5G Programmable Infrastructure Converging disaggregated network and compUte Resources

D6.2 Vertical Demo and Testbed setup and Initial Validation Results

This project has received funding from the European Union's Framework Programme Horizon 2020 for research, technological development and demonstration

5G PPP Research and Validation of critical technologies and systems

Project Start Date: June 1st, 2017

Duration: 30 months

Call: H2020-ICT-2016-2

Date of delivery: 31st July 2019

Topic: ICT-07-2017

Version 1.0

Project co-funded by the European Commission
Under the H2020 programme

Dissemination Level: Public

Grant Agreement Number:	762057
Project Name:	5G Programmable Infrastructure Converging disaggregated network and compUte REsources
Project Acronym:	5G-PICTURE
Document Number:	**D6.2**
Document Title:	Vertical Demo and Testbed setup and initial validation results
Version:	1.0
Delivery Date:	31st July 2019
Responsible:	University of Thessaly (**UTH**)
Editor(s):	Paris Flegkas (**UTH**)
Authors:	Paris Flegkas (**UTH**), Nikos Makris (**UTH**), Anna Tzanakaki (**UNIVBRIS-HPN**), Arash Beldachi (**UNIVBRIS-HPN**), Hamid Falaki (**UNIVBRIS-HPN)**, Nebojsa Maletic (**IHP**), Jesús Gutiérrez (**IHP**), Giorgio Bernardinetti (**CNIT**), Valerio Bruschi (**CNIT**), Aniello Cammarano (**CNIT**), Marco Faltelli (**CNIT**), Giacomo Belocchi (**CNIT**), Salvatore Pontarelli (**CNIT**), Juan Agustí (**COMSA**), Azahar Machwe (**ZN**), Vaia Kalokidou (**UNIVBRIS-CSN**), Peter Legg (**BWT**), Paula Ciria (**FGC**), Jim Zou (**ADVA**), Daniel Camps-Mur (**i2CAT**), Jens Bartelt (**AIR**), Ioanna Mesogiti (**COS**), Elina Theodoropoulou (**COS)**
Keywords:	Demonstration, Use Cases, Functional Splits, 5GUK smart city, Rail Demo, Stadium Demo, Timeplan. Initial Deployment
Status:	Final
Dissemination Level	Public
Project URL:	http://www.5g-picture-project.eu/

Revision History

Rev. N	Description	Author	Date
0	Table of contents and document structure	Paris Flegkas (UTH)	22.03.2019
0.1	Updated TOC and partner assignment to sections	Paris Flegkas (UTH)	26.04.2019
0.2	Initial Rail use case section	Juan Agustí (COMSA)	30.05.2019
0.3	Stadium section	Azahar Machwe (ZN),	22.06.2019
0.4	Smart city demo section	Hamid Falaki (UNIVBRIS-HPN) Arash Beldachi (UNIVBRIS-HPN) Anna Tzanakaki (UNIVBRIS-HPN) Nebojsa Maletic (IHP), Jesús Gutiérrez (IHP)	09.07.2019
0.5	Update on Section 3 Rail use case	Juan Agustí (COMSA) Peter Legg (BWT) Jim Zou (ADVA)	13.07.2019
0.6	Update on Section 4 Stadium use case	Daniel Camps-Mur (i2CAT) Vaia Kalokidou (UNIVBRIS-CSN)	21.07.2019
0.7	Update on Section 5 Smart city	Jens Bartelt (AIR)	23.07.2019
0.8	Section 2 Demos in NITOS, overall review	Nikos Makris (UTH), Paris Flegkas (UTH)	26.07.2019
0.9	Update on section 2 NITOS demos on functional splits, overall review	Ioanna Mesogiti (COS), Elina Theodoropoulou (COS)	29.07.2019
1.0	Final review and submission to the EC	Eckhard Grass (IHP)	31.07.2019

Table of Contents

List of Figures

List of Tables

Executive Summary

5G-PICTURE's Work Package 6 (WP6) focuses on the demonstration and evaluation of the main architectural functionalities and solutions developed in the technical WPs (WP2, WP3, WP4 and WP5). These demonstration activities are being carried out through a set of planned use cases that take place in the project demo sites, namely NITOS in UTH, smart city 5GUK testbed in Bristol, Rail deployment in Barcelona and a Stadium in Bristol.

In this context, deliverable D6.2 reports on the updated specifications, installations and initial validation results of the use cases and demonstrations of the project use cases that were described in D6.1. The results from validation experiments performed in testbeds as well as initial installations and setups of the demo sites are described in this deliverable. Moreover, updates on the test scenarios, detailed timeplans and associated risks are also included.

Results stemming from the final 5G-PICTURE demonstrators will be reported in D6.3.

1 INTRODUCTION

5G-PICTURE Work Package 6 (WP6) is the responsible for the experimentation and demonstration activities of the project aiming to prove the feasibility of the 5G-PICTURE solutions. More specifically, WP6 focuses on the demonstration and performance evaluation of the main architectural functionalities and features described in detail in the technical WPs in the following demonstration sites:

- the NITOS testbed with programmable heterogeneous wireless technologies at UTH, Greece,
- a 5G railway experimental testbed showcasing seamless service provisioning and mobility management in high-speed moving environments,
- a stadium with ultra-high user density, supporting media services, and
- a smart city environment available in the 5GUK testbed in Bristol, UK.

The first deliverable of WP6 (D6.1) reported on the definition and planning of the use cases to be demonstrated in the four (4) available demonstration sites mentioned above. The use cases were specified in terms of new equipment to be deployed in the current infrastructures, test scenarios and services to be executed, and a detailed timeplan until the end of the project when the final demonstrations will take place.

The approach for evaluating the proposed solutions in WP6 is first to use the available lab testbeds in the project to validate individual solutions in isolated lab conditions, to then start the deployment gradually in the demo sites. In this context, the results from the lab validation and integration tests and from the initial deployment in the demo sites are reported in this deliverable (D6.2). Finally, updates on the test scenarios, detailed timeplans and associated risks are also included.

More specifically, the following is a summary of the progress and the current status for each demo use case reported in this deliverable:

NITOS: We finalised the implementation and conducted the experiments of dynamically deploying a disaggregated 5G RAN as VNFs in the NITOS testbed orchestrated by OSM. The nodes used in the experiments comprise heterogeneous wireless technologies ranging from mmWave to Sub6, leveraging the integration of WiFi cells in our setup. Results measuring the combined throughput are reported, demonstrating also SDN-based resilience features in the transport network. Extensions for multidomain scenarios have also been specified.

Rail use case: Updates to the design of the architecture be deployed have been specified and the definition of the detailed tests reported in D6.1 has been refined in this deliverable. All the demo equipment was tested in COMSA premises in Madrid for integration and validation purposes performing stand-alone and end-to-end tests in order to prepare the demo configuration and simplify the installation process. At the same time, deployment has begun in Barcelona, all the tasks related with the physical installation, power, fibre, mechanical components, cabinets are successfully being carried out while all the tasks related to the train were finished during June.

Stadium use case: A detailed description of the experiments to be conducted in the stadium demo has been provided where the end-user application will be tested over the current stadium network and compared against our 5G deployment adding features such as network awareness, slicing, VNF deployment and orchestration and massive MIMO physical tests. Updates on the status of the implementation and results from lab tests are also reported related to the wireless access segment and the control and orchestration components. The Watchity application that is going to be used for the crowd-based content production has been validated together with an access mechanism used to issue network-initiated handovers.

Smart city use case: An updated description of the available technologies in the 5G-UK test-bed is provided in this deliverable with the detailed specifications of the enhancements through 5G-PICTURE technologies developed by various consortium partners namely the mmWave nodes from iHP and the massive MIMO RU with the corresponding CU and UE from AIR. The specific 5G-UK testbed architecture that will be used for the 5G-PICTURE demonstrations has been designed and the use cases and services to be demonstrated have been identified i.e. a VR/AR audio and video service and a smart city safety service using related city monitoring sensors. Finally, Initial results from lab tests of the massive MIMO to be deployed are also reported.

Organisation of the document

This deliverable is structured in six (6) main sections. Following the introduction section, Section 2 provides the results from the experiments at NITOS testbed in UTH describing the specific network topology and testbed setup for the dynamically orchestrated functional splits experiments and demos. Section 3 focuses on the Rail use case that will be demonstrated in Barcelona, presenting the current status of the deployment and results from testbed validation and integration tests performed with all the technologies involved in the demo. Section 4 presents the experiments that will be performed in the context of the stadium use case in Bristol. Updates on the implementation of the control plane components are described and initial validation from the Watchity crowdsource media application and wireless access technologies are reported. Section 5 concentrates on the smart city related demos to take place in the 5GUK testbed in Bristol. Updates on the infrastructure and the deployment of 5G-PICTURE technologies are presented with a detailed description of the scenarios and end-user applications to be used. Initial validation results are also included from the Massive MIMO antenna to be deployed. Finally, Section 6 provides a summary and the main conclusions of the deliverable.

2 Results from Testbed Demonstrations and Experiments

This section describes the first experiments conducted in the NITOS testbed for demonstrating the technology solutions developed by the project in WP3, WP4 and WP5. The demonstration is integrating the mechanisms and APIs for configuring disaggregated base stations developed in Task 3.2, the new technology component for aggregating different technology access as new DUs developed in T4.1, and the setup of the NITOS testbed in order to be managed as a distributed datacenter for hosting the VNFs of the project by using a domain orchestrator.

For the demonstration, we consider a 5G radio network, disaggregated at two different components, based on the interfaces standardized by 3GPP [3]. The disaggregation takes place at the higher Layer-2 of the OSI stack, realizing the 3GPP suggested Option-2 split [4], between the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) layers of the mobile stack.

Two different elements that can be deployed as services are defined through this split process: the Central Unit (CU) integrating the PDCP and above layers, and the Distributed Unit (DU) that handles the lower transmission and reception functions, up to the RLC layer. The specifications provide hooks for heterogeneous DUs to be integrated, such as 5G-NR, LTE and WiFi, managed by a single CU.

Leveraging our contributions in integrating WiFi cells as WiFi DUs in 5G disaggregated setups [5], we create the appropriate functionality for wrapping the network elements as services and deploying them through the Open Source MANO (OSM) orchestrator. OSM is one of the most widely adopted orchestration frameworks, complying with the NFV-MANO architecture. We use an extended version of OSM, that allows us to configure different types of wireless connectivity between VNFs, as shown in [6]. The software that we use for the network services is an extended version of OpenAirInterface (OAI) [7], that provides an implementation of the cellular base station stack Below we detail the experimental setup, and present some indicative results.

2.1 NITOS testbed experiment Setup

2.1.1 Radio Access Network (RAN)

For the wireless part of the network, we employ the OpenAirInterface platform appropriately extended in order to integrate WiFi technologies in the RAN. The functionality relies on the disaggregation of the traditional base station architecture to two different parts, the CU and the DU, and the introduction of signalling between these two entities. In [5] and [8] we present the signalling format, and the manner in which new DUs can be supported by OpenAirInterface. Through a thin software layer running on top of traditional WiFi Access Points, we are able to control the traffic that goes through the wireless network from the CU point of view (PDCP layer and onwards). The behaviour of the scheme resembles the operation of the LTE WLAN Aggregation scheme, introduced in 3GPP Release 14 [9].

Different policies can be applied, controlling how the traffic is split to the available DUs. For this demonstration, we use two DUs, an LTE and a WiFi, managed through the same CU, and we split the traffic with a 50% ratio to each DU. As the split for OpenAirInterface regards only the data plane operation of the platform CU and LTE DU are collocated on the same service.

However, as the data plane communication takes place over an IP interface, we emulate this behaviour by injecting delay on the interface equal to the mean measured delay between the CU and the WiFI DU (approx. 0.250ms). The configuration of the LTE network is a 5MHz LTE cell operating at FDD band 7, and as a UE we use an off-the-shelf dongle with our own SIM cards. For the WiFi network we use a 40MHz IEEE802.11n configuration, operating in an entirely free from external interference environment.

Table 2-1 Experimental settings for the RAN in NITOS

Network Parameters	Values
LTE frequency	FDD Band 7 – 2680MHz (DL)
LTE Antenna Mode	SISO
Number of Resource Blocks	25 (5MHz)
UE	Cat 4 LTE, Huawei E3372
WiFi Settings	IEEE 802.11n MIMO 3x3
WiFi Chipset	Atheros 9380
Backhaul/Fronthaul RTT	~0,450ms
Backhaul/Fronthaul Capacity	1 Gbps Ethernet

2.1.2 Transport Network

For the transport network, we employ two different links: 1) a mmWave point-to-point link, operating at the 60GHz V-band, and 2) an IEEE 802.11n WiFi link. The links are redundant and are used in order to backhaul the operation of the disaggregated wireless RAN. Primarily, the mmWave link is used, but in case of a failure traffic is switched over the WiFi link.

For this failover operation, we rely on the use of an OpenDayLight OpenFlow controller, that establishes the flows on the involved network nodes in order to redirect the traffic over the selected technology. The joint mmWave and WiFi network is seen as only one *provider* network at the orchestrator level, allowing the deployed VNFs to attach on it and make use of it. For our experiment setup, we use the LTE Evolved Packet Core (EPC) and a routing VNF that establishes static routing rules between the CU and the EPC as the two entities between which the failover link is configured.

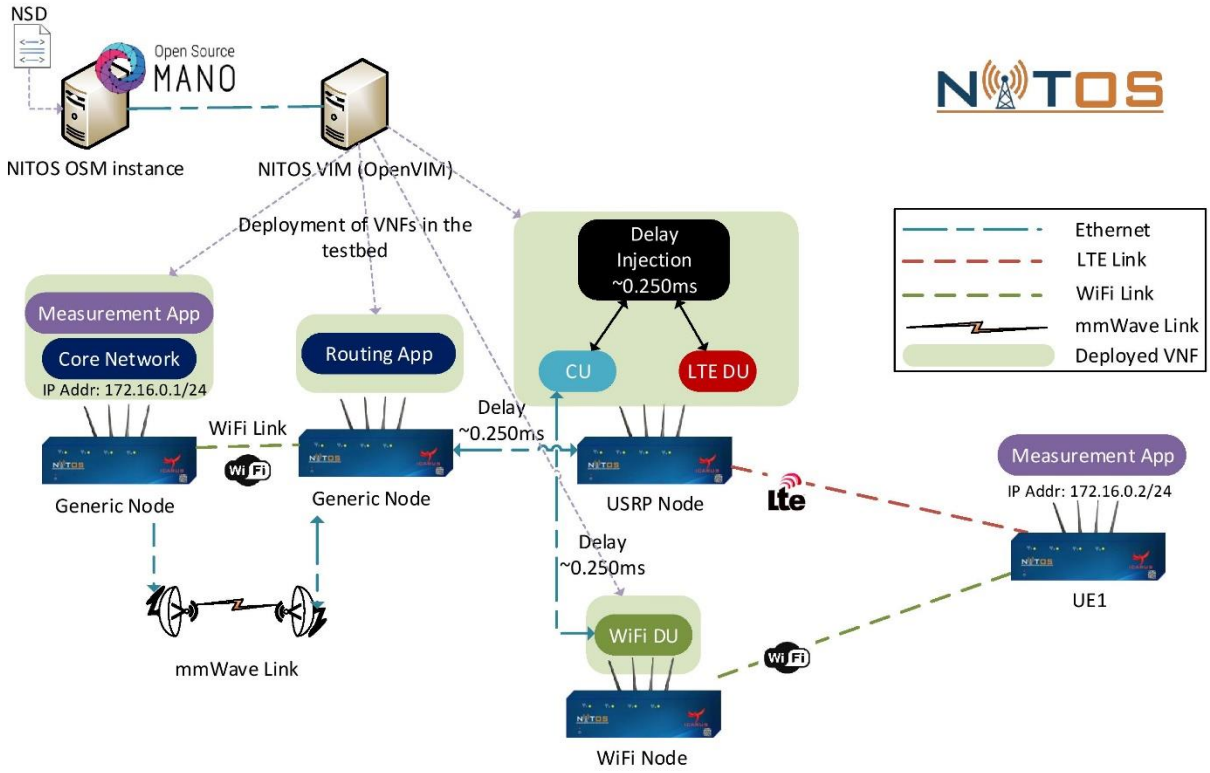


Figure 2-1: Experimental setup in NITOS

2.1.3 RAN as VNFs

For the operation of the wireless RAN we rely on the OpenAirInterface, the WiFi DU and the core network. For the first two software elements, the proper RF devices need to be present on the nodes. OpenAirInterface requires an appropriate RF front-end, which for our case is a USRP B210 device, that is attached on the OAI VNF. To do so, and to accomplish the transfer speeds between the VNF and the USRP device, we pass-through the entire USB controller of the compute node. Similarly, for the case of the WiFi DU, we pass-through the WiFi device on the compute node's PCI port to the VNF.

When deploying the VNFs, further configuration is needed for the running services. This is accomplished through Cloud-Init, and by a lightweight service [10] exposing some of the network parameters needed for the proper setup of the network. These include the address configuration for OAI communication with the Core Network, the radio parameters (number of antennas, PLMNID, etc.). Through a REST API, we instruct *Cloud-Init* to execute a string of commands for the configuration of the OAI and WiFi DU instance, interconnect them (at the application level) and connect them with the core network.

2.1.4 Orchestration Infrastructure

NFV-MANO has been developed considering mainly datacenter resources, with the networking being programmed through the SDN concept, and services being deployed using either virtual machines or light-weight containers. The advent of fully softwarized architectures for the RAN creates fertile ground for the re-consideration of services deployed in the network, moving beyond just application servers towards full stack networking systems. This fact also expands for wireless networks as well, with the ability to setup fully softwarized 5G base stations [7] with an appropriate radio front-end device (Software Defined Radio - SDR).

Considering that such applications usually assume distributed compute infrastructure, like for the case of deploying a base station along with a Core Network, the compute infrastructure needs to extend to generic networking devices, including heterogeneous equipment for the wireless operation. These technologies are not currently addressed by any orchestrator or through SDN production grade software.

As our orchestrator solution we employ the Open Source MANO (OSM) [11] platform, the most widely adopted framework for NFV-MANO. Our goal is to provide services running on top of different wireless networks deployed in the testbed. Traditionally, tools like OSM do not deal with network connections other than Ethernet, and make use of network interface virtualization enablers such as SR-IOV. Moreover, none of the widely

available VIMs support configuration for the wireless network. As similar solutions for the virtualization of the wireless interfaces also exist, they can be used in order to provide slices of wireless connectivity to orchestrated services, even for off-the-shelf equipment.

The target facility used for the development and applications of our proposed extensions to the orchestration software is the NITOS testbed (http://nitos.inf.uth.gr), located in University of Thessaly, Greece. The testbed is providing in a 24/7 fashion remotely accessible resources, targeting at experimentally driven research in wireless networks.

The testbed is providing access to over 100 physical nodes, equipped with key technologies:

- All the nodes are high-end PCs, equipped with Core-i7 processors and 8 GBs of RAM each, featuring at least two IEEE 802.11 a/b/g/n/ac cards, compatible with Open Source drivers (e.g. ath9/10k) used for WiFi related research.
- Two commercial off-the-shelf LTE access points are available for experimentation, along with the respective Core Network solution. Both femtocells and core network are programmable through the available testbed services [10]. About half of the nodes are equipped with LTE dongles, that allow the establishment of an operator-grade LTE network, using testbed specific SIM cards.
- Over 20 different SDR devices exist in the testbed, which are compatible RF front-ends for open source implementations of base stations (such as OpenAirInterface).
- Six mmWave devices are installed in the testbed, reachable from all the nodes of the testbed, and supporting the creation of high-throughput wireless point-to-point links.
- All the nodes of the testbed are interconnected through different hardware OpenFlow switches, organized in a tree topology. Users can set their own controller to manage the flows of the nodes that they are using.

The fact that traditionally NFV-MANO has been developed for orchestrating services and functions over datacenters hinders us from considering VNFs with wireless network services being deployment over them. Nevertheless, the structure of a testbed can be considered as a distributed set of nodes managed by an infrastructure manager such as Openstack [12] or OpenVIM [13].

As all of the testbed nodes also use Ethernet connections, we use them as the management plane of the orchestrator. For the differentiation of the services deployed over the nodes, we organize the testbed in four different "datacenters" as follows:

- *SDR datacenter*: all the nodes with SDR capabilities are included in this datacenter. VNFs/PNFs related to the execution of services interfacing SDRs are using this datacenter. Example VNFs scheduled for this datacenter may include OpenAirInterface RAN VNFs, for setting up the eNodeB part of an LTE network.
- *LTE datacenter*: all the nodes that have LTE dongles are included in this datacenter. All the services using the LTE network to transmit data are using this datacenter.
- *WiFi datacenter*: all the nodes with WiFi connections are included in this datacenter. Similar to the previous one, all the VNFs/PNFs deployed can use a WiFi connection.
- *Ethernet/mmWave datacenter*: the rest of the nodes that use Ethernet connections. Through the Ethernet network, the nodes are able to use the mmWave equipment.

Depending on the type of services that will be deployed, we plan the deployment of the VNFs on top of the physical nodes. The VNFs (Virtual Machines with ready to provision services) are making use of a bridged Ethernet connection with the physical interface that transmits the data over the air. Depending on the type of the physical interface used, we employ bridges based on either *bridge-utils* or Open-vSwitch [14].

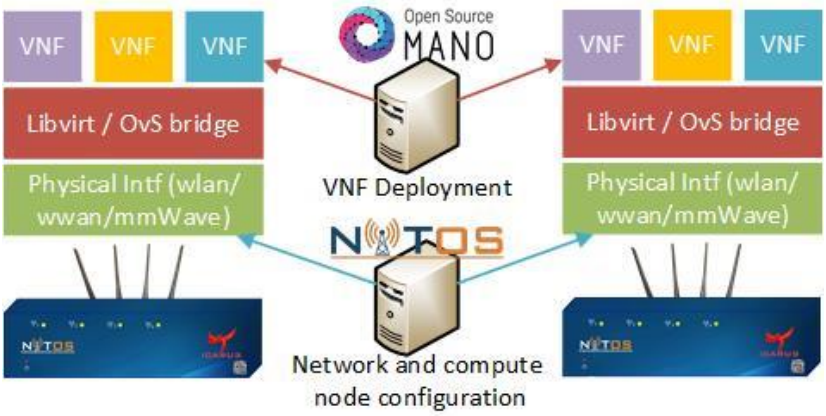


Figure 2-2: VNF instantiation on a NITOS node: each VNF is bridged to the underlying physical wireless network (WiFi/LTE/mmWave), configured through the NITOS testbed tools.

For the purposes of further testing the distributed multi-domain deployment, it is under preparation the split of the "LTE datacentre" in two datacenters located at two separate sites: the NITOS one as afore described and the COSMOTE one. The part of COSMOTE testbed to be used consists of a cloud infrastructure. The latter will be manageable by the NITOS testbed orchestrator to deploy on it VNFs of the NITOS LTE network (e.g. of the EPC). More specifically, the COSMOTE testbed physical infrastructure to be used is shown in detail in the following figure. The network and compute node configuration is similar to the NITOS one. Besides testing in lab environment the multidomain deployment capabilities, latency and deployment time will be the main KPIs to be tested with this configuration.

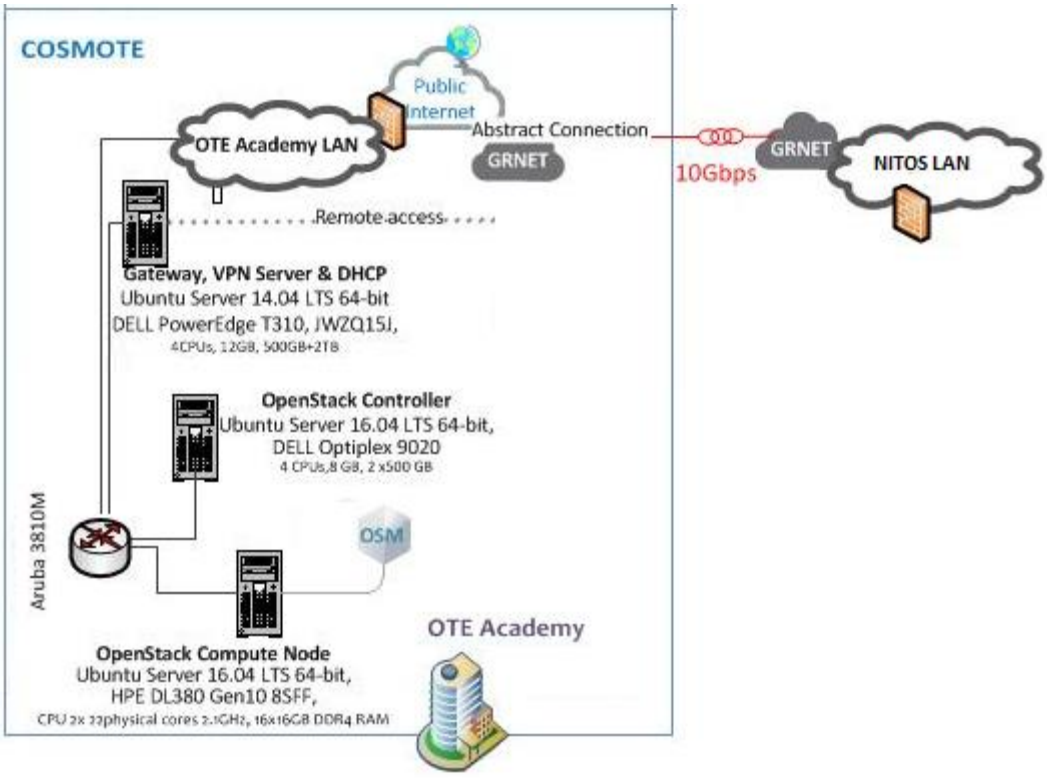


Figure 2-3: COSMOTE site physical infrastructure to be interconnected with NITOS

2.2 Results

We use the OSM instance in order to deploy the disaggregated network. Through the *Cloud-Init* mechanism, we invoke all the APIs for configuring the different VNFs, in terms of setting up their configuration files and launching the instances of the base station software. Below, some screenshots of the process are shown.

Figure 2-4: OSM dashboard for deploying VNFs in NITOS

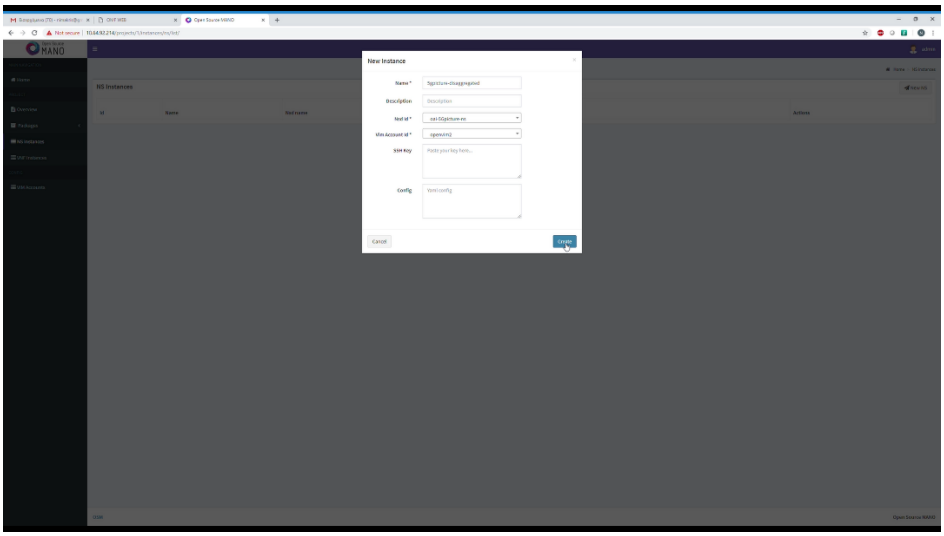


Figure 2-5: Selection of the disaggregated network service description

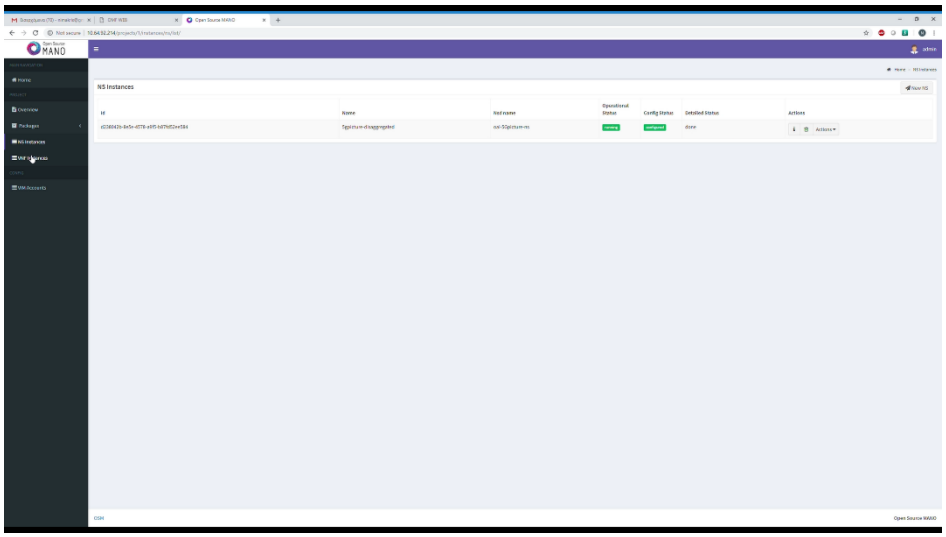


Figure 2-6: NSD is deployed successfully over the NITOS nodes

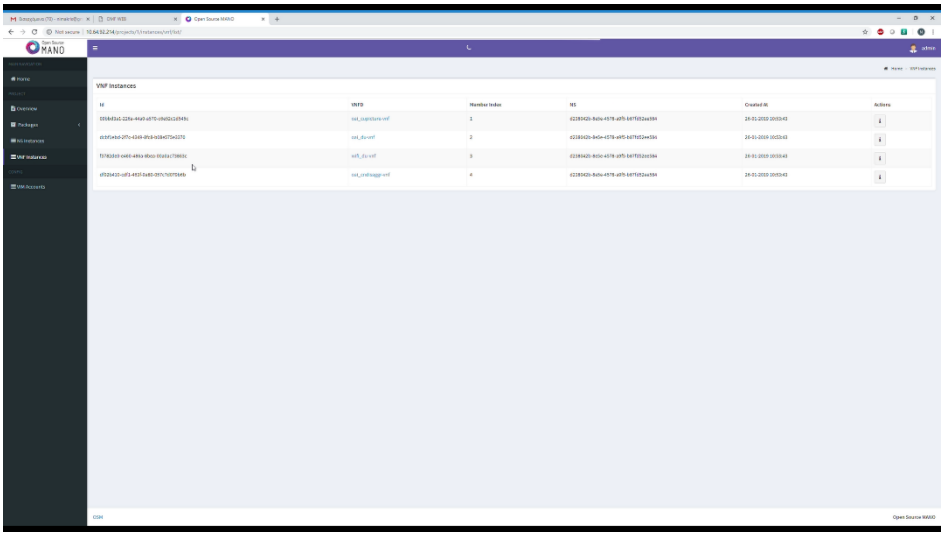


Figure 2-7: List of VNFs running in the disaggregated base station instance

After the instantiation of the network, we experiment by attaching a node to the WiFi and LTE DUs of the network. We inject 40Mbps of traffic through the *iperf* application at the core network (EPC) and measure the traffic delivered at the UE side. The UE is connected concurrently to the LTE and WiFi DU.

Figure 2-8 shows the measurements at the two communication sides: we see that traffic reaching the UE is less than what is injected at the EPC side, as it depends on the radio characteristics. LTE SISO mode with 5MHz bandwidth may achieve up to 16Mbps in our setup, and as the traffic is divided over the two DUs (20Mbps/DU), only about 36Mbps is reaching the UE.

Figure 2-9 shows how the traffic is split between the two DUs, based on what is measured at the output of the Core Network. The WiFi DU network traffic is higher than the LTE DU, reflecting the aforementioned settings. At the 150sec point of the experiment, we stop the WiFi DU and see that the UE gets only 16Mbps of traffic (Figure 2-8).

Figure 2-10 shows the traffic measured on the transport network (mmWave and WiFi). We see that although changes at the transport network technology happen twice, the connection between the core network and the RAN is preserved and the UE continues to receive traffic.

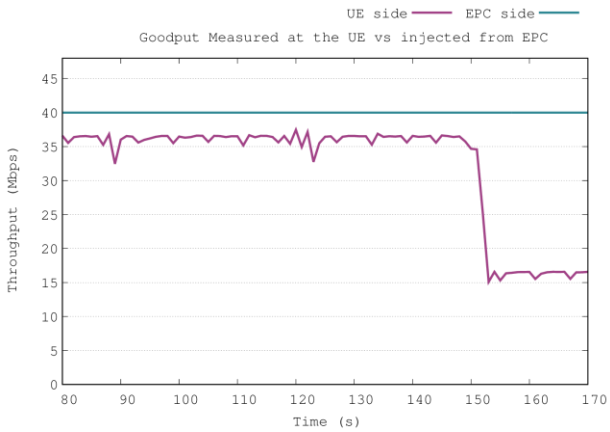


Figure 2-8: Experimental results after deploying the VNFs on the NITOS node: Application Goodput Traffic injected at EPC vs reaching the UE

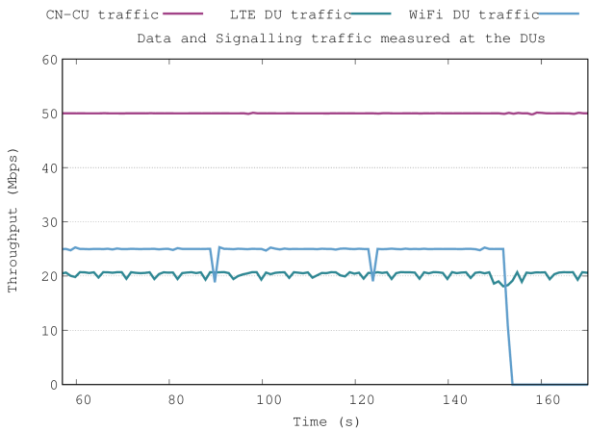


Figure 2-9: Traffic (payload and signalling overhead) measured at the WiFi and LTE DUs

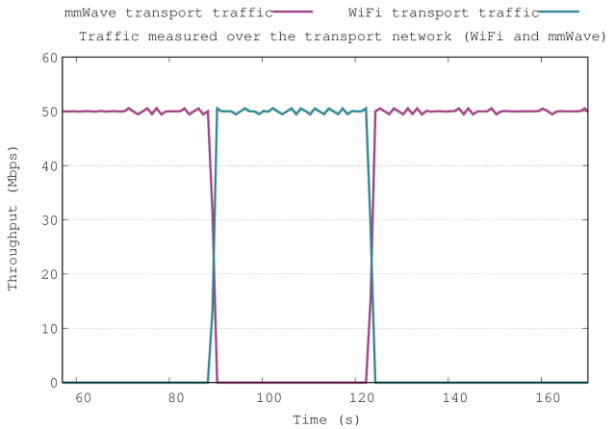


Figure 2-10: Traffic measured at the transport network (mmWave and WiFi)

3 Rail Use Case

3.1 Introduction / updates on the scenario to be demonstrated

This section develops the architecture described in 5G-PICTURE deliverable D6.1 “Specification of Vertical Use cases and Experimentation plan” section 4 (Rail Use Case) [1], that presents the deployment in phases and the use case scenarios to be executed in the rail environment in Barcelona. The general network architecture and the deployment of technologies are specified in detail in this document. Also described is the TAN (Train Access Network) and TCN (Train Communication).

Due to several reasons, three changes have been introduced since the original demo design was written:

- Protection switch of G.metro passive WDM will not be used in the demo. TAN redundancy was finally re-designed as a second, completely independent network. It is to say, the best way to provide the redundancy is to install two separate but identical passive WDM links on both sides of the track, each one with their own mmWave units. Due to this, currently it makes no sense to install the back-up Head End Equipment (HEE) and the filters in the corresponding stanchions’ cabinets.
- A specific CCTV software will be used for GDPR compliance. This software pixelates people’s faces in the demo recordings.
- The Micro Rain Radar station will not be used because of budget issues.

The main objective of the railway use case is to demonstrate the feasibility of having a common telecommunications infrastructure in a railway moving environment to transmit information from different services both critical regarding the operation and non-critical regarding the clients (passengers).

The following paragraphs provide some ideas in order to write the test plan in the future, and also provide a description about how the scenario will be demonstrated.

Project’s KPIs must be measured in two ways:

- Parameters related to bidirectional ftp transfers between devices connected to the on-board Wi-Fi AP’s and a server located at Martorell station
- Parameters related to the live-recording of CCTV files produced by the images captured by the on-board high definition cameras. Optionally, these images can be displayed in a screen located at Martorell station.

These transactions will be realized in two modes:

- Manual mode: the actions are initiated by an operator
- Automatically: each time the train passes through the demo track section, a trigger initiates an ftp transfer from the NUC PC provided by CNIT and the recording of the images captured by the CCTV cameras.

The files will be automatically sent to Martorell station, where it will be automatically stored. Each time one of these events will be executed, a log register with the KPI’s will be generated, containing these end-to-end parameters:

- Min/max/average throughput
- Min/max/average packet delay and jitter
- Min/max/average data BER
- Min/max/average packet loss rate
- Number of CRC errors
- Start time/End time and date
- Train Direction (Olesa-> Abrera/Abrera-> Olesa)

Additionally, each TCN/TAN element might store additional information about these transfers (obtained through iPerf or similar tools)

The demo will not only consist in this kind of test: specific functional tests (traffic prioritization, network redundancy, traffic prioritization, FlowBlaze functionality) will be realized on some dates.

3.2 Testbed Validation/integration tests

In order to prepare the demo configuration and simplify the installation process, all the demo equipment was tested in COMSA premises in Madrid during weeks 24 and 25 (June 10th-20th).

This testbed is not intended to be a phase I or an advance of the demo test plan. It is focused on the installation process, trying to minimize the impact of failures and reduce the installation time, trying to identify potential failures and anticipate some problems that sure will appear in the ultimate deployment.

The testbed objectives are:

- Verify all the equipment works properly and there are no HW issues
- Define the configuration to be used in the real deployment (with the exception of fine-tuning parameters that only can be obtained on-site)
- Check e2e connectivity

Also, the testbed includes some specific tests defined for each partner, which are described in the following paragraphs.

3.2.1 Individual Validation Tests

3.2.1.1 Blu Wireless Test Plan

Total equipment:

- 8 Trackside DN-101LC units.
- 2 dual antenna train TN-201LC units.

Part-1: Functionality: 1 day.

1. Test unit functionality using RJ45 interfaces.
2. x4 forwarding facing DN101LC units with x2 forward facing TN-201LC antennas.
3. x4 rear facing DN101LC units with x2 rear facing TN-201LC antennas.
4. Check throughput/performance/stability.

Part-2: Functionality with fibre interfaces: 1 day

1 Install new SFP+ modules and fibre patch lead.
2 Test unit functionality using interfaces.
3 x4 forwarding DN101LC facing units with x2 forward facing TN-201LC antennas.
4 x4 rear DN101LC facing units with x2 rear facing TN-201LC antennas.
5 Check throughput/performance /stability.

Part-3: Network: 2 days.

1. Review new network IP configuration from Comsa
2. Update Blu Wireless units with new network configuration.
3. Re-test Blu Wireless units
4. Disable auto iPerf
5. Test bridged interfaces on DN-101LC for external data generation.
6. Soak test overnight.

3.2.1.2 ADVA Test Plan

Targeted end-to-end performance metrics: (HEE-> TEE and TEE-> HEE for the 8 DN101LC AP's)

- Insertion loss / received power (dB/dBm)
- Throughput (measured by iperf transmitting between CO server and APs)
- Bit error rate (BER) (measured by Ethernet traffic analyzer)
- Latency / PDV (jitter) (measured by Ethernet traffic analyzer)
- Wavelength stability (ΔGHz/min) (measured by optical spectrum analyzer)

3.2.1.3 CNIT Test Plan

The demo will consist of four elements:

- An FPGA board to be installed in the train, which provide the FlowBlaze node for the train (**FBT**).
- A small form factor computer to act as client to be installed in the train (**CLI**).
- An FPGA board hosted in a server, which provide the FlowBlaze node for the ground. (**FBG**).
- A Linux server, which host **FBG** and will provide the server functionalities to test the session continuity (**SER**).

The characteristics of the elements, together with the individual test plan are reported below. The mandatory and the enhanced functionalities of the FlowBlaze node are highlighted.

CLI characteristics

The **CLI** is a standard Linux box which will provide basic network tools (ping/tcpdump/wireshark etc) and will be connected to the rest of the system using a 1000Base-T Ethernet interface. The **CLI** is also equipped with a Wi-Fi interface (IEEE 802.11ac) that can be used to simulate the user behaviour on the Wi-Fi connection. The **CLI** will be also configured to act as an iPerf client/server to provide throughput and packet loss measurements.

Individual testing of CLI:

Since this is a standard Linux box we only need to check the basic Wi-Fi and 1000Base-T Ethernet connectivity with the switch/access point hosted in the train.

SER characteristics

The **SER** is a Linux server which will provide basic network tools (ping/tcpdump/wireshark etc) and will be connected to the rest of the system using 2x10 GbE interfaces and a management 1000Base-T Ethernet interface. The **SER** will be used to simulate an internet server for the train users. The **SER** will be also configured to act as an iPerf client/server to provide throughput and packet loss measurements.

Individual testing of SER:

The 2x10 GbE interfaces will be connected to the **FBG.** The connectivity test has been performed at CNIT in Rome during the month of May 2019. A basic connectivity test will be performed when the SER will be connected to the **FBG.**

FBT characteristics

The FPGA board installed in the train will provide the FlowBlaze node executing the following functionalities:

- Packet generation: will generate a probe/keep-alive signal to the **FBG** node to update the binding between the source address of the train Access Point (AP) and the VLAN-id of the antenna connected to the train.
- Packet deduplication: will remove duplicated traffic originated form the **FBG** node, when it is configured to minimize packet loss using multiple destination antennas.

Individual testing of FBT:

The FBT will be tested as following:

- Check if the internally generated packets are correctly forwarded to the output port which will be connected to the train antenna.
- Send duplicate traffic to ***FBT*** (e.g. using the ***SER***) and check if it is correctly deduplicated.

FBG characteristics

The FPGA board installed at ground will provide the FlowBlaze node executing the following functionalities:

- VLAN learning: the **FBG** node will learn the antenna connected to the train binding the AP source address with the incoming VLAN id.
- VLAN tagging: the **FBG** node will set the VLAN id previously learned to the packet coming from the **SER** toward the **CLI** (that it is behind the AP).
- Packet deduplication: will remove duplicated traffic originated from the network, if multiple antennas are used to forward the traffic coming from the train.

Individual testing of FBG

The FBT will be tested as following:

- Send packets with a specific VLAN id to the interface port which will be connected to the internal network and check if the VLAN id is correctly stored in the internal FlowBlaze memory. The packets will be generated using the **SER.**
- Send packets to the interface port which will be connected to the external network and check if the VLAN id is correctly set and forwarded to the internal network. The packets will be generated/checked using the 2 **SER** 10 GbE interfaces.
- Send duplicated traffic to ***FBT*** (e.g. using the ***SER***) and check if it is correctly deduplicated. The packets will be generated/checked using the 2 **SER** 10 GbE interfaces.

Test Results

The above-mentioned tests were performed in COMSA premises in Madrid during weeks 24 and 25 (June 10th-20th). The rest results are as follows:

- Individual testing of CLI: **passed**.
- Individual testing of SER: **passed**.
- Individual testing of FBT:
  - Forwarding of internally generated packets: **passed**.
  - Deduplication function: **passed**.
- Individual testing of FBG:
  - Store VLAN id: **passed**.
  - Set learned VLAN Id: **passed**.
  - Send duplicated traffic to FBT: **passed**.

3.2.1.4 COMSA Test plan

<u>CCTV SYSTEM</u>

1) Assembly of the equipment in the test model:

a) Mounting the engraving rack and feed.

b) Connection of the recorder to an Ethernet network switch.

c) Fix the two cameras in the room. Feed them with the two POE Injectors through an RJ45 cable.

d) Connect each POE injector to the Ethernet network.

2) PC Server/Client assembly. Equipment configuration: Operating system, SADP application and Management tools3) Configure the recorder through the SADP software:

a) Register both cameras.

b) IP assignment of the devices.

b) Enable pixel face recognition

c) Setting the time. Possibility of NTP.

4) Configure the recorder through the management software:

a) Configure the channels (16 available)

b) Pixel (Mosaic Area): Body / Face

c) Add all the Components.

d) Type of storage.

e) 4T hard disk management.

f) Access: Client / WEB Client

Wi-Fi

1) Assembly of the Access Point in the room.

a) Ethernet connection between AP and POE injector.

c) Install POE Injector. Power them at 230V ac.

d) Ethernet connection between POE injector to a network switch.

2) Configuration of the Wi-Fi access point based on the plan of physical and logical interconnections (IP addressing, VLANs, etc.) defined in the project.

3) Creation of the Wi-Fi passenger network.

4) Internet connectivity test of telephones and/or PCs through the passenger network

3.2.2 Integrated tests and demo configuration

It will be desirable to configure the equipment with all the parameters aligned between all the partners (IP addresses, VLAN tags, etc.), in such way that only minor changes will be needed after the installation. Anyway, a minimum connectivity scenario at service level (Wi-Fi, CCTV) is needed to be up and running to satisfy the testbed gate.

Additional CNIT End to end tests:

After the individual test, the following end to end test will be performed:

- Basic connectivity tests:

1) static **CLI** to **SER** connection: a ping will be generated from the **CLI** and it will be checked if the reply is correctly returned.
2) dynamic **CLI** to **SER** connection: the VLAN id of the **CLI** will be changed and the ping test will be performed again.
3) Netcat based test. A nc client/server connection will be instantiated to check the TCP/UDP connectivity

- Throughput/packet loss test: an iPerf client/server connection will be instantiated between the **CLI** and the **SER** and the throughput and packet loss will be measured. The test will be performed both in a static condition and changing the VLAN id associated to the **CLI.**

3.2.3 Testbed results

Testbed in Madrid was satisfactory for most of the individual components.

It was checked all the equipment work fine, with the following exceptions:

- 100G Ethernet aggregator presents a firmware problem and cannot be used at all (its role was replaced by a train switch) -> ADVA will resolve the firmware issue by the second integration test.
- TEE modules have a physical bandwidth limitation and might not be able to work with the 10GbE line rate ->
    - 4 AP's will use tuneable BiDi at 10GbE (tested in Madrid June 22th) –> the two further stanchions from the station will use this
    - 4 AP's will use the proposed TEEs at 1GbE (tested in Madrid June 27th) –> the two closest stanchions from the station will use this
- SFP+ inside AP's: excessive temperature issue (founded on June 27th). After several hours, SFP+ inserted in trackside BWT units shows a temperature around 85ºC.

Only three end-to-end tests were executed in the testbed:

1) A CCTV circuit, using tuneable BiDi's

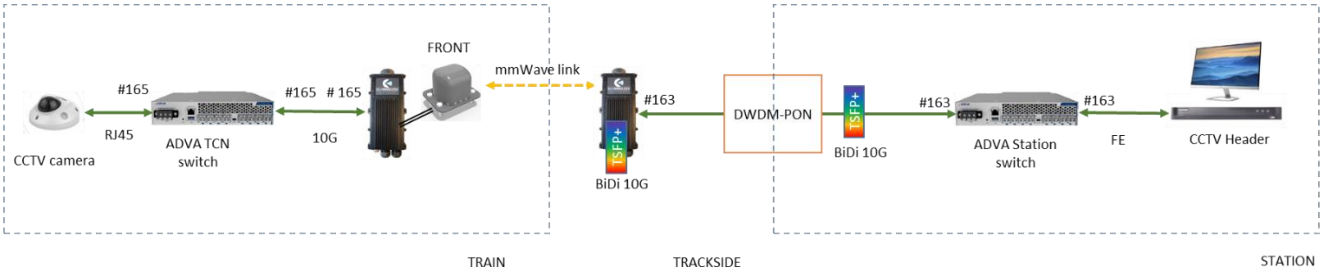


Figure 3-1 CCTV Circuit using BiDis

2) The same CCTV circuit, using TEEs at 1GbE

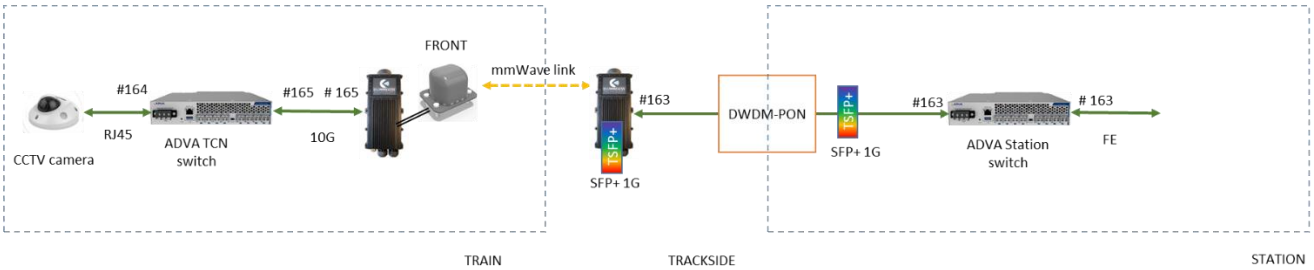


Figure 3-2 CCTV Circuit at 1 GbE

3) e2e circuits for management (without using the mmWave link)

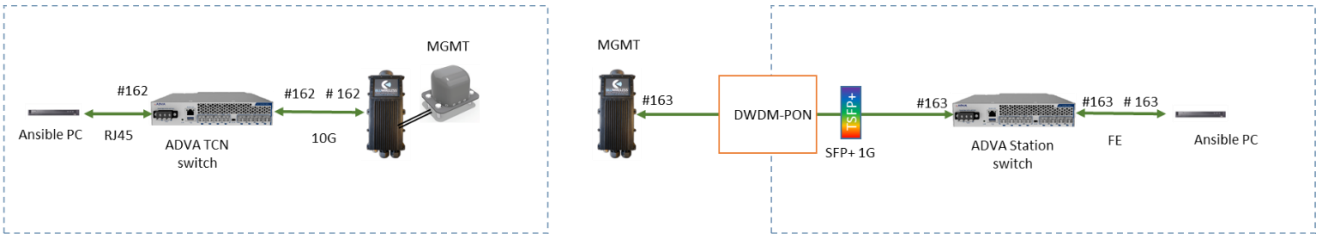


Figure 3-3 e2e circuits without the mmWave links

For several reasons and the problems found, there was no time to execute the rest of the tests in Madrid (including proposed CNIT tests). The timing for checking and finishing the installation on-board (this task had to be finished at end of June, because otherwise, timing to work on board had too many restrictions) was the main priority. Anyway, in the current situation, the execution of most of them has no meaning, until all the issues are fixed.

Performance issue:

- Each train contains four antennas on-board and not all are connected simultaneously
- Initial design was made with only one link per unit, something that is incorrect, assuming that each unit is permanently connected

Next figure shows the exact components of the on-board units:

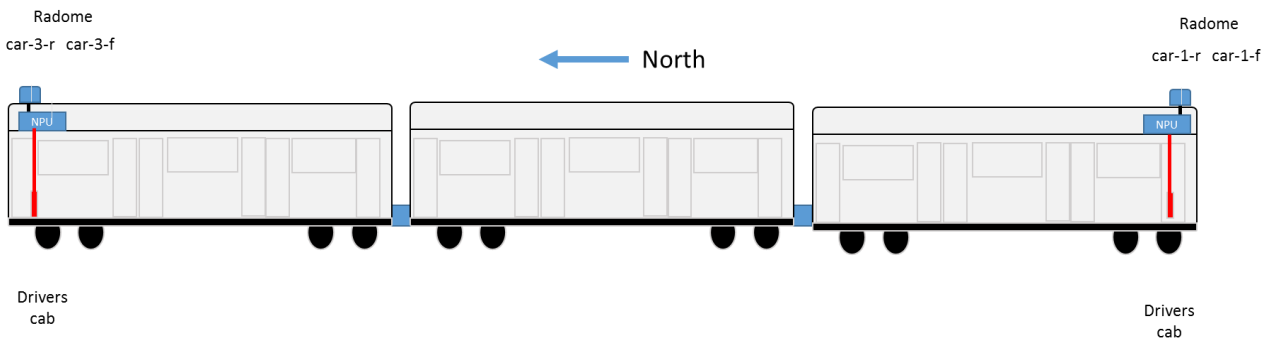


Figure 3-4 On-board units

Initially, it was expected that system behaviour would be similar to that in the next figure. That is, the train units are always “magically” connected to the mmWave AP’s on the track along all the demo length.

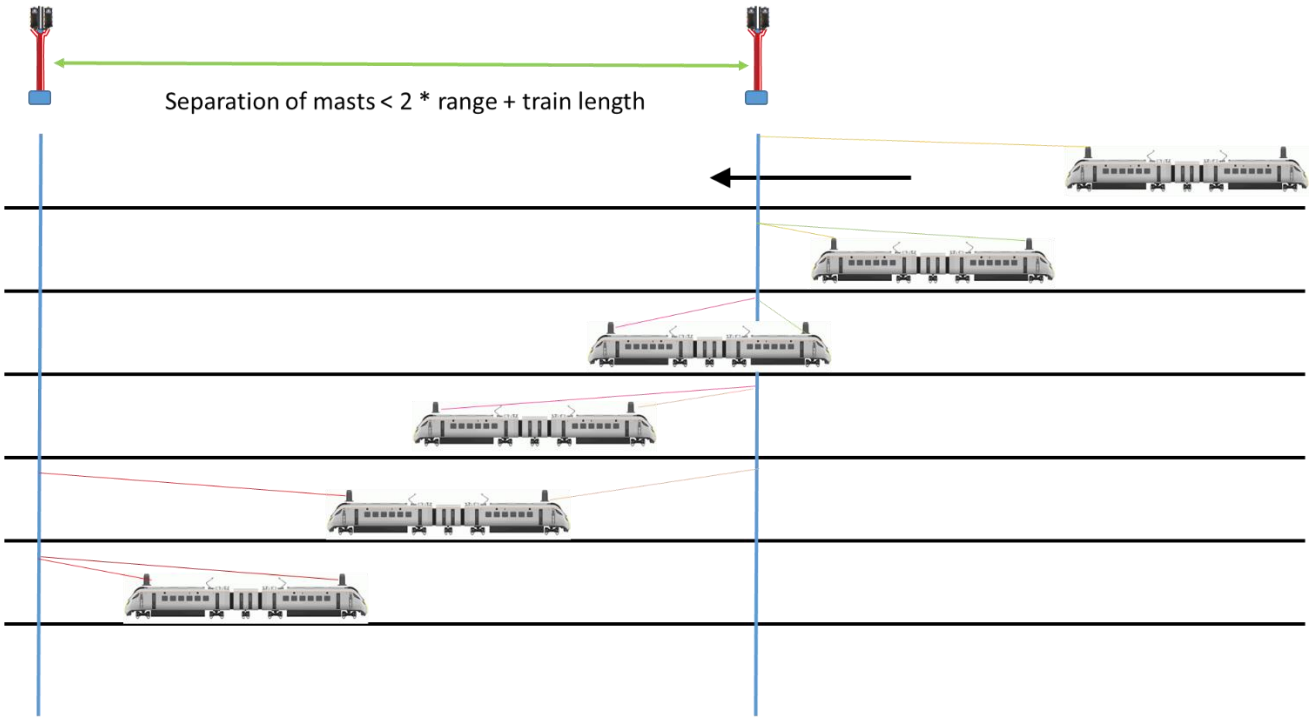


Figure 3-5 Expected system behaviour

However, the actual behaviour is as follows:

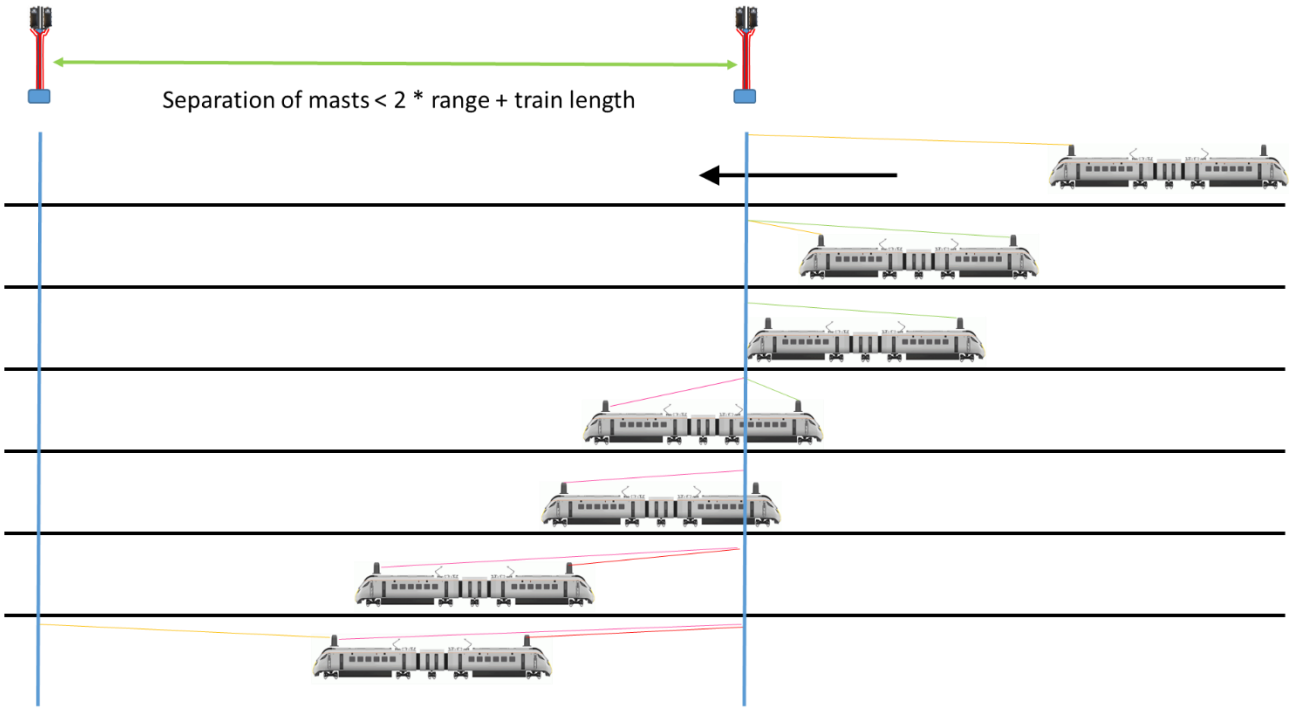


Figure 3-6 Real system behaviour

Depending on the train position, outgoing traffic can be sent to an unconnected link. Therefore, this traffic will be dropped, decreasing the link performance.

Currently, two main solutions are proposed to solve this issue. In both cases, FBT must duplicate the traffic to both sides of the train:

1) Use only one antenna for each TN-201LC train unit (disabling the other). The antennas enabled are the inside ones, even train pantograph can reduce the direct sight of the mmWave links
2) FBT send all the traffic to all the antennas

This issue is still under discussion. Anyway, there are other implications for the service level. The next figure shows how the bridging and the networking of the BWT units works:

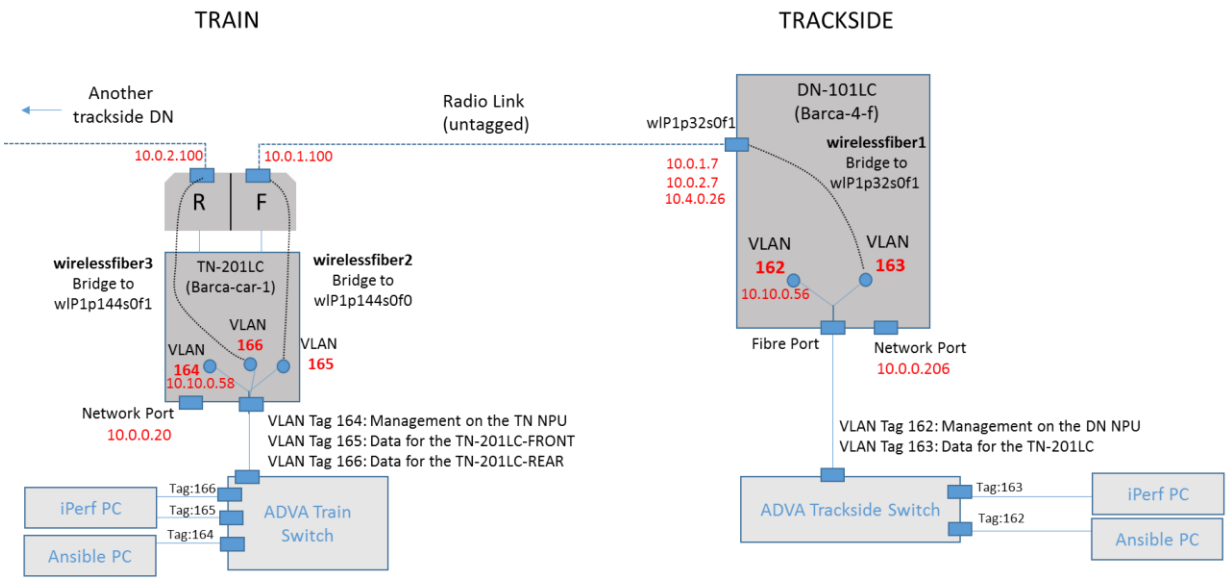


Figure 3-7 Networking architecture of BWT units

The picture above shows that to reach a particular TN-201 LC antenna, traffic has to be sent over a specific VLAN tag (165 or 166). Together with this other (CCTV circuit), the result is:

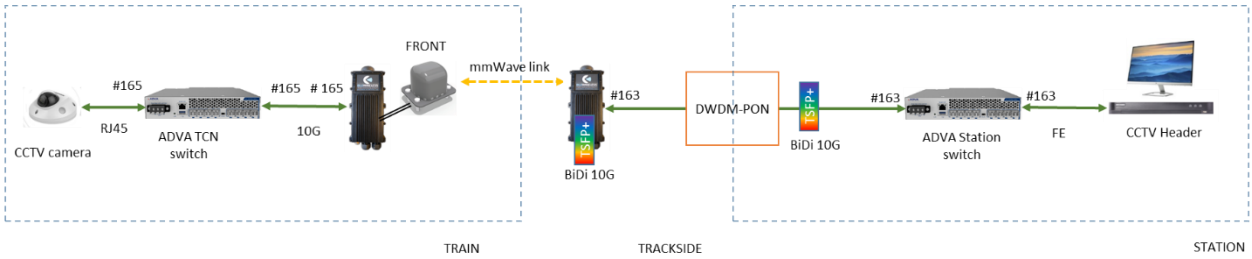


Figure 3-8 Overall VLAN configuration

- A CCTV connection relies on one antenna only (in this case, front of one of the units)
- While this antenna is not connected, traffic is dropped.
    - Depending on the train position traffic will be dropped,
    - Translates in a service outage for some seconds.

Regarding VLAN tags/IP addresses it shall be noticed that: Management, Wi-Fi and CCTV has to be on separate VLANs in order to show that the architecture supports virtual connections for different railway stakeholders.

Additional aspects to mention:

- Testbed was executed without the use of the planned IP's/VLAN tags
- It is necessary to obtain a global configuration that allows remote access to all the demo equipment (on-board included). This requires a dongle on-board (connected to the NUC PC) and a PC at Martorell station.

3.3 Initial installation

Due to the issues found in the testbed, the demo equipment installation has to be postponed until these ones are resolved and checked.

Anyway, all the tasks related with the physical installation, power, fibre, mechanical components, cabinets, etc will continue. Installation of testbed related equipment has been postponed to the second half of September.

With the above exception, all the tasks related to the train were finished during June.

Figure 3-9 Train installations

Here is a summary of the task finished:

- All the works planned in the pit for the deployment of the fibre optic cabin to train cabin were carried out.
- The connections between carriages and the flexible tube were installed at the two intersections between carriages.
- The fibre has been drawn all along, passing through the upper trays next to the train access door and has also been led through the new tubes installed between carriages.
- Reflectometry tests passed successfully.

Figure 3-10 Connection between carriages

- Assembly of the two FO distributors in cabin 1 and 2. It was carried out the fusions with six pigtails of each distributor.
- A hole has been drilled in the wall of cabin one, so that the cables can be fed into the large cabinet.
- Installation of power cable between Low Voltage and the cabinets in both cabins

Figure 3-11 Power installation

- The two special HPU supports in cabin 1 and 2 were installed. Two guides have been machined between the two existing beams so that the HPU can be moved in the required position.
- 35mm diameter new tube fixed to the TETRA ground scale (widen hole) on the train roof.
- New box for cabling and TETRA antenna reinstalled on the train roof.
- Waterproof tests passed successfully.

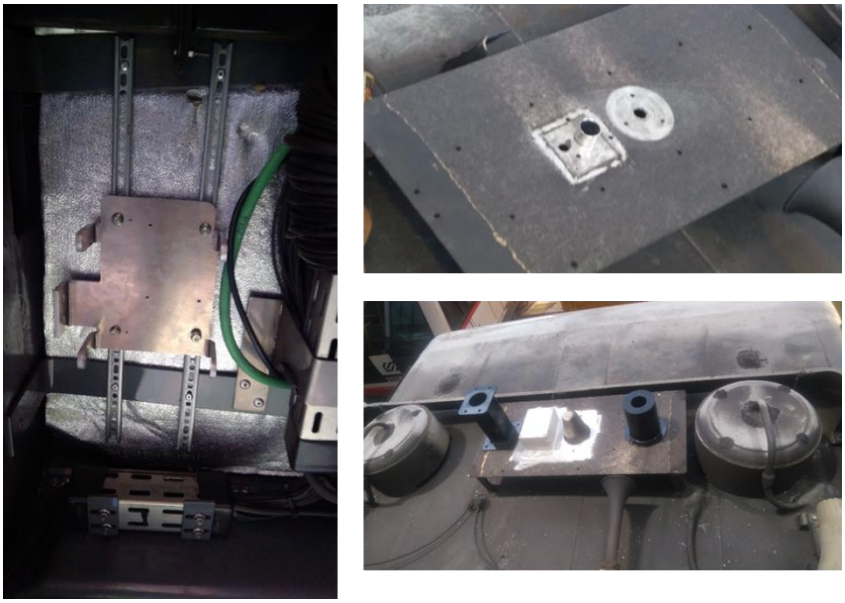


Figure 3-12 Train roof installation

- Assembly of the specially designed cabinets: a small cabinet for cabin one (see left side photos below) and a big cabinet for cabin two (right side)

Figure 3-13 Assembly of cabinets

- Demo equipment on-board checking done; they were installed and uninstalled in their appropriate locations, verifying all the space requirements, and the power and fibre connections. In this way, we also protected the demo equipment against unnecessary risks (vibrations, heat, etc) during summer.

Moreover, all the tasks along the track have started and will be continued in July. Below, some photos related with these are shown.

Figure 3-14 Track side installations

Then, all the previous tasks will be finished on time (it is to say, in July). In this way, the demo equipment can be installed in the second half of September, when the second testbed is finished.

3.4 Updated planning/risks

All the risks defined before this document has been disappeared of have been solved. New ones have been found, all of them related with the issues founded in the testbed.

The identified risks were:

1. Lack of space on-board to install equipment new: finally, it is possible to install three TAN switches in front and middle train vehicles. This risk is closed.
2. License for 60 GHz required by Spanish admin. Finally, an agreement with the Spanish administration has been reached about the spectrum license. Then, this is not a risk for the project anymore.
3. Excessive jitter and/or excessive duplicate traffic. Finally, a FlowBlaze will be installed on-board. That means that this issue can be closed.
4. Passive WDM SFP+'s inside mmWave AP's box not ready for the demo timeline. As it was shown in the testbed, this is not the case. Then, this risk is closed.

The last risk is replaced by the following one:

5. Excessive heat for Passive WDM SFP+'s inside mmWave AP's box (chance: high; impact: high). Some actions have been defined, addressed to improve heat dissipation. In the worst case, AP's can be powered off remotely via Bluetooth when SFP+ temperature will increase over the defined limit (85ºC).

Planning update:

- Final agreement for the "four antennas" issue solving (July 18th)
- We recently tested a FlowBlaze configuration in which we are able to send packets to the 4 antennas, generating two packets with different VLAN ID which are forwarded to 2 different ethernet ports. This configuration should allow to use the four antennas. As a fallback, we will also provide a FlowBlaze configuration in which only two antennas (connected to the front and the rear of the train) will be used.
- New Testbed in Madrid: September 2nd-13th. At this date all the testbed issues must be solved (or their respective contingency plan applied)
- Demo equipment installation (including Remote Access): September 16th-20th and September 30th-October 4th
- Final test plan definition and automation October 4th-9th

4 Stadium Use Case

4.1 Experiments

This section provides additional details about the use-cases. Initial descriptions have been provided in D6.1[1].

The first use-case is the end-user application over the stadium network as is to get a baseline. Then we test the application over the 5G Network. Here we do not have programmable connectivity between the application and the network. Following this, we implement network awareness in the end-user application. Finally, we show the use of VNFs in a network slice. There is also the physical test of massive MIMO at the edge from University of Bristol. Figure 4-1 shows the network control components for the demo.

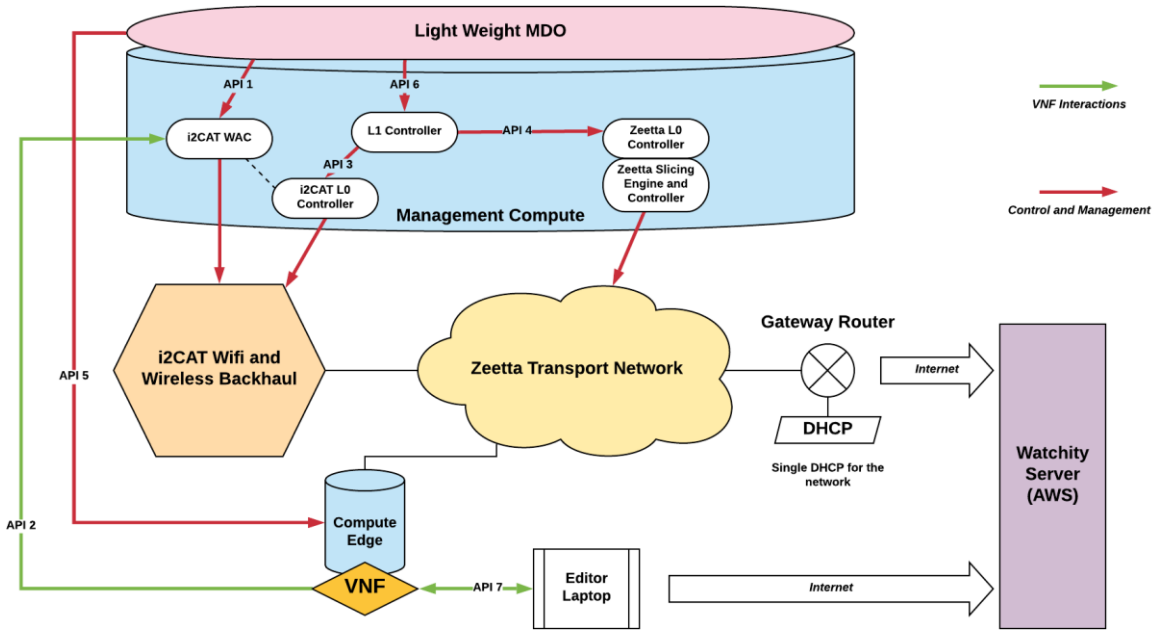


Figure 4-1: Demonstration network control components

4.1.1 Experiment 1: Benchmark application "as is" over the current stadium network

Baseline infrastructure:

- I2CAT WiFi network deployed in Fan Zone
  - Note: This has to be the same basic infrastructure than in the other experiments, to be able to compare results
  - All traffic connects to a single SSID which emulates "public stadium WiFi"
- Stadium wired network
- External cloud hosting Watchity app (Amazon)

Client devices:

- <=6 tablet/phone recording and upstreaming video.
  - Specs: Any high-end Android phone should work
  - The Watchity license we are using allows for up to 6 clients.
  - Watchity clients can use one of several transmission profiles. The profile is fixed (no rate adaptation). I2CAT requested to increase the available profiles up to 4 Mbps (HD)
- >= 2 laptops creating background traffic to congest the network (using iperf)
- >=1 phone/laptop visualizing the edited stream
- 1 laptop to be used by the video editor accessing the editor service in the cloud (Amazon)

Measured KPIs:

- Number of upstream streaming Watchity clients that can be supported.
  - We can have up to 6 clients
  - We can test the highest profile available Given profiles and background
- Watchity KPIs: Note: All these KPIs are measured at the Watchity cloud server
  - Upstream Data rate stream → Depends on the used profile
  - Upstream Per-client delay & jitter → Measured in the cloud (Amazon)
  - Upstream Per client packet loss → Measured in the cloud (Amazon)
  - Stream synchronization [Measured subjectively]
    - Note: To measure synchronization we propose to have the Watchity clients recording a millisecond clock (e.g. https://www.youtube.com/watch?v=9cQT4urTlXM). Manually we will determine synchronization comparing different frames
- Data-rate achieved by background traffic throughput (these can be downlink iperfs)

Demo experience: We visualize the edited stream

4.1.2 Experiment 2: Network service Deployment Experiment

The goal of this experiment is to validate how the 5GOS allows to deploy connectivity services over the stadium infrastructure dynamically, e.g. only during match day.

The network envisioned service will contain:

- Wireless connectivity at selected APs in the Fan Zone: SSIDs in a subset of APs
- Transport services: e.g. VLANs dynamically provisioned to carry the traffic from the deployed SSIDs
- Network functions, including:
  - VNF-1: Dataplane function to identify Watchity traffic and notify the control plane
    - Watchity user traffic is: RTMP – TCP:1935
    - Maintains mapping between IP – MACs for Watchity clients

Baseline Infrastructure:

- Same as experiment 1
- Compute resources to host VNFs: 1 server (config to be decided)

Client devices:

- 2 WiFi clients to validate that the network service is up and running

Measured KPIs:

- Time required to instantiate the network service
- Complexity in the configuration required to deploy a new service [subjective KPI]

4.1.3 Experiment 3: Benchmark application "as is" over 5GPICTURE stadium network

Baseline infrastructure: Same as experiment 2

Experiment Goal: Illustrate how 5GPICTURE intelligent network can autonomously detect and prioritize Watchity traffic in order to enhance QoE, as compared to Experiment 1

- How to prioritize Watchity traffic in the wireless segment? Note: Most traffic is upstream
  - Suggested mechanism: I2CAT boxes will have two wireless interfaces in the access domain (e.g. one at 2.4 GHz and one at 5GHz). The same SSID will be radiated over both interfaces, however the 5GHz will be pre-configured with a white list so that only explicitly allowed clients can connect. The I2CAT WiFi controller will expose an API that will allow to move selected clients to the 5GHz SSID. Hence, the proposed workflow is:
    - 1. All clients (Watchity and background) by default will connect to the SSID at 2.4 GHz
    - 2. VNF-1 (see experiment 2 description) will detect Watchity traffic
    - 3. VNF-1 will notify 5GOS (NETOS) about IP@ of Watchity clients

        - 4. NETOS will maintain mapping IP@-MAC@, and will notify I2CAT RAN controller to prioritize MAC@
        - 5. The I2CAT RAN Controller will maintain the AP attachment point of each client device, and upon the request will move the prioritized client to the 5 GHz SSID using network trigger mobility.
- How to prioritize Watchity traffic in the wired segment?
    - Note: Let's assume background traffic is downlink. We can throttle this traffic in the wired network, which would free wireless bandwidth for the Watchity upstreams.
        - Option-1: A queue discipline in a downstream switch where all non-Watchity traffic is classified. This queue discipline should throttle all downstream traffic bound to a given AP, to a value that should be adjusted to give enough room for the Watchity streams in the uplink.

Client devices: Same as Experiment 1

Measured KPIs: Same as Experiment 1

Demo experience: We visualize the edited video stream, which should now have better quality than in Experiment 1

4.1.4 Experiment 4: Demonstrate Upstream Capacity increase through Massive MIMO

Baseline infrastructure:

- National Instruments Massive MIMO kit: 4 racks (Each rack terminates in 16A connectors, and a 4x 13A extension block which also has a 16A termination on it. The total current requirements are about 20 amps, split 8 amps for rack A, 8 amps for all of racks B, C and D, and 4 amps for items on the 13A extension).

Client devices:

- 12 single antenna client devices (same number of laptops required). The total current requirement at the **user** side is no more than 13A.

Measured KPIs:

- Spectral efficiency
- Error Vector Magnitude
- Measure the required time to transmit a fixed quantity of data comparing: conventional cellular access vs. using spatial multiplexing and user-grouping

Demo experience:

- We want to show the superiority of Massive MIMO, in terms of bandwidth and spectral efficiency, compared to WiFi

Massive MIMO Testbed Deployment

The Massive MIMO testbed, depicted in Figure 4-2, comprises a base station (BS) and 12 available users. The BS is divided into 4 racks, providing 32 RF ends each, i.e. 128 in total. The RF ends are connected to a patch panel antenna array in a 4x32 configuration with vertical and horizontal polarisations operating at 3.51 GHz. The BS will serve simultaneously up to 12 users with one antenna each, Video streams can be transmitted in both uplink and downlink using User Datagram Protocol (UDP) ports. Currently, the Massive MIMO testbed is connected via Ethernet, however fibre connection is an ongoing work.

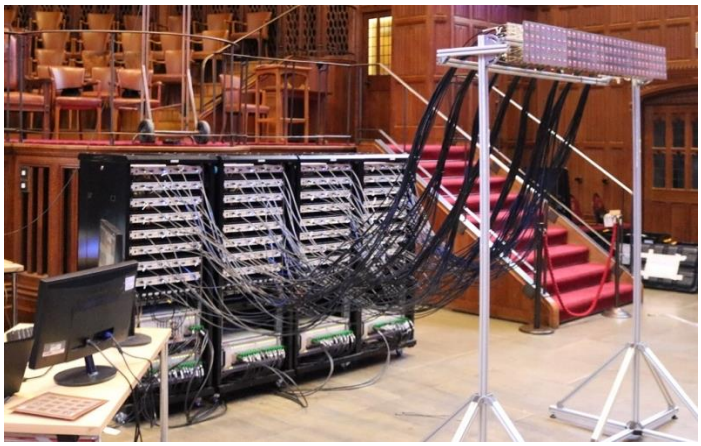


Figure 4-2: Massive MIMO Testbed: (left) Base station end, (right) Users end.

During the demonstration, 12 uncoded 16-256 QAM video streams (raw UDP streams) will be transmitted in Uplink in real time. Performance will be monitored and evaluated through real-time outputs showing throughput, constellation maps, Error Vector Magnitude (EVM) and possibly Bit Error Rate (BER). As discussed in D6.1 [1], two scenarios will be investigated: an indoors and an outdoors one, looking at both linear and distributed antenna deployments.

Scenario 1: West End Indoors

In this scenario, we are planning to initially place the 4-racks BS in area L1, as depicted in Figure 4-3, with users employed on the opposite side. There has been an update on the distributed Massive MIMO approach, where initially 2 racks would be placed into area L1 and 2 racks into L2. Our plan now is to distribute the BS antennas into four spots (L1, L2, L3, L4), as shown in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, and place users in the area in between.

Figure 4-3. Scenario 1: West End Indoors Scenario.

Scenario 2: Stadium Bowl Outdoors

In the outdoors scenario, there is no update on our plan. We will first deploy the 4-racks BS on one balcony (A1 or A2 in Figure 4-4), with users employed on the opposite side. For the distributed approach, two racks will be deployed on A1 and two on A2, with users placed in the seats in between the two balconies.

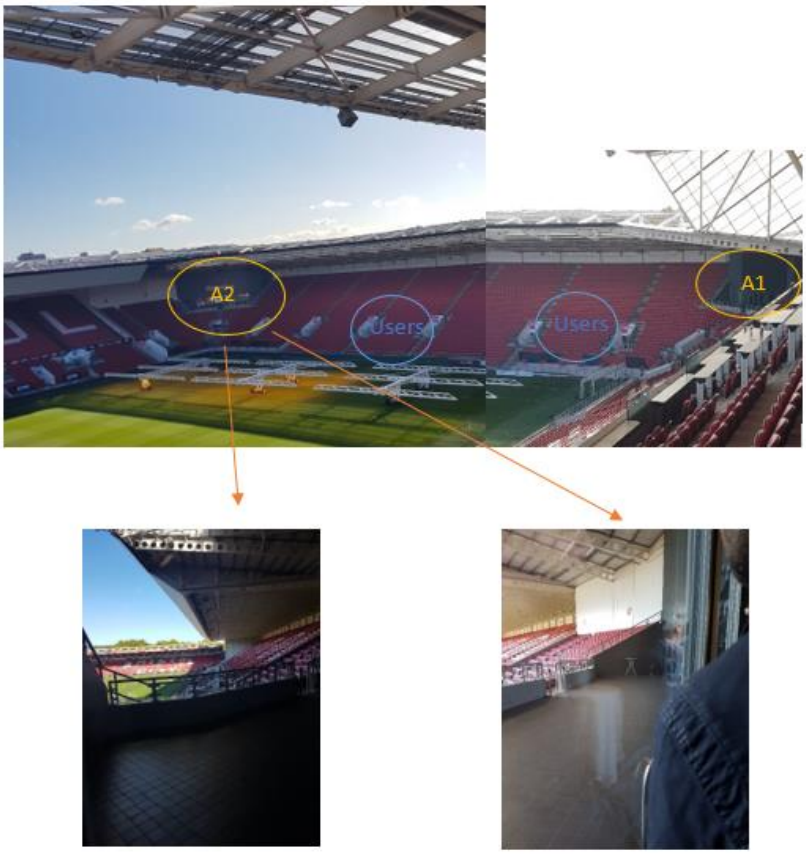


Figure 4-4. Scenario 2: Stadium Bowl Outdoors Scenario.

4.2 Demo Locations and Layout

The demo location is provided in Figure 4-5. The i2CAT AP and Wireless backhaul will be deployed in the Fan Zone area. The Zeetta Mobile Lab will be deployed at that location as well.

Figure 4-5: Demo Locations and Layout

Massive MIMO demo will be in the West Stand Concourse for the indoor tests and the South Stand Balconies for the outdoor (bowl) test.

- For the indoor scenario (West End), both linear and distributed Massive MIMO deployments will be considered. For the linear deployment, all four racks will be placed at a specific area and clients will be distributed at the opposite side. For the distributed scenario, two racks will be placed at one side, two racks at the opposite side and clients will be distributed in between.
- In the outdoors scenario (Stadium Bowl), again, both linear and distributed deployments will be explored. In the linear case, all racks will be at one of the balconies and clients will scattered in front of the balcony. In the distributed Massive MIMO case, two racks will be placed at one balcony, two racks at the opposite balcony and client devices will be placed in between the two balconies.

4.3 Partner Contributions

Partner contributions are presented in Table 4-1. This is the confirmed list of contributions.

Partner	Equipment/Tool	Target Testbed/Site
ZN	Wired Ethernet network	ZN Internal and Stadium
ZN	Wireless Network	ZN Internal and Stadium
ZN	Controller and Orchestrator	ZN Internal and Stadium
I2CAt	Controller for WiFi	ZN Internal and Stadium
I2CAt	Controller for Backhaul	ZN Internal and Stadium
I2CAt	Wifi Access Points and Backhaul nodes	ZN Internal and Stadium
I2CAt (Media)	Watchity Application	ZN Internal and Stadium
UTH	Compute (OSM and VNFs)	ZN Internal and Stadium
UNIVBRIS-CSN	Massive MIMO Kit	UNIVBRIS-CSN Lab and Stadium
ADVA	Compute (OpenStack)	ZN Internal and Stadium

Table 4-1: Partner Contributions

4.4 Implementation Update

The details of the proposed network for the Stadium demo can be seen in Figure 4-6.

The SDN switches and Compute will be in the Zeetta Lab-On-Wheels. The SDN Switches will be used to demonstrate a transit provider network (ZN) who uses network slicing to provide support for multiple connectivity (with class of service) requests from different tenants (one of them being the edge network of wireless nodes).

I2CAT will provide their Wireless nodes for the access network. There will be multiple high-priority and low priority clients along with background traffic laptops. The Wireless nodes will demonstrate the network at the edge in a Stadium/Smart-venue/Mega-event.

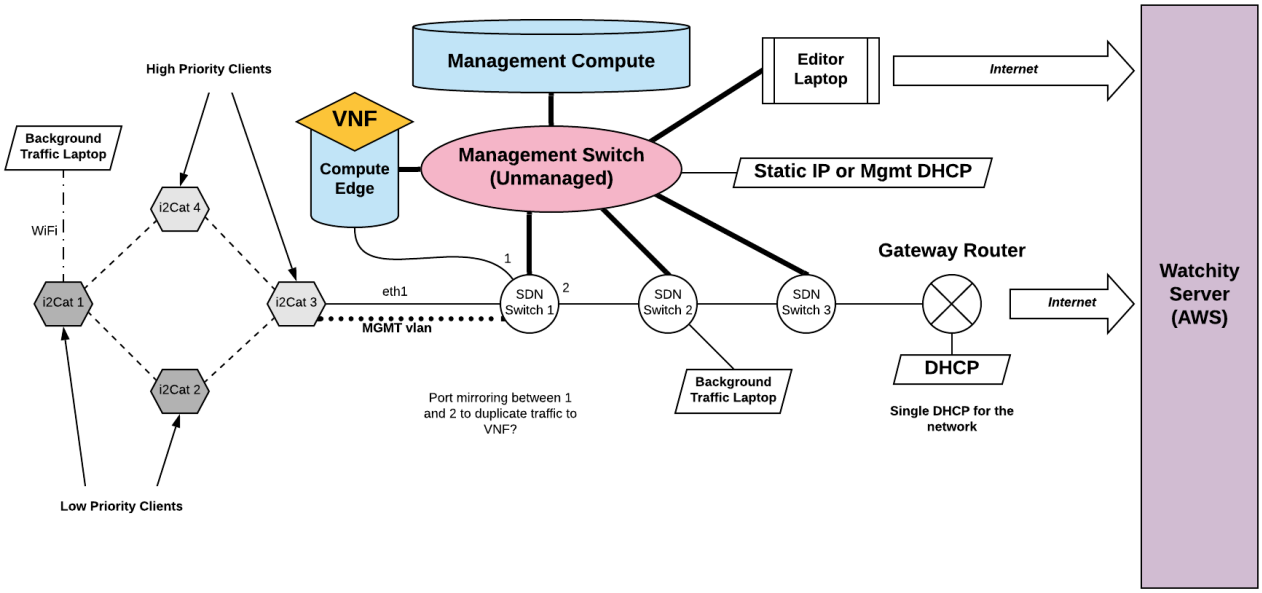


Figure 4-6: Network layout (data plane and control plane)

4.4.1 5GOS as a Solution

We are implementing different parts of the 5G OS as a solution for this demo to provide multi-tenancy support.

There are three domains in this case with Domain Orchestrators and Controllers in each domain:

1. Wireless Access/Backhaul (i2CAT)
2. Transit (ZN)
3. Compute (UPB, UTH)

Over these domains we have a 'light-weight' Multi-Domain Orchestrator to provision services.

4.4.2 Developments related to the wireless access segment

The wireless access and backhaul segment of the stadium demo is going to showcase the capabilities of the Joint Access-Backhaul Technical Component developed in WP4 (SWAM data-plane); the interested reader is referred to section 3.7 in D4.2 for a detailed description. In addition, we built an SDN controller using the NETCONF interface for the I2CAT boxes reported in section 3.2 of D3.2 that allows to instantiate dynamically the access-backhaul data-plane reported in D4.2.

Figure 4-7 provides a detailed description of the physical set-up that will be deployed in the fan zone outside the Bristol stadium. Four joint access-backhaul nodes provided by I2CAT will be mounted on portable posts, with an inter-node distance of around 50-100 meters (to be calibrated on site). Each node features three different wireless interfaces based on IEEE 802.11ac technology, where two of them are used to provide wireless backhaul (connect nodes with each other), and one is used to provide wireless access.

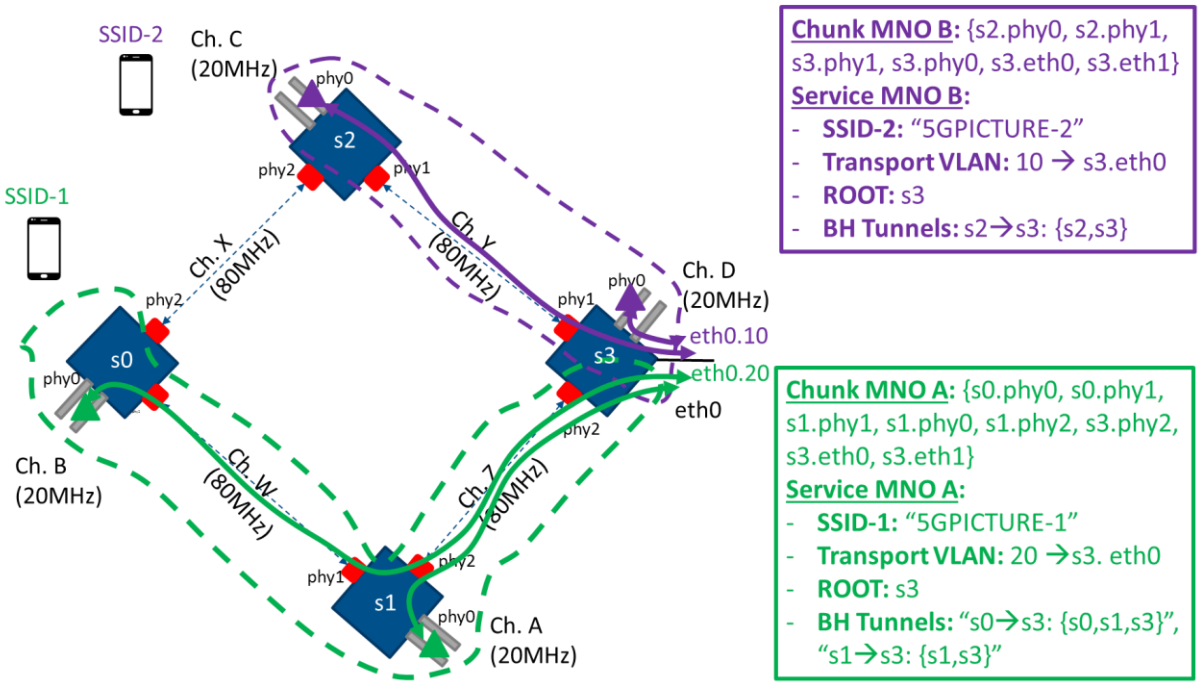


Figure 4-7. Physical topology and high-level service definition

The infrastructure offers the ability to define slices on-demand, whereby a slice consists of a wireless service (i.e. an SSID), instantiated as a virtual access point in a sub-set of the available I2CAT nodes (s0 - s4), as well as the required wireless backhaul connectivity. In order to support the planned use case, two concurrent slices will be deployed, a low priority one for general access, and a high priority one reserved to support media uploads from the Watchity clients. The purple and green boxes in Figure 4-7 illustrate the high level definition of the aforementioned service slices that include an SSID, the path through the wireless backhaul, and the transport VLAN where this traffic needs to be delivered. Notice that the transport VLAN is the way that the slices on the wireless segment are bound to the corresponding slices on the wired segment.

An initial implementation of this technology was demonstrated at EuCNC 2019 in Valencia, for which all the necessary REST APIs for service deployment were developed. Figure 4-8 depicts the exact definition of various API endpoints that we describe next:

- *Topology*: Provides a description to the higher layers of the 5GOS (Domain Orchestrator) of the I2CAT boxes available in the infrastructure, as well as their component physical interfaces and backhaul links.
- *Chunk*: Allows to provision an infrastructure chunk, which is a set of physical resources, meaning backhaul links and physical access interfaces that are reserved for a given tenant. The same physical resource can be allocated to more than one tenant.
- *SWAM service*: This is the definition of the joint access-backhaul service, which includes the identifiers of the physical access interfaces where the service will be instantiated (*selectedPHYs*), a description of the service credentials (*wirelessConfig*), and the transport VLAN where this traffic has to be delivered to (*vlanId*).

We used the testbed deployed for EuCNC to benchmark the response time of the previous API endpoints, which we report in the form of CDFs obtained across 20 different measurements in Figure 4-9, Figure 4-10 and Figure 4-11.

Figure 4-9, on the left hand side, depicts the time required to retrieve the wireless topology from the SDN controller, which we can see is below 500 ms. A relative short time is required because I2CAT boxes are registered with the controller as soon as they connect to the network, and so the controller always keeps topology information in memory to quickly reply to queries coming from the higher layers of the 5GOS. Similarly, the right hand side of Figure 4-9 depicts the chunk provisioning time, which is also observed to be very small (< 200ms). The reason is that the chunk provisioning has no direct effect on the I2CAT boxes, but

it is only state information kept by the controller. The enforcement of the configuration on the devices is going to take place during the service instantiation, whereas the chunk definition is used to limit the physical resources that a tenant can use to provision its services.

Figure 4-11 depicts the service provisioning time that is now significantly higher, i.e. up to 15 seconds for a service involving two I2CAT boxes (purple service in Figure 4-7), and up to 24 seconds for a service involving three boxes (green service in Figure 4-7). The reason the service instantiation takes longer is that now the SDN controller needs to interact with each I2CAT box through the NETCONF interface to instantiate the virtual access points associated to the service, to adjust the SWAM data-path with its various bridges described in D4.2, and to provision wireless backhaul tunnels. Multi-second timeouts are inserted in this process to make sure that no failure occurs in the process.

Finally, Figure 4-10 depicts the time required to configure an interface from the controller, e.g. set the channel in a wireless interface, which is in the worst case around 1 second.

The obtained performance benchmarks validate that dynamic wireless service instantiation can be done in real-time, and through an automated workflow enabled by the 5GOS.

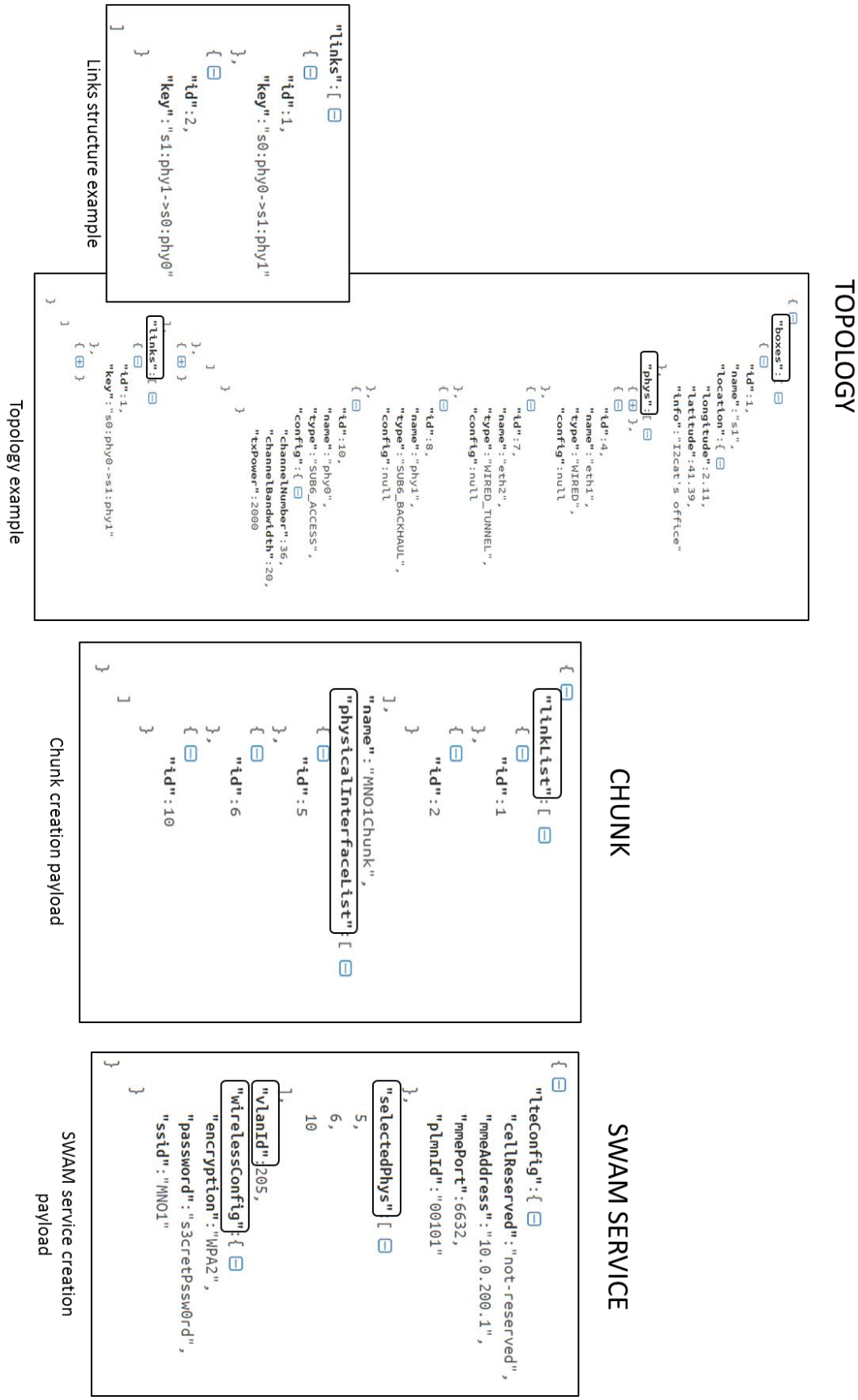


Figure 4-8. Detailed API definition

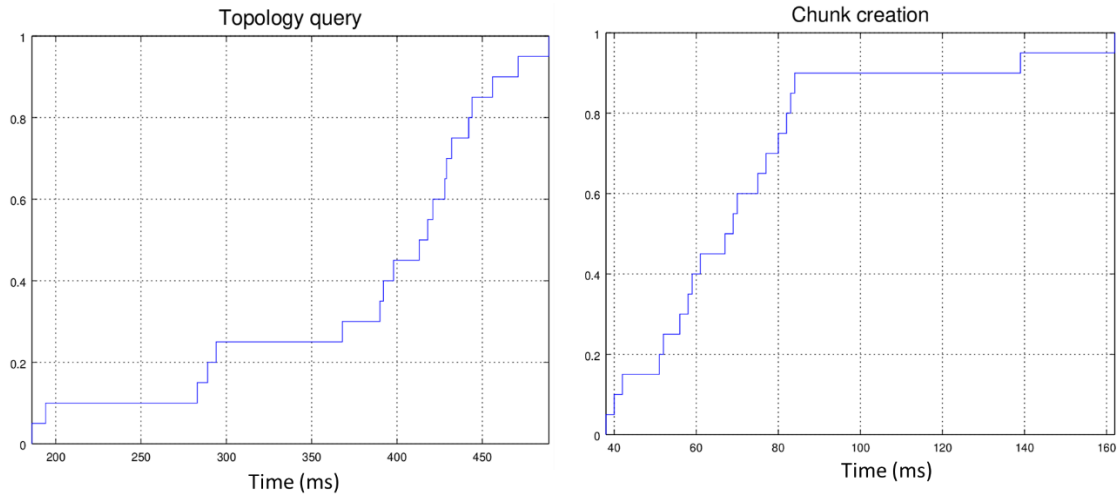


Figure 4-9. CDF of Topology and Chunk creation times

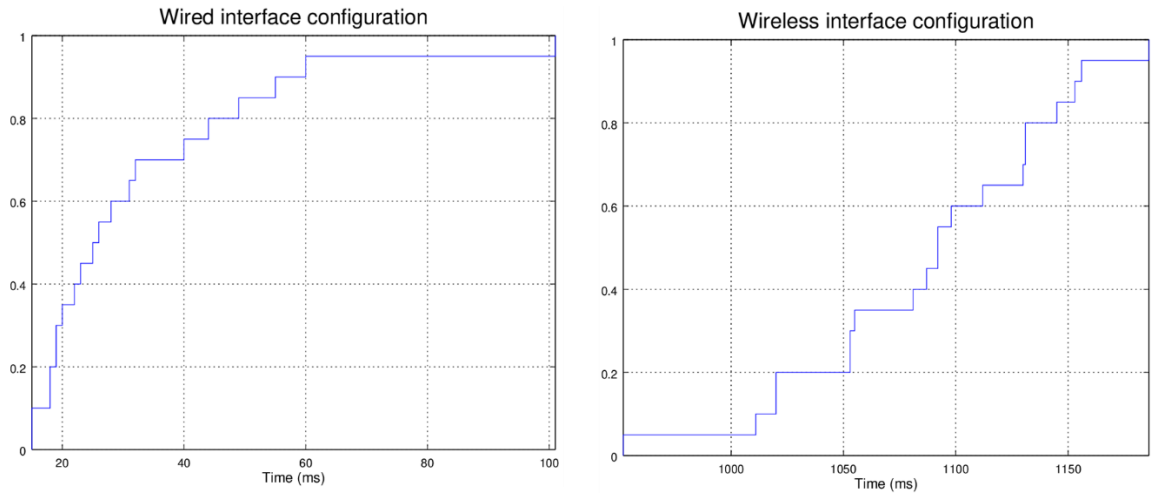


Figure 4-10. CDFs of wired and wireless interface configuration times in the SWAM box

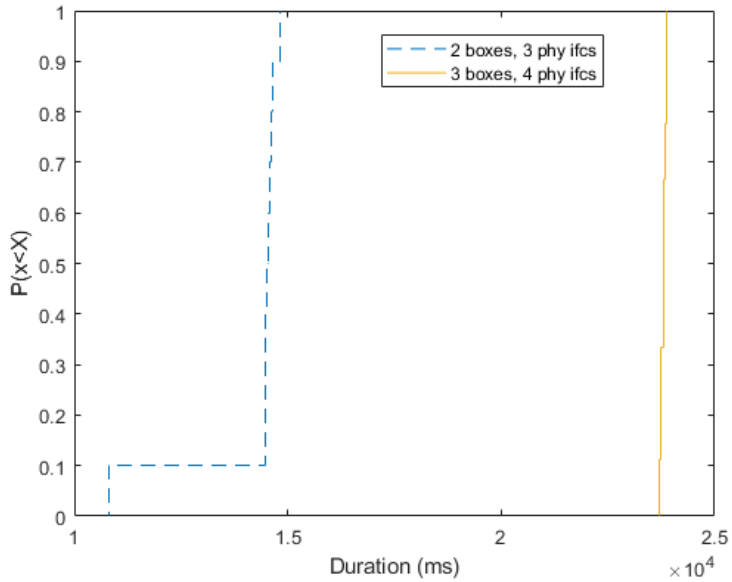


Figure 4-11. CDFs of SWAM service provisioning time for different number of boxes in the chunk

4.4.3 Watchity application and Network initiated handover validation

In this section we validate the components of the Watchity application that is going to be used as a basis of the crowd-based content production use case for the stadium. In addition, we also validate an access mechanism in the I2CAT wireless controller that can be used to issue network initiated handovers. This mechanism is key in the stadium use case to force Watchity users to access the network through the high priority slice.

We start describing the various components present in the Watchity application, which are illustrated in Figure 4-12. We recall that the main concept behind the Watchity application is to have distributed cameras in the stadium or the fan zone, which record various events and stream the recording live to an audience. These recordings are all uploaded to a production platform running in the Cloud (in AWS), where a content producer receives the various streams and produces an edited stream that is then broadcasted. Any Watchity user can subscribe to the published stream to see the live event.

Looking at Figure 4-12 point 1 we can see two tablets acting as cameras, which are recording a video played on a third tablet (this peculiar set-up is used only for validation purposes). Figure 4-12 point 2 depicts the Watchity production portal that is accessed from a separate laptop accessing the AWS backend. We can see in there two small screens with the videos uploaded from each camera, and in a bigger screen the video being published to the Watchity audience. It is worth highlighting that the Watchity application introduces a several seconds delay in the published video, in order to avoid fluctuations in the received video. Figure 4-12 point 3 depicts the Watchity public stream being received over a laptop. Finally, Figure 4-12 point 4 depicts the dashboard of the I2CAT wireless controller that is receiving telemetry (airtime and data-rate) from each access point in the network.

In our validation setup we consider two access points in the network, one representing the low priority slice and the other one the high priority slice. Initially, both cameras connect to the low priority slice. Subsequently, we launch a heavy iperf stream also connected to the low priority slice and validate that using our 5GPICTURE network initiated handover mechanism we can indeed move the Watchity clients over to the high priority access point in order to avoid any impact of the background traffic on the published video stream. Running various experiments we validate that our network initiated handover mechanism is able to quickly move Watchity cameras to the high priority access point. Our evaluation has been so far qualitative, but we plan to extend this study with a quantitative analysis of video KPIs in D6.3.

We proceed now to describe the design of our network initiated handover mechanism, which we refer to as FALCON. Figure 4-13 depicts the detailed network initiated handover workflow:

- A new FALCON service is registered indicating the identifiers of the SWAM services belonging to a specific chunk (see previous section for chunk and swam service definitions). The Input Builder module then recovers the information of the virtual APs (vaps) belonging to those services, including the identifiers for the vaps and their current channels. A configuration file indicates the logical relation between high priority and low priority vaps, so that the controller knows to what vap stations need to be moved to.
- To actually move a station a POST is called indicating the target station's MAC address. The Input Builder module has previously collected the information of the stations connected to each vap in the service. Based on the collected information a JSON message is created and is sent to the Handover Manager module, which is the API talking to the NETCONF interface used to move the stations to the new vap through the Channel Switch Announcement message.

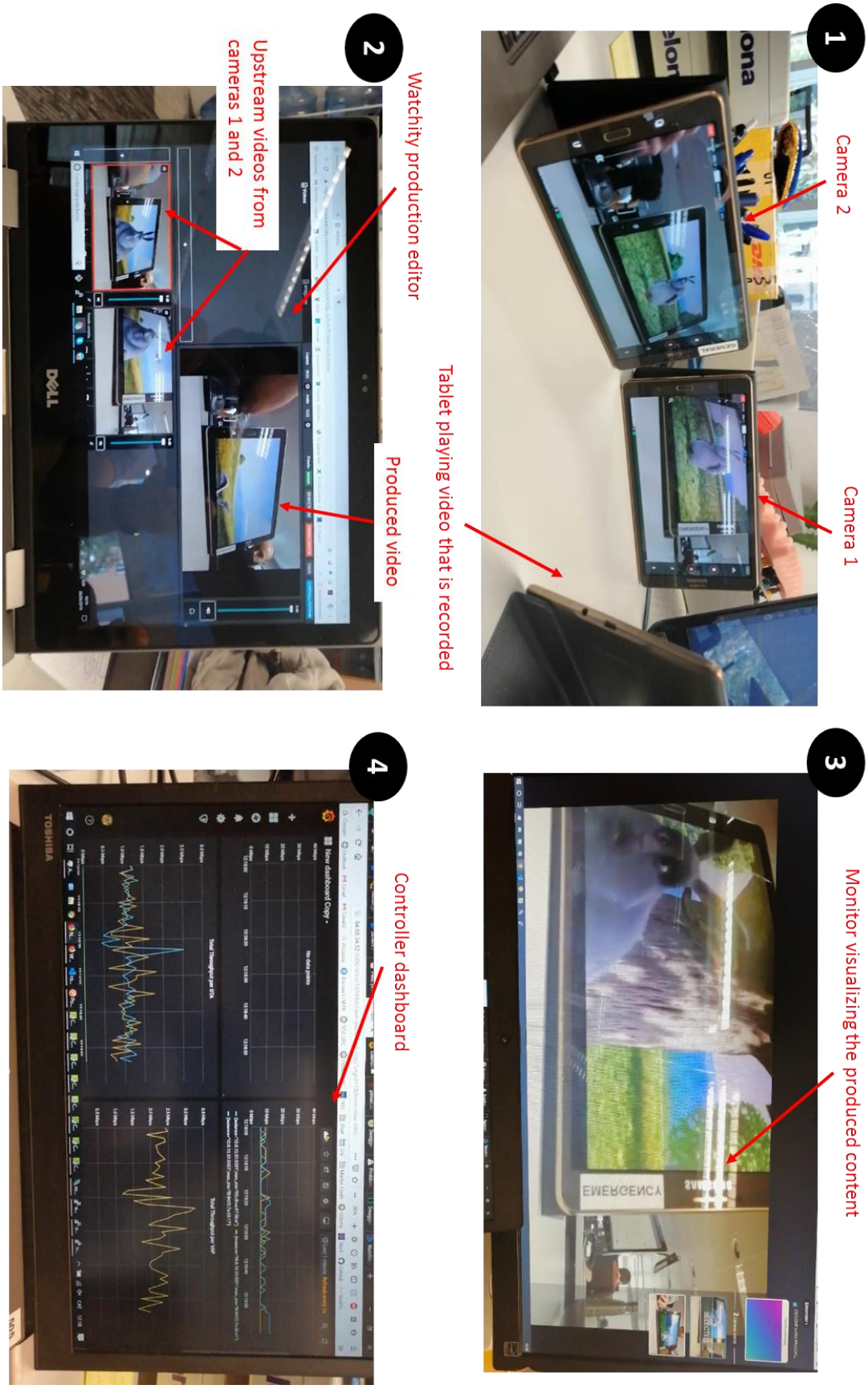


Figure 4-12. Watchity validation set-up

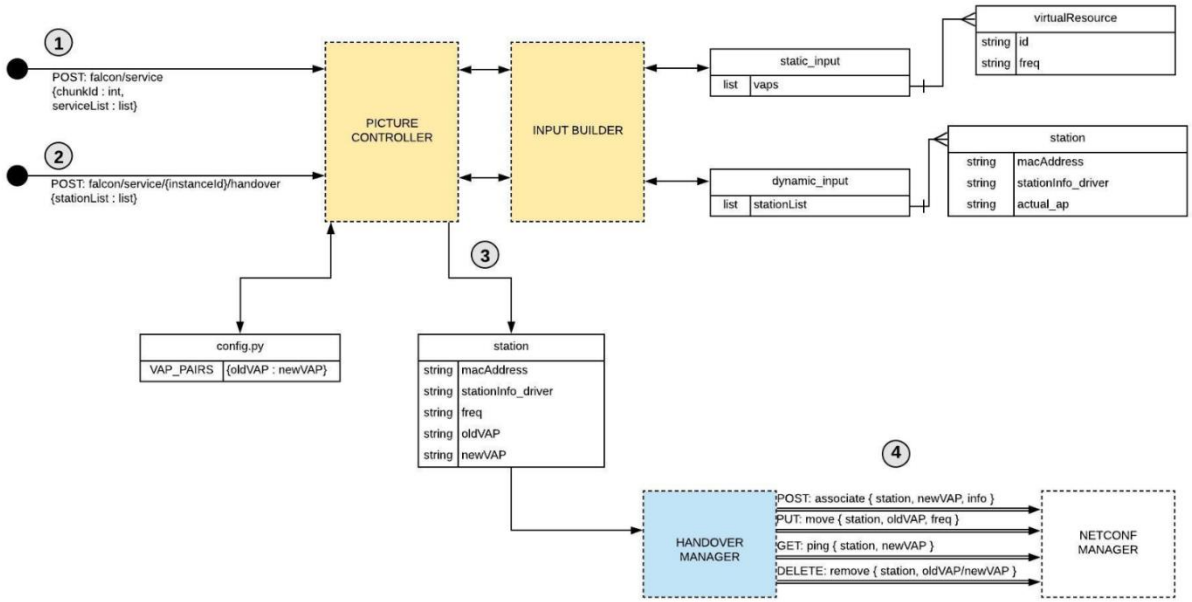


Figure 4-13. Network initiated handover workflow

4.4.4 Integration between Transit Network and Wireless Access Control

One interesting aspect of this demo is where we have two different networks being controlled and managed independently (wireless and transit). The edge network needs to be able to request connectivity from the transit network, with a pre-defined class of service, to support applications at the mega-event/smart-venue.

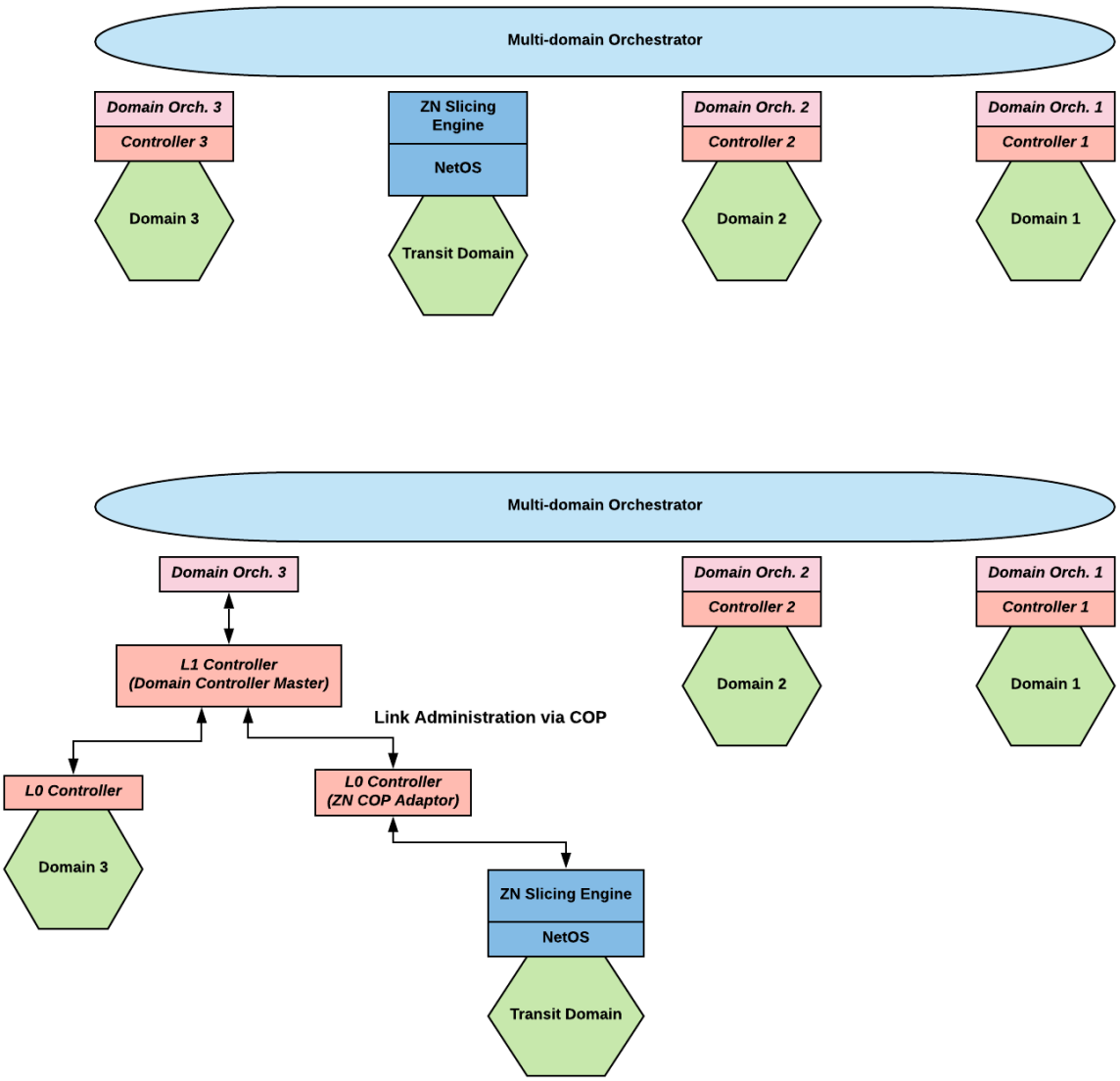


Figure 4-14: Some options for integrating a transit network within the 5GOS Architecture

There are a few options of how this integration with the transit network can be achieved within the context of the 5G OS. These are shown in Figure 4-14.

The first option is to treat the transit network as a different Domain and integrate at the Multi-Domain Orchestrator level. This is shown in the top half of Figure 4-14.

The second option is to treat the transit network as a part of an existing domain. To use this option the transit provider needs to implement a standard interface adapter over their own orchestrator-controller stack to allow external Domains to see the transit network as just another controller domain in their network that provides connectivity with class of service. This is shown in the bottom half of Figure 4-14.

In this case we have chosen to implement a standard interface adapter (option two). This is described in Figure 4-15.

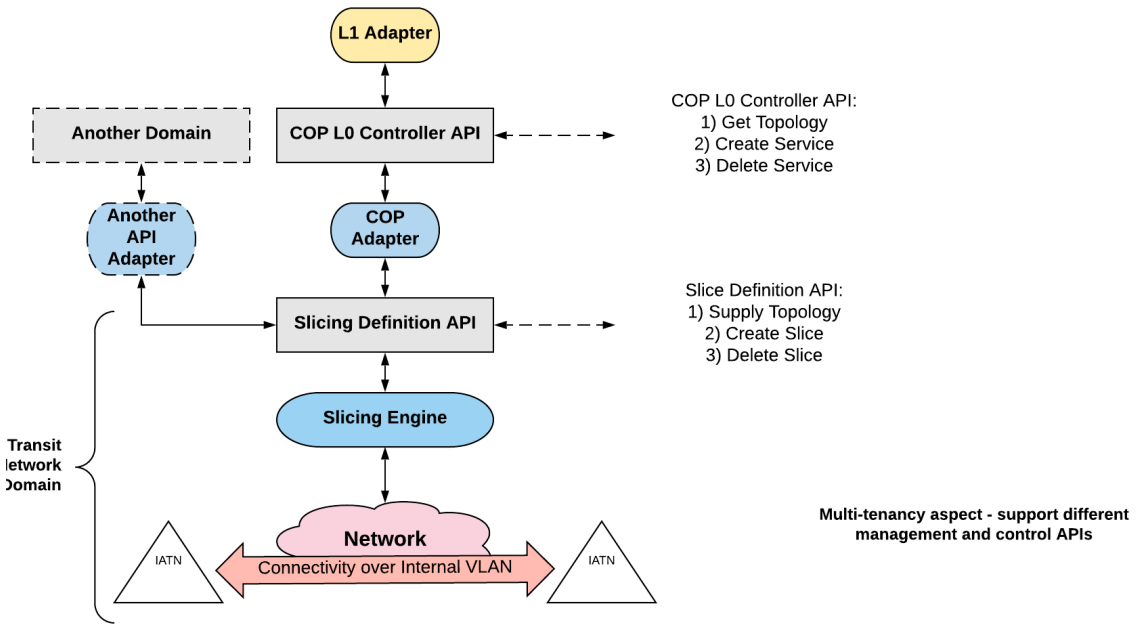


Figure 4-15: Integration between Transit and Edge Access

The integration interface used is COP (Controller Orchestration Protocol) [15]. ZN have their Orchestration and Control stack consisting of the Dynamic Slicing Engine as the orchestration application and the NetOS Controller as the controller application. Over this we implement a L0 controller that integrates with the L1 controller of the requesting networks domain.

A point to be clarified here is that as the slicing engine 'implements' any requests received via the L0 controller, there is a pre-requisite to partition out resources which have been set aside for this tenant (i.e. the mega-event/smart-venue/stadium). In this case as we are creating slices at Layer 2 – we reserve a VLAN range to be used to service requests coming from the L0 controller.

The slice definitions for the slicing engine are being created dynamically (on-the-fly). This means we are not using a 'special' integration between the L0 controller and the Slicing Engine. We create a COP Adapter that generates dynamically a slice definition for the Slicing Engine, based on the incoming connectivity request from the L0 adapter. This is shown in Figure 4-15.

As we are using the Slice Definition APIs as normal, we can allow parallel requests for slices to be serviced as well. These may originate from other tenants or from the direct users of the transit network (for non-transit services) as well as by the network provider itself for their own use.

This is a powerful concept where we are able to serve multiple tenants and provide each tenant a context to operate within and if required a set of resources. For the mega-event/smart-venue/stadium the context is connectivity and the set of resources is a VLAN range. There can be other contexts with services that are more complex than connectivity or which require a combination of VNFs, PNFs and pPNFs to provision.

As this implementation was carried out as part of Task 5.4, additional details and results are provided in D5.4.

4.5 Risk Update

- Change in Senior Management: Explicit authorisation required from Ashton Gate
- Facility Availability and Deployment Permissions – during 'busy' season
- Unpredictable weather – especially important for outdoor demos

Risk Addressed:

- Demo plan presented to the Stadium senior management again for a detailed site survey (July 2019)
- Continued engagement for confirming the demo dates

- Worse case facilities will be hired through the commercial channels (there is budget for this)
  - Update: Stadium has advised that the facilities are available at a cost of 10k – 15k EUR, to be confirmed. This is the best way forward as the planned demo dates are in the middle of the busy season. For example, there is a Rugby match on 20th of March 2020.
- Further de-linking of the demo from Stadium network will improve chances of full Stadium participation
- Use 'Mobile Lab' – with same class of switches and WiFi APs as in Stadium network – turn-off existing WiFi for few days
- Option for relocating demo indoors in case of bad weather
- Second, detailed site survey being planned with the focus on Massive MIMO demo over the summer break of 2019

4.6 Zeetta Mobile Lab

Figure 4-16 Zeetta Mobile lab

Zeetta Mobile lab consists of one or more switches, wireless access controllers, wireless access point and micro servers in a wheeled box which can be moved easily. It can take any 1U sized box.

It requires external power supply and connectivity.

For the Stadium demo we expect to have one of these Mobile Labs in the Fan Zone. We are planning to deploy three switches in the Mobile Lab. These will also contain server nodes as well to provide compute facilities.

4.7 Timelines

Timelines for the Stadium Demo are provided below. These have been updated to reflect the demo date change to March 2020.

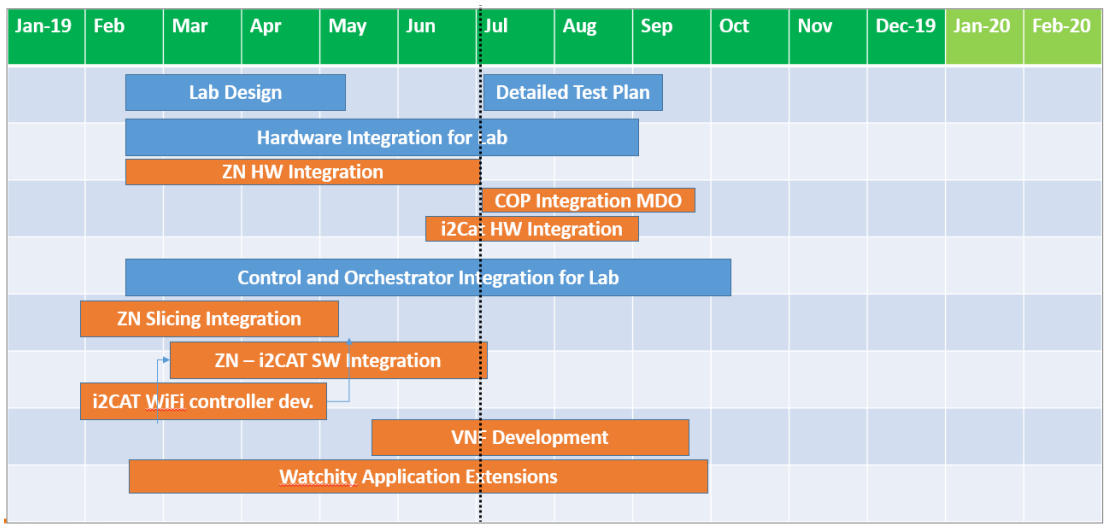


Figure 4-17 Timeline 1: Development of Demo Components

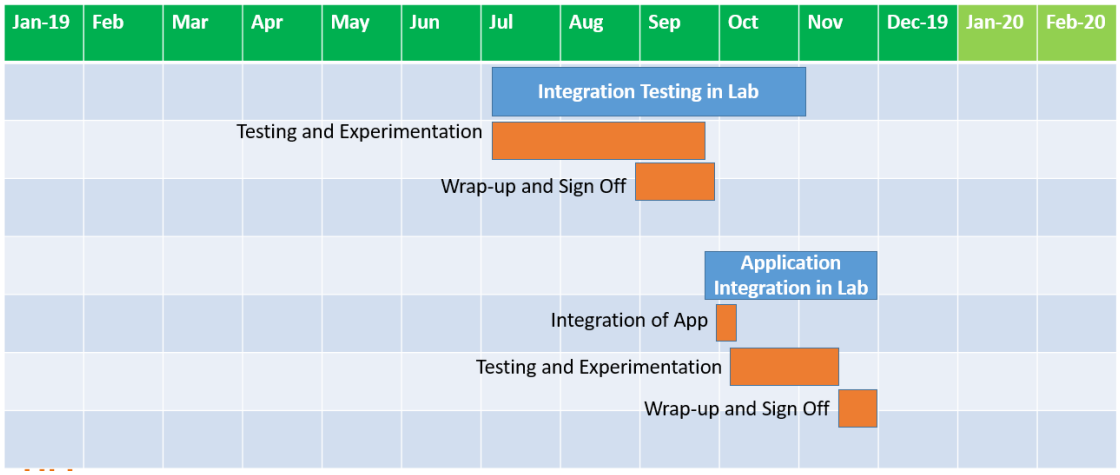


Figure 4-18 Timeline 2: Integration and Testing in Lab

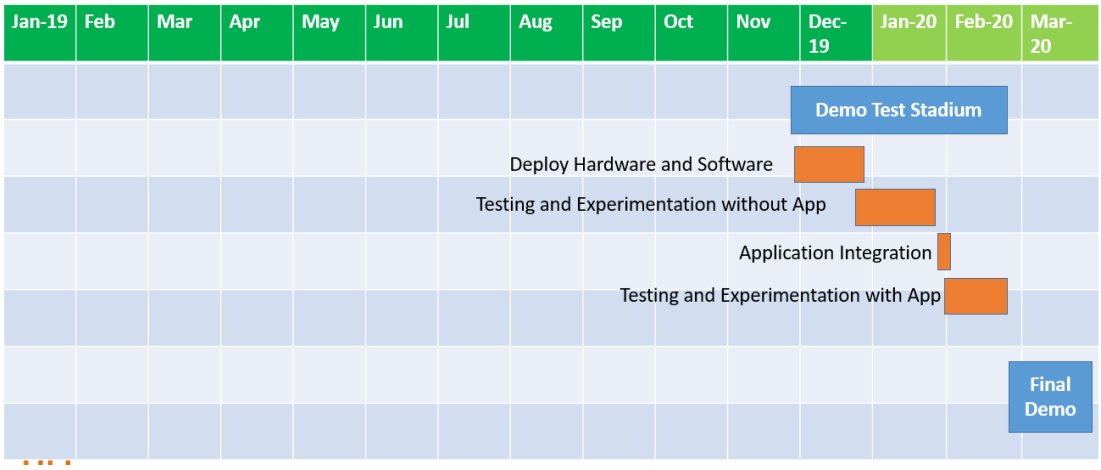


Figure 4-19 Timeline 3: Stadium Integration, Testing and Final Demo

5 Smart City Use Case

5.1 Current Infrastructure Description

In order to explore and validate the deployment of 5G in an architecture that combines existing technologies and innovations, the University of Bristol (UNIVBRIS) has deployed a rich testbed comprising several networking and computing technologies, interconnecting a significant area in the Bristol city centre. This testbed aims to provide a managed platform for the development and testing of new solutions delivering reliable and high-capacity services to several applications and vertical sectors targeted in this case by 5G-PICTURE.

UNIVBRIS' 5G testbed is a multi-site network connected through a 10 km fibre with several active switching nodes, which are depicted in Figure 5-2. The core network is located at the High-Performance Network (HPN) laboratory at the University of Bristol and an extra edge computing node is available in another central location, known as Watershed. As shown in Figure 5-1, the access technologies are located in two different areas in the city centre: Millennium Square for outdoor coverage and "We The Curious" science museum for indoor coverage.

Figure 5-1: Distribution of the testbed access technologies.

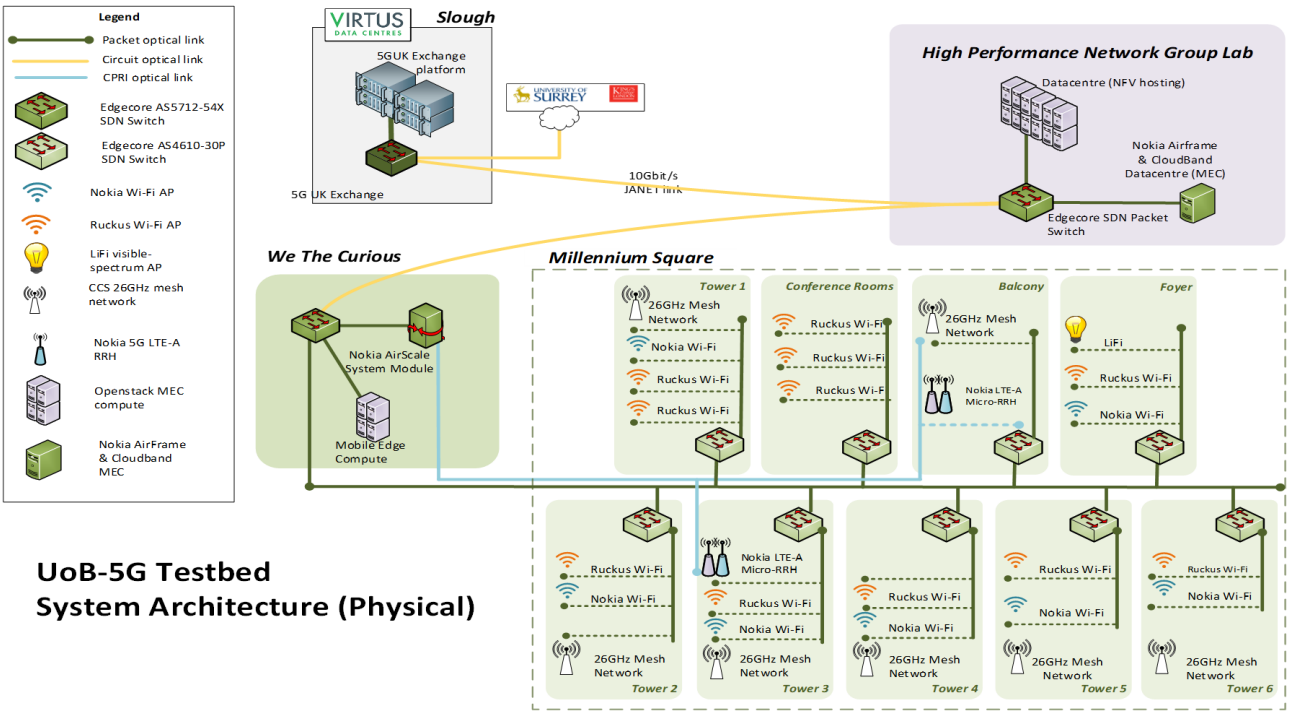


Figure 5-2: University of Bristol top level system architecture.

A summary of the testbed constituent equipment and capabilities is:

- Multi-vendor software-defined networking (SDN) enabled packet switched network.
  - Corsa switch (Corsa DP2100).
  - Edgecore switch (Edgecore AS4610 series & AS5712-54X).
- SDN enabled optical (Fibre) switched network.
  - Polatis Series 6000 Optical Circuit Switch.
- Multi-vendor Wi-Fi.
  - SDN enabled Ruckus Wi-Fi (T710 and R720).
  - Nokia Wi-Fi (AC400).
- Nokia 4G and 5G NR.
  - 4G EPC & LTE-A (Dual FDD licensed bands for 1800 MHz and 2600 MHz; with 15 MHz of T&D licence in 2600 MHz band).
  - 5G Core & 5G NR Massive MIMO (TDD band 42/43 at 3.5 GHz; with 40MHz T&D licence) The project expected availability after mid-2019 with Handset availability August 2019.
  - Further network expansion since last report deliverable D6.1 [1] includes addition of Fibre connectivity to MShed museum where an antenna mast has been installed to allow installation of the 5GNR Massive MIMO active antenna solution operating in band 42/43 along with an LTE macro cell in band 7.
  - Nokia 64x64 M-MIMO 5GNR (NSA) with digital beam forming will be installed at MShed in August 2019 to provide coverage in Millennium Square
  - Further installation of 5GNR is planned for Autumn 2019 as shown in Figure 5-3: with the map of the coverage and fibre connectivity between the Core network at the University of Bristol and locations nearby the Millennium Square.

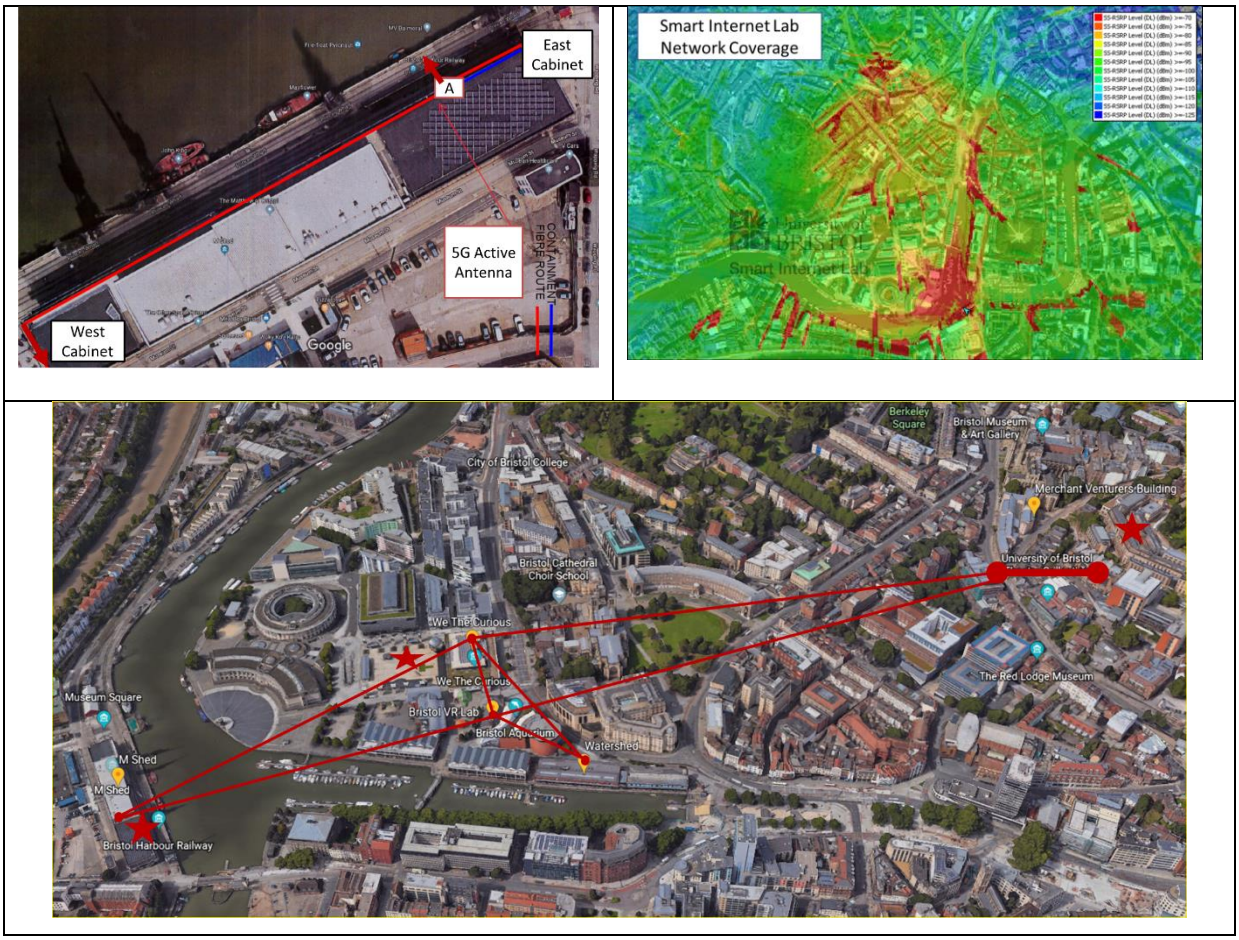


Figure 5-3: Planned 5GNR network service coverage

- Self-organising multipoint-to-multipoint wireless mesh network.
  - CCS MetNet a 26 GHz with 112MHz T&D licence providing 1.2 Gb/s throughput.
- LiFi Access point
  - pureLiFi LiFi access points supporting 43 Mb/s.
- Cloud and NFV hosting
  - Nokia Multi-access Edge Computing (MEC).
  - DC for Application/VNF hosting, built upon.
    - 11x Dell PowerEdge T630 compute servers 700+ vCPU cores, 1TB+ RAM and 100TB of HDD storage.
- Advanced fibre optics FPGA convergence of all network technologies enabling considerable flexibility, scalability and programmability of the front/back-haul, to provide experimentation with
  - Elastic Bandwidth-Variable Transponders.
  - Programmable Optical White-box.
  - Bandwidth-Variable Wavelength Selective Switches (BV-WSS).

The available equipment is controlled using a rich software stack (showed in Figure 5-4) that is composed by:

- two different NFV orchestration and management solutions:
  - Open Source MANO release THREE (opensource).
  - NOKIA CloudBand (proprietary based on a version of OSM and OpenStack, providing network slicing and virtualisation in rapid service creation). Available July 2018.
- two cloud/edge computing solutions:
  - Openstack Pike (opensource).

- Nokia MEC (proprietary).
- one SDN controller responsible for providing connectivity:
  - NetOS (proprietary, based on the OpenDaylight opensource).
- A content distribution
  - InterDigital solution is shown for the optimisation of the content delivery
    This solution is only available for the 5G Smart Tourism project.

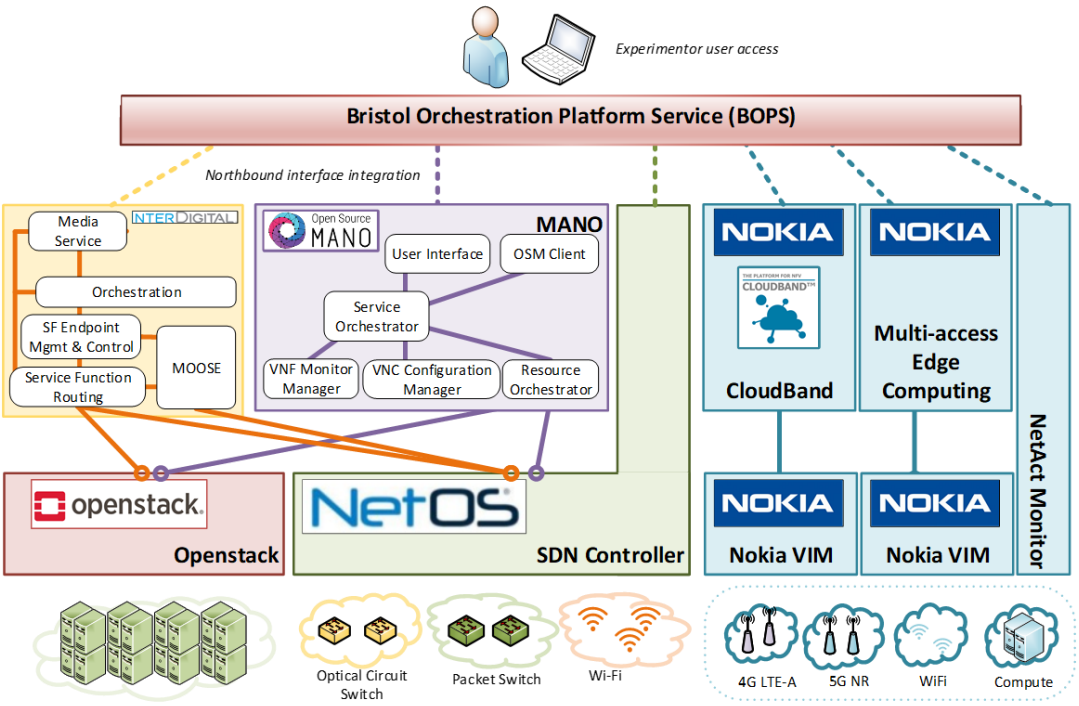


Figure 5-4: Software used for management and orchestration of the testbed resources.

Within any of our projects, Test Network will be used to support different verticals demonstrators, such as entertainment, finance, manufacturing and automotive testing. The diverse range of access technologies are interconnected, sharing the same underlying system while being used by the 5G-PICTURE framework to provide connectivity for the demonstrators, showcasing seamless integration between heterogeneous network components, an important concept in 5G. Additionally, the alternative and innovative technologies available for fixed access, can be used to demonstrate the principle of access-agnosticism, also important for the 5G vision.

The state-of-the-art radio access technologies deployed in Millennium Square will deliver high-bandwidth, high-bitrate and high-reliability connections to the user equipment, therefore enabling the usage of the network-intensive distributed applications for the 5G-PICTURE demonstrators. In particular, the availability of LTE-Advanced (LTE-A) and future installations of 5G access points (Nokia 5G NR) will be especially important in 5G-PICTURE to demonstrate applications that require mobility while keeping user experience continuity.

The SDN capabilities expressed by the NetOS controller, will facilitate network slicing through optical, electrical and radio technologies via on-demand SSID creation, demonstrating another key concept in the 5G architecture that will be explored by 5G-PICTURE to provide a multi-tenant environment, where the multiple demonstrators, or even final users, can coexist independently with different connectivity specifications.

The high performance and edge computing capabilities will power resource-intensive applications developed for the 5G-PICTURE demonstrators. In these applications, hardware acceleration and GPU-processing will be used to deliver enhanced performance and enable low-latency/real-time user interaction.

While the University of Bristol's Test Network expanding the current network has connectivity to a number of locations with active network entities as shown in Figure 5-5 where fibre connectivity is made to new centres like MShed and other cities are connected via leased L2 lines.

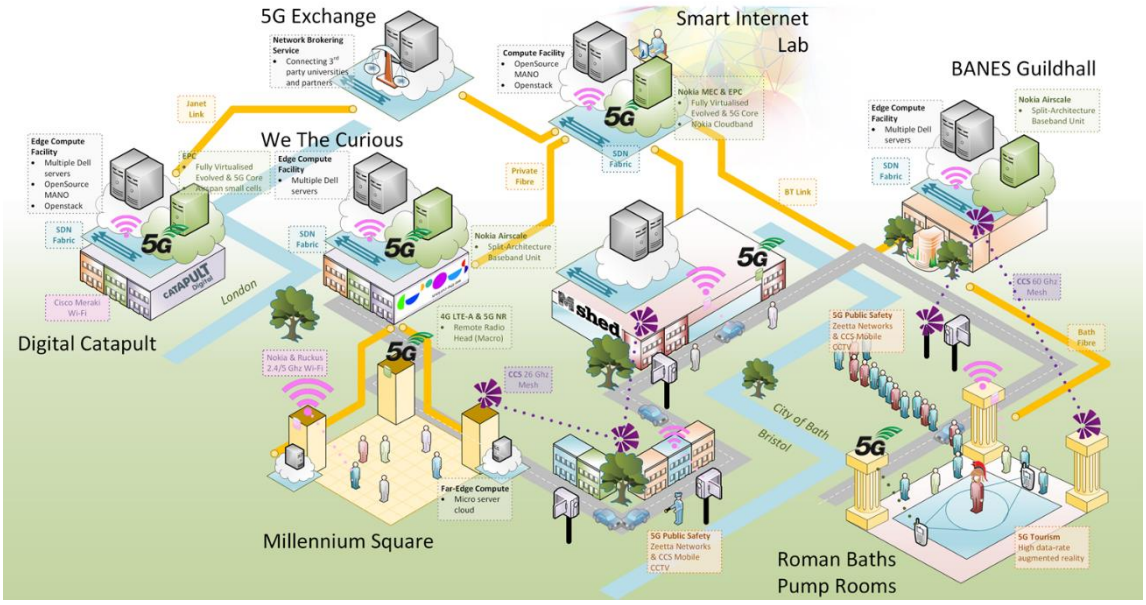


Figure 5-5 5GUK University of Bristol's Network Connectivity

Finally, the University of Bristol 5G testbed will deliver an automated and programmable environment, which will be used by the 5G-PICTURE southbound interface to create fully integrated orchestration for both application components and network services.

5.2 Updates on the Infrastructure, deployment of new hardware/software

The 5G-UK test-bed described above provided to the 5G PICTURE consortium through the University of Bristol will be further enhanced through 5G-PICTURE specific technologies developed by various consortium partners in the framework of the project. These technologies include:

5.2.1 IHP's contribution to 5GUK

IHP will bring to the 5GUK testbed its own universal platform for high-data rate wireless communication systems, which is based on a high-performance FPGA-ARM-SoC. It features GS/s data converters and Gigabit Ethernet transceivers (see Figure 5-6).

The implementation in the FPGA includes both PHY and MAC processors together with a control interface. The Point-to-Multi-Point (PTMP) Medium Access Control (MAC) processor is suitable for 60 GHz multi-gigabit single-hop wireless communication. It introduces a MAC scheme and the link establishment using beam steering/beamforming antennas with very narrow (pencil) beam characteristic. The current solution allows setting up mmWave links with a data rate of up to 4 Gb/s. The small cells offer point-to-multipoint capabilities (implemented real-time in the MAC) for up to two slave stations. The mmWave nodes support beam-tracking and fast beam switching. To date, the PHY/MAC platform is capable to operate as a transparent ETHERNET link. The platform will be enhanced with programmable network processors to allow network functions to be easily configured/modified or controlled by an SDN controller. The platform will feature soon SDN capabilities. The casing/housing of the solution for outdoor installation is currently being designed.

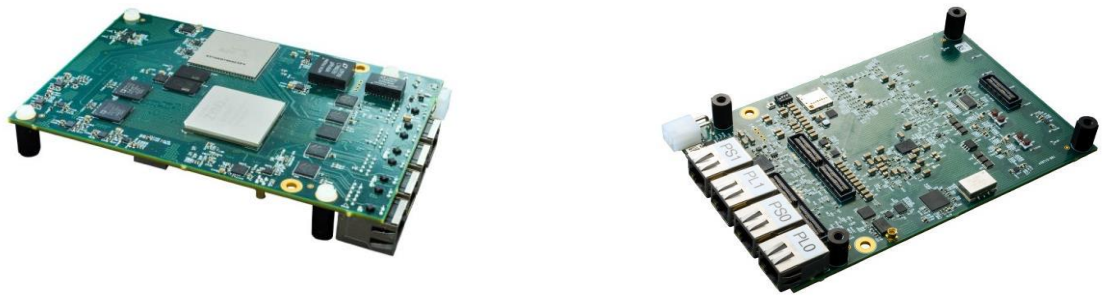
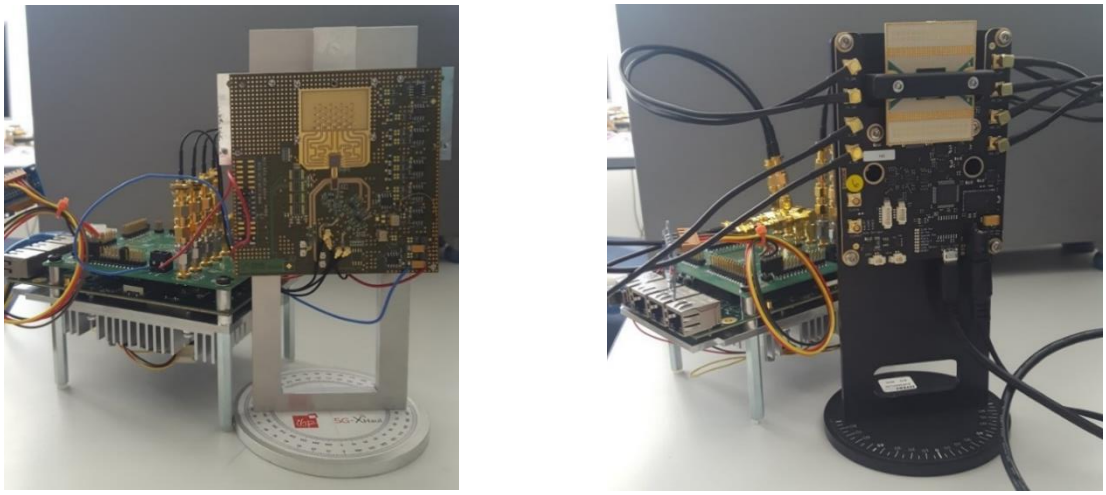


Figure 5-6. IHP's FPGA platform for mmWave baseband processor and MAC implementation.

For integration with abovementioned FPGA platform, IHP has developed its own mmWave RF-frontend beamforming solution (Figure 5-7 a), allowing full control of all transmission parameters, and features amplitude tapering, 4 frequency channels compliant with IEEE 802.11ad, and fast beam switching with 8 predefined beams. Additionally, other (COTS) RF-frontends are available and can be used over the course of the project (Figure 5-7 b). This is the case of Sivers IMA RF beamforming modules.



a) b)

Figure 5-7: a) IHP's RF Front-End, b) COTS RF Front-End attached to the FPGA boards.

5.2.2 Airrays 5GUK Demonstration

AIR will provide an active massive MIMO Antenna Proof-of-Concept platform (Radio Unit, RU) that is currently under development. The platform will be available approximately mid. 2019. Along with the antenna, AIR will provide a central unit (CU) that provides the antenna with FH samples, and a receiver, that can receive air interface signals from the antenna. An overview of the targeted setup is shown in Figure 5-8:

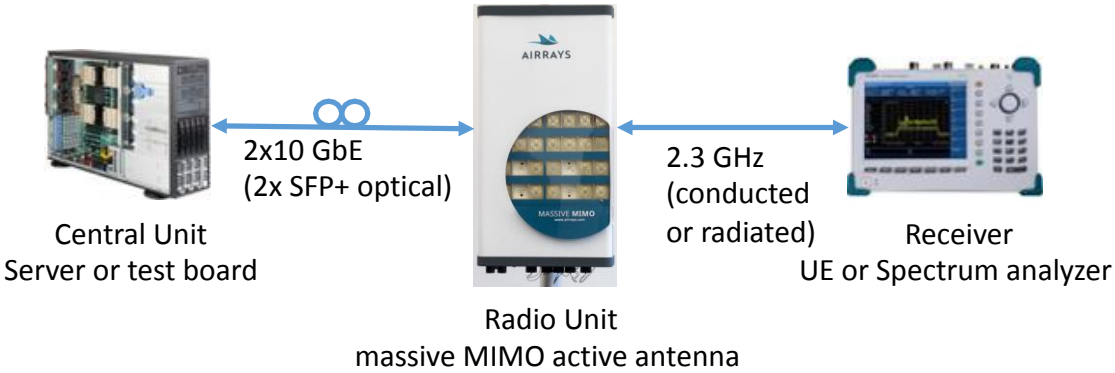


Figure 5-8: Targeted Setup.

In a minimal variant, the setup will be deployed indoors within 5GUK's labs, the CU will be FPGA-based test board (CU emulator), the receiver will be a spectrum analyzer, and the transmission from the RU to the receiver will be conducted via an RF cable. Depending on several factors (availability of 3rd party hardware, availability of license for band 40, overall integration effort), the setup could be extended to be deployed outdoors, with a commercial CU, over-the-air transmission, and a (test-) UE as receiver.

The Fronthaul interface between CU and RU transports eCPRI/xRAN frames as payload of standard 10 GbE Ethernet. The link could be combined with hardware from 5G-PICTURE partners ADVA, and/or UNIVBRIS, e.g. Ethernet switches, PON, or TSON for a joint demonstration.

The RU will also feature a NETCONF/YANG-based configuration interface. The interface allows to, e.g. configure carrier power or activate/deactivate carriers. The YANG model can be provided to be included into other partners' NETCONF clients, enabling a potential integration into a 5G OS.

The RU will look similar to the figure below (figure shows predecessor platform).

Figure 5-9: Predecessor RU platform:

Relevant parameters of the RU are given as follows:

- Frequency Band: 2300 MHz – 2400 MHz (LTE band 40).
- Duplex mode: TDD.
- Air interface: LTE.
- Fronthaul interface: 2x SFP+, 10 GbE, eCPRI/xRAN payload.
- Max. number of carriers: 3 (fronthaul limited to 2x 20 MHz).
- Max. occupied bandwidth: 60 MHz.
- Max. transmit power: 120 W (for 60 MHz OBW, lower power possible).
- Max. EIRP: 75 dBm (for 60 MHz OBW, lower EIRP possible).
- Transceiver Configuration: 64T64R (64 transceivers).
- Antenna element configuration: 4V8H2P (4 rows vertical, 8 columns horizontal, 2 polarisations).

5.3 Demo and Experiment Scenarios Description

As discussed in detail in deliverable D2.2 [2], the 5G-PICTURE data plane considers a set of highly configurable wired/wireless infrastructures and interfaces, integrated in a single transport solution. At the wired segment, 5G-PICTURE adopts a hybrid network solution deploying passive and high capacity elastic optical networks. At the wireless segments, 5G-PICTURE combines mmWave technologies. To further enhance spectral efficiency, a dense layer of small cells operating in the frequency range of 100 MHz-100 GHz is also considered. As the transport network technologies considered in 5G-PICTURE have very different characteristics, including rates of operation spanning from few Mb/s up to several Gb/s, and adopt a wide range of protocols and technology solutions, we rely on high-speed programmable multi-Protocol/PHY interfaces to enable mapping of traffic across infrastructure domains. The interface solutions utilise state-of-the-art Field Programmable Gate Array (FPGA)-based HW to perform a wide range of functionalities including traffic adaptation, protocol mapping, etc.

The overall network architecture that will be used to support the 5G-PICTURE use cases to be demonstrated in the 5G-UK test-bed will be based on the overall 5G-PICTURE architecture and is illustrated in the figure below. This includes Mobile Edge Computing (MEC) capabilities located both at the HPN lab in the form of an available DC and at the “We the Curious” site. The optical transport network will exploit the installed fibre connecting the HPN lab with the “We the Curious” and the “Millennium Square” sites across the city of Bristol leveraging the Time Shared ptical Network (TSON) technology developed by HPN in the framework of 5G-PICTURE. In the “Millennium Square” the IHP mmWave technology will be exploited to support the wireless access network requirements of the use cases as well as end user equipment that HPN will provide. In addition, an active massive MIMO Antenna Proof-of-Concept platform available through Airrays will be also installed at the “millennium square” or at HPN Lab and will be interconnected to the overall 5G-PICTURE test-bed to support the FH services to be demonstrated.

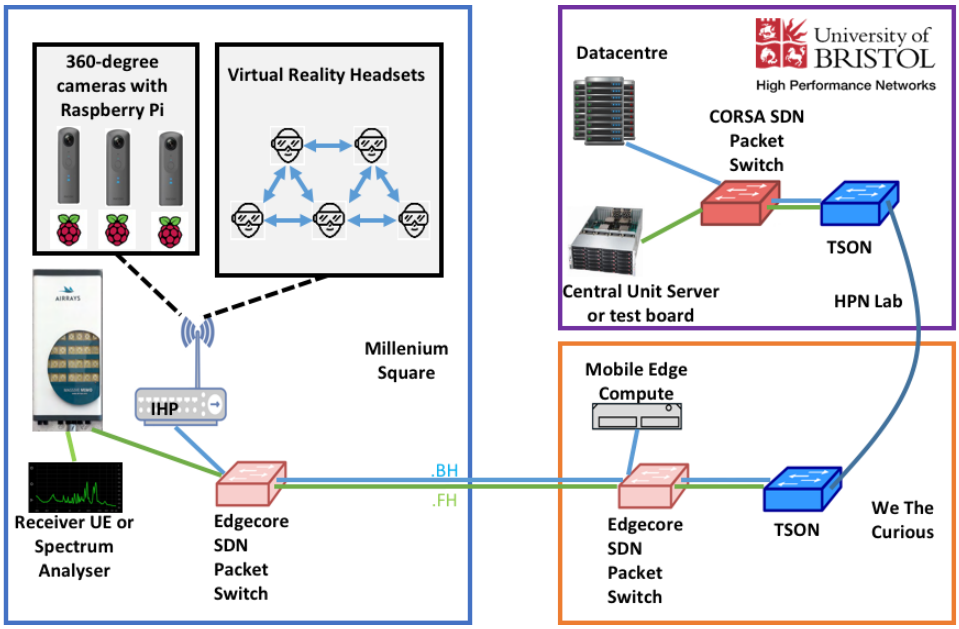


Figure 5-10: 5G-UK test bed architecture for the 5G-PICTURE demonstrations.

The Use Cases and Services that have been identified to be demonstrated over the 5G UK test-bed extended to include the 5G-PICTURE technologies are listed below.

5.3.1 Use Case: VR /AR

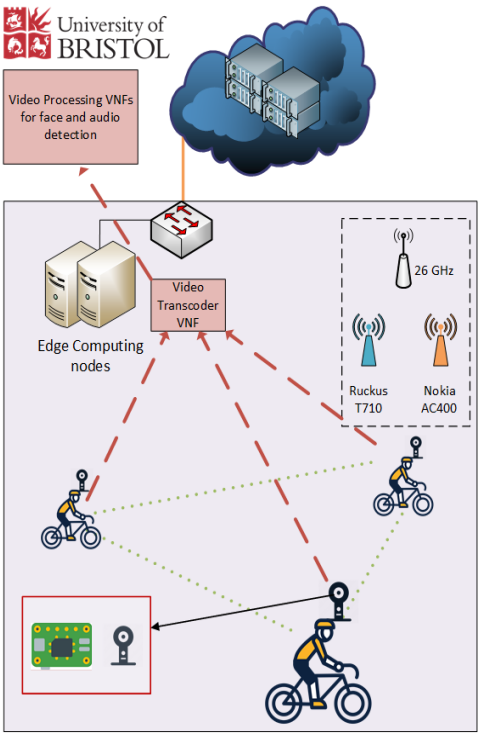
This creative & production processes includes visual and audio data capture of an artist performing in a private space in Bristol. The use case creation will involve working with the artists and development team in order to expand the visuals into a real-life environment around Millennium Square in Bristol. An audio specialist will work on the sound tracks so it adapts to the environment; while the development team further creates the data into an Augmented Reality experience.

Current plan aims to validate this application in the Millennium Square, on 19th October 2019. The created application will then be use at 5G-Picture trials as per the project plan.

Service description for the trial: Using the 5G testbed on Millennium Square along with this AR/VR application, we will be able to create a 5-8 minutes AR/VR experience for 5 to 10 people at a time. We expect this use case to be used at every occasion 5G Picture Trial is taking place at Millennium Square.

5.3.2 Use Case: Smart City Safety

This use case looks for monitoring the city with audio and video sensors. These sensors are deployed in a bike helmet and they are attached to a Raspberry PI (RP) that communicates via Wi-Fi to the Cloud or Edge (MEC – Mobile Edge Computing). The RP sends video and audio to be processed in a DC. Using VNFs, the overall ecosystem should be able to perform audio and video transcoder a long of the network. In addition, audio and video processing using machine learning to detect suspicious activities in the city should take place. Once the suspicious activities have been detected the system is able to notify the security department with the right information. Based on the information the security guards spread in different location will be able to take the right action.



The setup will be equipped with 3 x 360-degree cameras on 3 bike helmets with each attached to a Raspberry Pi. The camera is sending audio and video to the cloud storage and the face detection software ready to process data from the cloud. The VNFs are not yet available.

Hardware Required:

- 3 x 360-degree camera
- 3 x Raspberry Pi 3 Model B
- 3 x Audio Sensor

The setup will require a video server to store data gathered from the IoT devices. The processing functions would run as VNFs on the cloud infrastructure. The end-user can access the video server to use the services.

The Safety Use Case use case will be carried out in 5G Bristol Testbed. It will involve the Harbour side area of the Bristol City Centre, adjacent to the Millennium Square, where a significant part of 5G Bristol testbed's RAN is located.

As shown in the adjacent figure the public areas will be equipped with 360-degree cameras on the bikers' headgear who can move around the area on bicycles easily and at the same time can do the real-time surveillance of the area. The feed from the 360-degree cameras on the headsets will be passed on to the processing functions running on the compute nodes where the face detection and recognition algorithms will run along with the voice recognition. In case of any issue, the alert will be generated to the security agencies. In case of detection of high-impact issues (e.g. fire breakout), the application will also allow the provisioning of emergency networks called Incident Area Networks (IAN) to trigger emergency services.

The 5G technologies to be used in the Safety Use Case has flexibility in the choice of the backhauling as millimetre wave or wired fibre network.

The following scenarios will be trialled in the Public Safety use case: Video Monitoring: 360° degree video will be streamed from the areas running the experiment to MEC nodes/central datacentres, where a series of face detection algorithms will be used to identify potential security incidents.

5.3.3 Updated planning/risks

Only change to report is that the use case for AR/VR application will be demonstrated on 19th October as the validation step in the development of the application to be used later in the project when other tests are in progress during the final trial.

5.3.4 Massive MIMO Initial Testing (Airrays)

The Xilinx massive MIMO antenna is a proof-of-concept platform to demonstrates the benefits both of sub-6 GHz mMIMO as well as the functional split 7.2 and corresponding fronthaul interface. Initial testing of the antenna was performed in cooperation with TUD at an outdoor site at TUD Ccampus, as well as in an anechoic chamber. The goal of these tests was to verify basic functionality of the antenna via over-the-air measurements before integration in the 5GUK testbed.

Setup

The outdoor site is shown in the figure below:

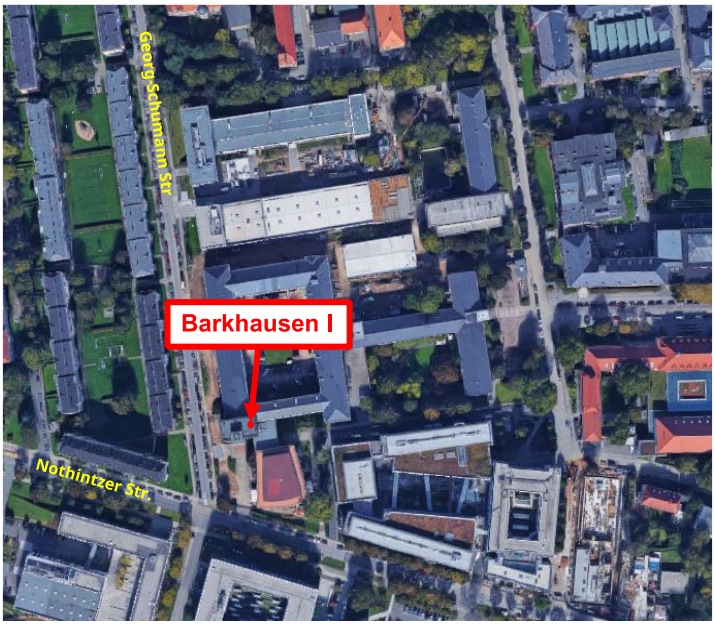


Figure 5-11: Outdoor testing site at Barkhausenbuilding, TUD

For the test, a directive measurement antenna was used to measure the radiated signal coming from the mMIMO antenna. By electronically steering the beam of the mMIMO antenna, a beam pattern can be measured. Figure 5-12 shows a diagram of the setup, and Figure 5-13 and Figure 5-14 show the installed measurement antenna and mMIMO antenna, respectively.

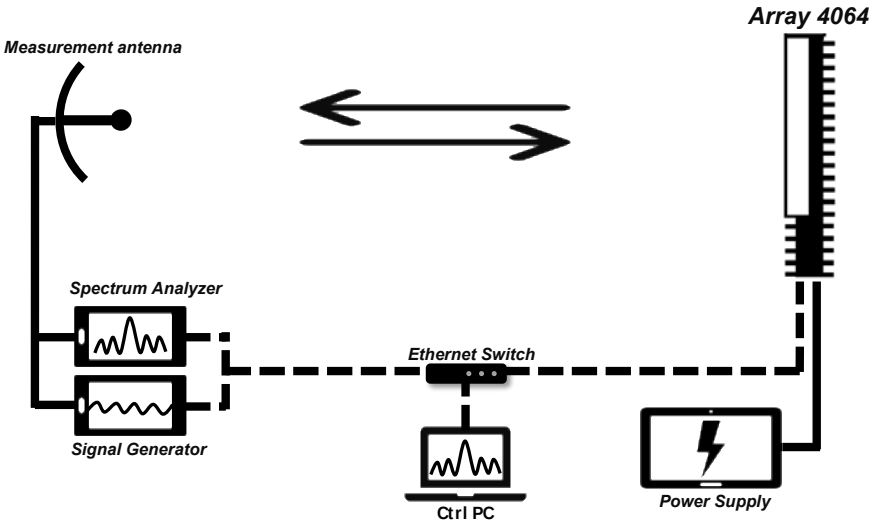


Figure 5-12: Massive MIMO initial test setup.

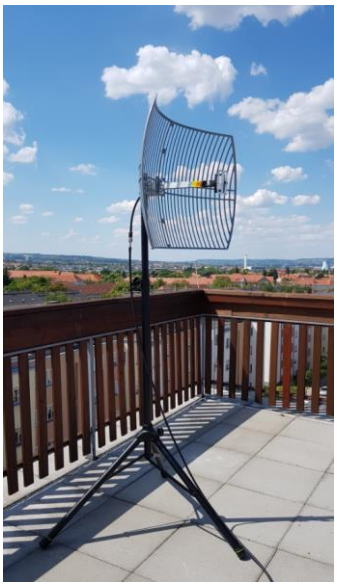


Figure 5-13: Measurement antenna installed at TUD outdoor test site

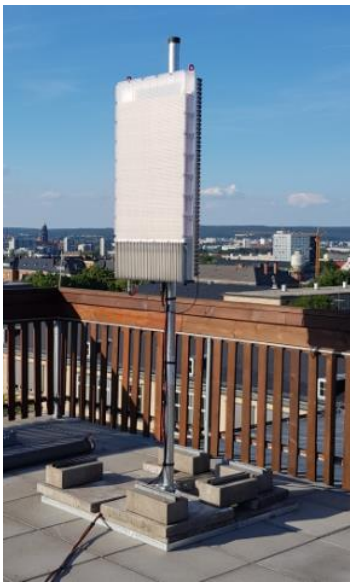


Figure 5-14: Massive MIMO antenna installed at TUD outdoor test site

Although no dedicated fronthaul interface was used, the fronthaul protocol (eCPRI/ORAN via Ethernet) was verified by generating fronthaul packets in the antenna's memory, and then internally streaming them to the fronthaul ports as if they had been received via optical fiber. In addition, the control PC used remote procedure calls (RCPs) as used in ORAN's management plane to configure and control the antenna, thereby verifying the configuration and management interface.

The same setup was used in the anechoic chamber, with the added benefit that the anechoic chamber provided more precise measurements due to the absence of reflections and provided a positioner to rotate and tilt the mMIMO antenna.

Results

Note while for the outdoor tests, the x-axis shows the steering direction of the beam (i.e. the signal is received at boresight, but the beam is steered in the direction indicated in the x-axis), for the anechoic chamber measurements on the x-axis give the observation angle of the receiver (i.e. the receiver is positioned at the indicated angle from the antenna's boresight).

Figure 5-15 shows an exemplary result of a beam measured at the outdoor site versus its ideal pattern. As can be seen, the patterns match quite well, only at angles of more than 60°, there is a notable difference. Since the antenna is only designed for a steering range of -40° to 40°, this difference can be neglected in practical circumstances.

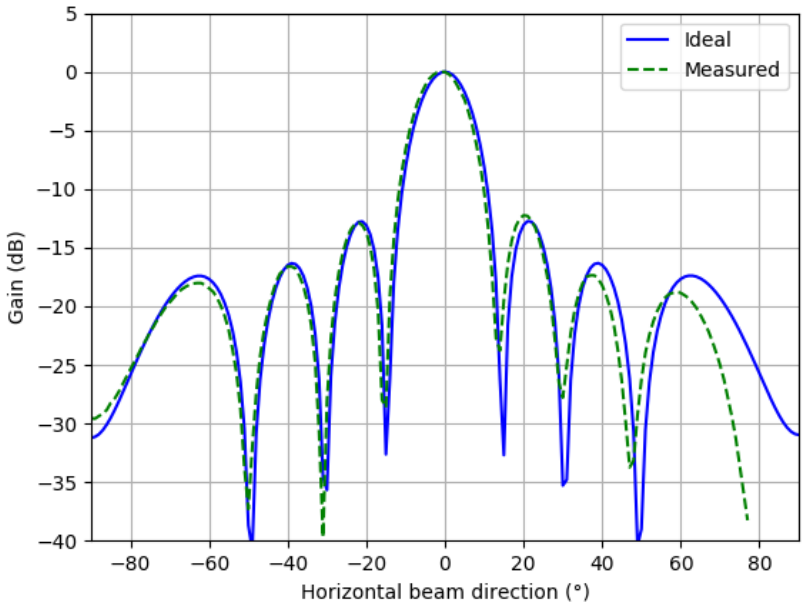


Figure 5-15 Beam measured at the outdoor site versus its ideal pattern

Figure 5-16 now shows a similar beam from the anechoic chamber, with 2 polarisations plotted separately versus the theoretic results. Note again that the results match quite well, the only differences appear well beyond 60°.

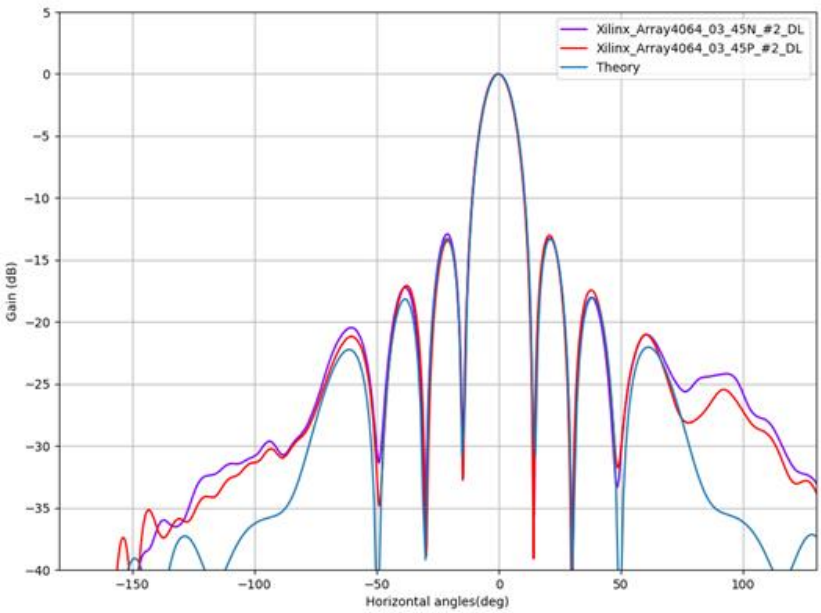


Figure 5-16 Beam with two polarisations vs theoretic results

In summary, the initial tests verified that the mMIMO antenna, as well its fronthaul and management interface are working as expected. The next step is to integrate UNIVBRIS's TSON fronthaul technology to verify the compatibility. After this, the setup is ready for installation in the 5GUK testbed for the final evaluation.

6 Summary and Conclusions

In this deliverable, the initial demo site setup and validation tests of the demonstration activities of 5G-PICTURE are presented. More specifically, results from testbed experiments and initial deployment of equipment in the project demo sites are described, including also updates on the planning and test scenarios for all 4 major demos.

First, results from the experiments at NITOS testbed in UTH are described for the dynamically orchestrated functional splits experiments and demos. The current status of the Rail use case has also been reported regarding the deployment and results from testbed validation and integration tests performed with all the technologies involved in the demo. For the Stadium demo, updates on the implementation of the control plane components are described and initial validation from the watchity crowdsource media application and wireless access technologies are reported. In the context of the smart city related demos to take place in the 5GUK testbed in Bristol, updates on the infrastructure and the deployment of 5G-PICTURE technologies are presented with a detailed description of the scenarios and end-user applications to be used. Initial validation results are also included from the Massive MIMO antenna to be deployed.

As it is shown in this deliverable, the work progresses according to plan for all project demos and provides the grounds for a successful demonstration of the 5G-PICTURE solutions in the specified use cases towards the end of the project lifetime. Results from the final demonstrations will be reported in D6.3.

7 References

[1] 5G-PICTURE deliverable D6.1, “Specification of Vertical Use cases and Experimentation plan”, 2018.

[2] 5G-PICTURE deliverable D2.2, “System architecture and preliminary evaluations”, 2018.

[3] 3GPP, “3GPP TS 38.401 V0.2.0 (2017-07), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NG-RAN; Architecture description (Release 15),” 2017.

[4] 3GPP, 3GPP TR 38.806 V15.0.0 (2017-12), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study of separation of NR Control Plane (CP) and User Plane (UP) for split option2; (Release 15),” 2017.

[5] N. Makris et al., “Cloud-based Convergence of Heterogeneous RANs in5G Disaggregated Architectures,” in IEEE ICC, 2018.

[6] N. Makris et al., “Integrating NFV-MANO with Wireless Services: Experiences and Testbed Development,” in IEEE NFV-SDN, 2018.

[7] N. Nikaein et al., “OpenAirInterface: A flexible platform for 5G research”, ACM SIGCOMM Computer Communication Review, 2014.

[8] 5G-PICTURE Project, Deliverable D4.2: Complete design and initial evaluation of developed functions

[9] 3GPP, 3GPP TS 36.360 V14.0.0 (2017-03), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); LTE-WLAN Aggregation Adaptation Protocol (LWAAP) specification (Release 14), 2017

[10] N. Makris et al., “Enabling Open Access to LTE network Components; the NITOS testbed paradigm,” in 1st IEEE NetSoft, 2015, pp. 1–6.

[11] ETSI, “Open Source MANO,” https://osm.etsi.org/

[12] O. Sefraoui, M. Aissaoui, and M. Eleuldj, “OpenStack: toward an open-source solution for cloud computing”, International Journal of Computer Applications, vol. 55, no. 3, pp. 38–42, 2012.

[13] R. Mijumbi, J. Serrat, J.-L. Gorricho, S. Latr´e, M. Charalambides, and D. Lopez, “Management and orchestration challenges in network functions virtualization”, IEEE Communications Magazine, vol. 54, no. 1, pp. 98–105, 2016.

[14] B. Pfaff, et al. "The design and implementation of Open vSwitch", 12th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 15). 2015.

[15] Straus project Deliverable 3.2 “Preliminary report on the building blocks for the network virtualization, openflow control and sdn orchestrator”, June 2015.

8 Acronyms

Acronym	Description
5G OS	5G Operating System
AP	Access Point
BDT	Bounded Delay Transport
BH	Backhaul
CLI	Client computer on the train
COP	Controller Orchestration Protocol
CU	Central Unit
DC	Datacentre
DU	Distributed Unit
FBG	FlowBlaze node for the ground
FBT	FlowBlaze node for the train
HEE	Head End Equipment
HSS	Home Subscriber Server
LTE	Long Term Evolution
MANO	Management and Orchestration
MEC	Mobile Edge Computing
MME	Mobility Management Entity
NF	Network Function
NFV	Network Function Virtualisation
NS	Network Service
OSM	Open Source Mano
PNF	Physical Network Function
PON	Passive Optical Network
PTMP	Point-to-Multi-Point
QoS	Quality of Service
RAN	Radio Access Network
S/P-GW	Serving/PDU Gateway
SDN	Software-Defined Networking
SER	Server computer for testing session continuity
SLA	Service-Level Agreement
SM	Statistical Multiplexing
TAN	Train Access Network
TCN	Train Communications Network
TEE	Tail End Equipment
TSON	Time-Shared Optical Network
UE	User Equipment
USRP	Universal Software Radio Peripheral
VDU	Virtual Deployment Unit

VIM	Virtualized Infrastructure Manager
VNF	Virtual Network Function
VNFD	VNF Descriptor
VNFM	VNF Manager
VR	Virtual Reality
WDM	Wavelength Division Multiplexing