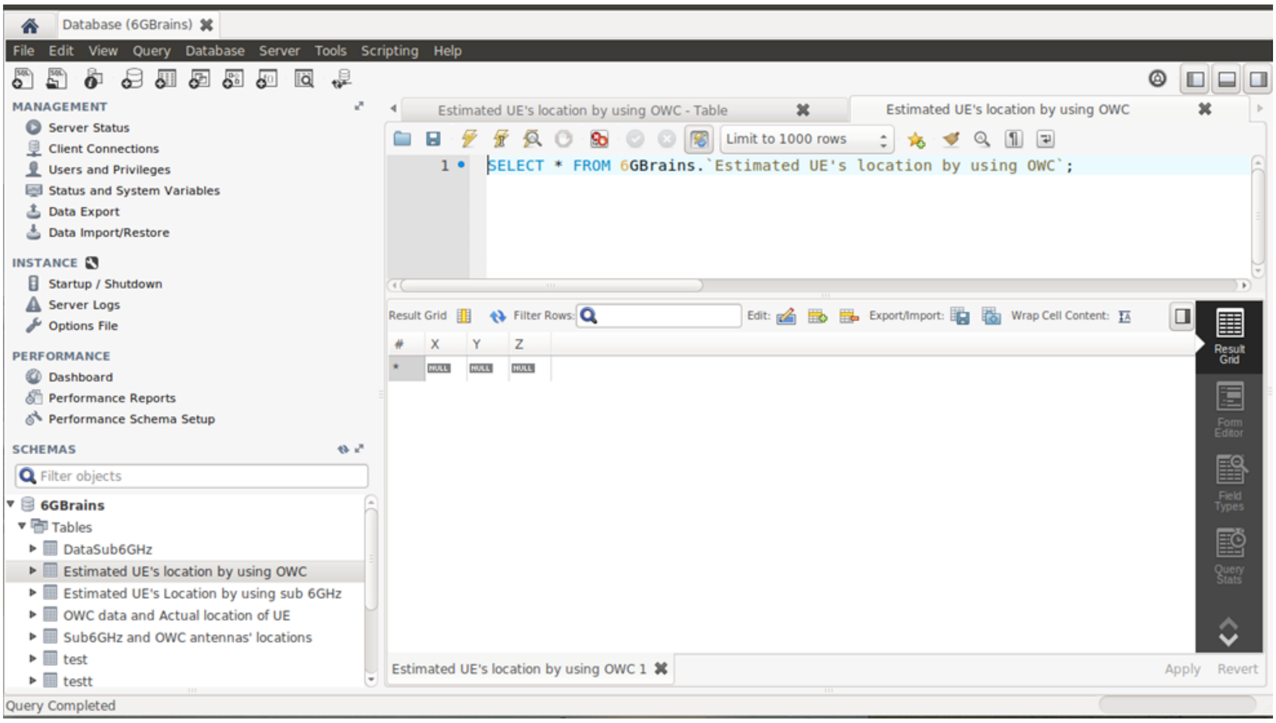

Figure 30 – UE location using OWC

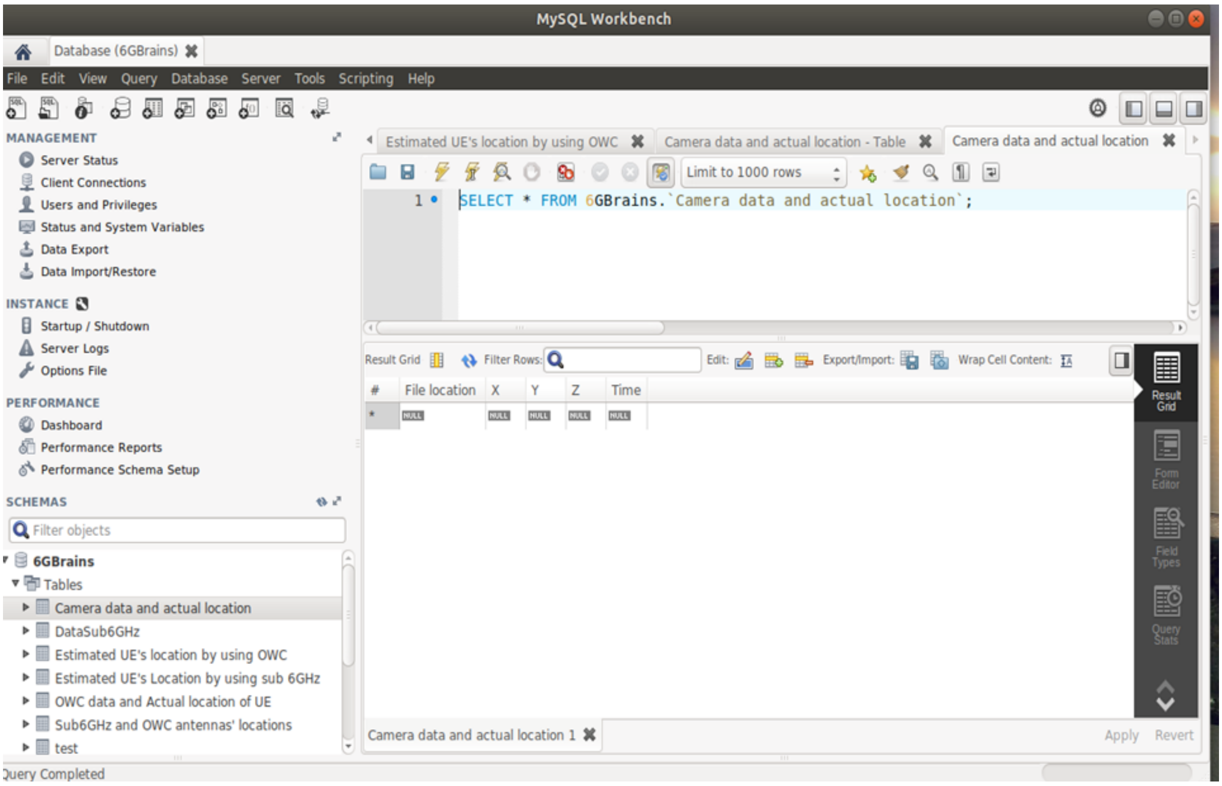

Figure 31 – Camera Data and Location

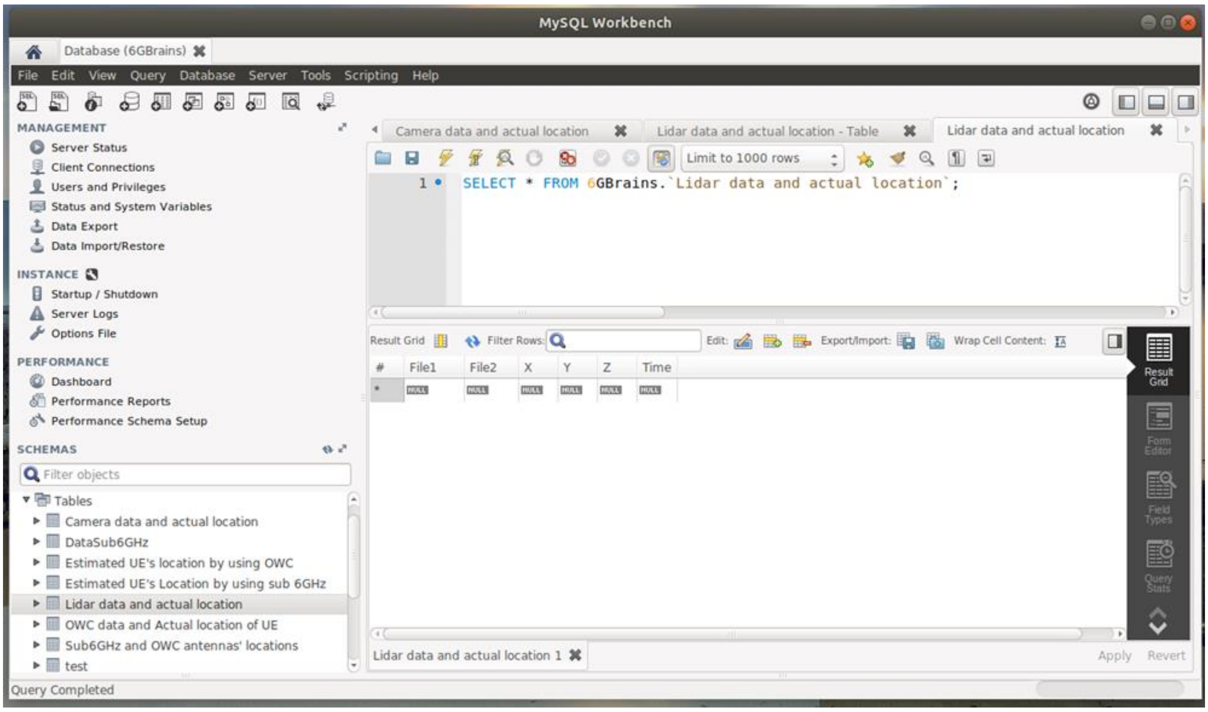

Figure 32 – LIDAR data and location

5.1.3 Remote access to Open stack & MySQL Database Linux Servers

To remote access the Dell 730 OpenStack Server and the Dell 740 RAN Host and MySQL database server install x2go remote access client on your Linux PC, which are described in Section XX of Deliverable 4.1.

The available Linux machines for access are the

- Dell 730 OpenStack Server
- Dell 740 RAN Host and SQL database

The password for remote access can be obtained on application from: john.cosmas@brunel.ac.uk

Now the remote terminal can be accessed.

6 Preliminary Integration and Testing Experiments and Procedure

6.1 System integration testing

In order to proceed with the integration of the OWC system with its dedicated Radio interface the following steps are required:

Radio to OWC interface testing:

- Circulator TX/RX signal crossing

A signal is generated on RU side is flowing through the circulator port and should be available at the SMA output port

A received signal on the SMA port is flowing through the circulator and should reach the RU internal port

- Down conversion of RF signal

A signal is generated on RU side and transferred to the OWC interface (emission chain of OWC). Signal is down converted and should be in the defined frequency range between 1 and 101 MHz. Signal is checked after conversion stage.

- Up conversion of OWC communication signal

Signal is generated by OWC system and reached the up-conversion stage (reception of OWC). Signal is upconverted onto the 3.3 GHz band and transmitted to the RU. Signal is checked after conversion stage.

Communication channel testing

- TX chain is checked including signal generation by RU, down conversion, signal conditioning for OWC system and signal emitted by the light source.
- RX chain is checked including, signal reception on the photodiode, signal conditioning for the OWC stages, up conversion, transmission of the signal to the RU.
- Communication is established between RU and UE, either Planet CO smartphone or 5G portable device

Cell free test method

Cell free network will be deployed with 2 different Radio Units with 2 independent antennas and User equipment will be moved from one antenna to the other and Hand off time will be retrieved. The cell free network configuration is expected to take only a few microseconds as compared to the standard values of few hundreds of milliseconds.

The experimental tests are:

- Bitrate

- Coverage
- Latency
- Distance from Time of Arrival (ToA)
- Distance from Angle of Arrival (AoA)

These experiments will determine if the expected technical KPIs listed in Section 4 of Deliverable 2.1 can be achieved with the OPTI-6G technical solution.

Table 8: Table of Independent and Dependent Variables for each experiment

Independent Variable	**Dependant Variable**	**Experimental Testbed (see section 3.1)**
Bit Rate	X, Y and Z location in Coverage environment	1
Coverage X, Y and Z location	Bit rate and throughput	1
Latency	X, Y and Z location in Coverage environment	1
Distance from Received Signal Strength (RSS)	X, Y and Z location in Coverage environment	1
Distance from Time of Arrival (ToA)	X, Y and Z location in Coverage environment	1
Distance from Angle of Arrival (AoA)	X, Y and Z location in Coverage environment	1
Cell Free Network area handover	Connection and Packet loss whilst transitioning access area coverage boundaries	2

6.2 Technical Experimental Testing

Testbed 1 uses one RU (RU1) for testing general performances of the system and KPIs. Please also note that the exact same setup will be used for ToA and RSS localisation. It uses RU with four up and one down converters at RU and one up and down converter at UE.

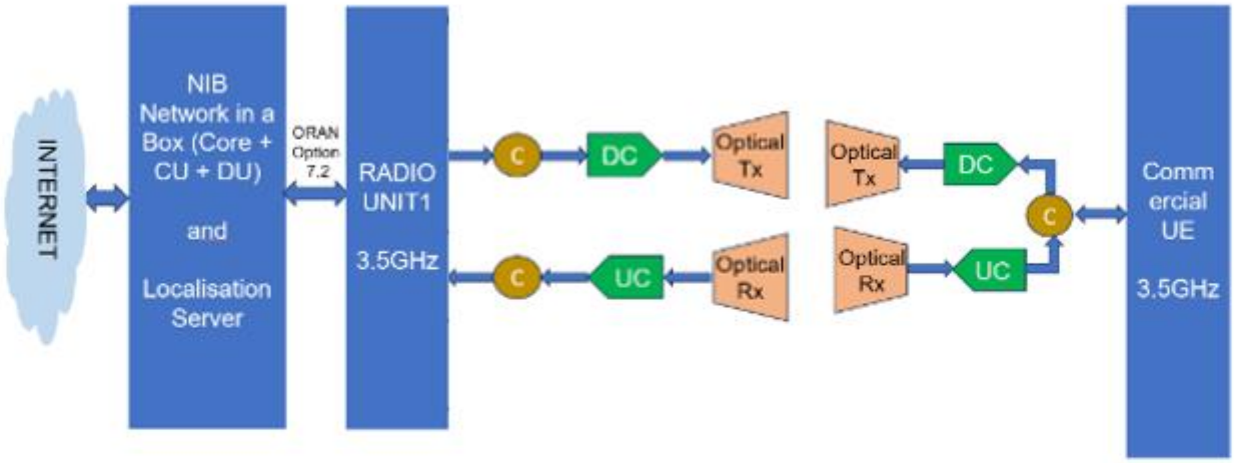

Figure 33 – Testbed 1 for communication and KPIs verification

Testbed 2 uses two RUs (RU1 and RU2) for cell free network demonstration and KPIs testing it includes one up and down converter for each RU and one up and down converter at UE side

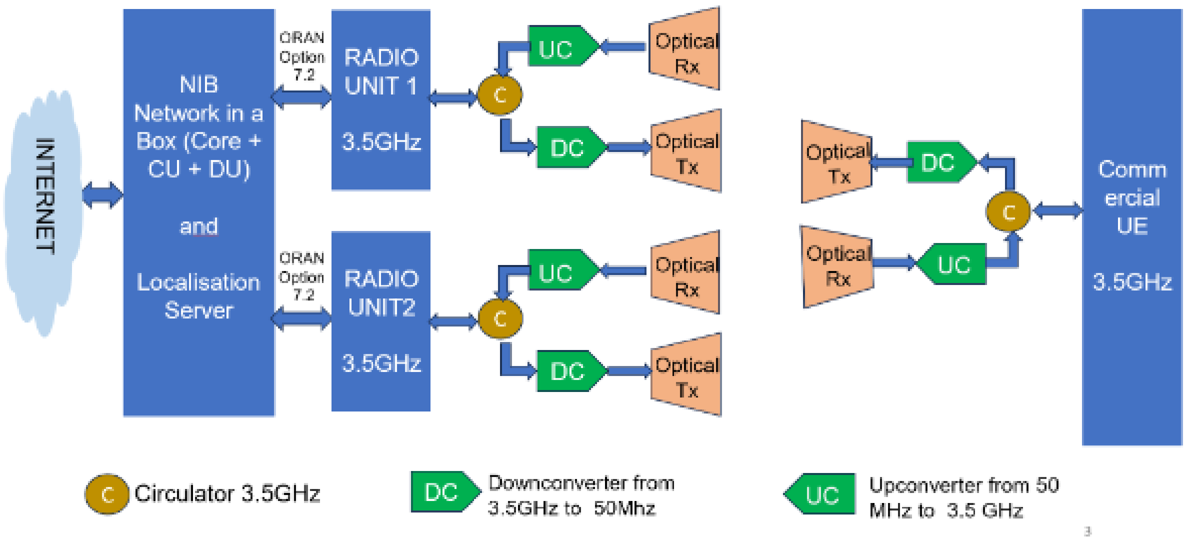

Figure 34 – Testbed 2 for Cell Free network testing

7 Conclusions

This document has outlined the detailed system design and architecture for OPTI-6G. It provides a comprehensive overview of the system's functional requirements, non-functional requirements, and technical specifications.

The proposed architecture is well-suited to meet the objectives and constraints of the project. It is designed to be scalable, reliable, and maintainable. It includes dedicated output for monitoring and control of the system, ensuring good level of QOS as well as data confidentiality, integrity, and availability.

The technical specifications provided in this document will serve as a blueprint for the development and implementation phases of the project. By following these specifications, the development partners can ensure that the final system meets the required quality standards and delivers the expected functionality.

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