5G Programmable Infrastructure Converging disaggregated network and compUte REsources

D6.1 Specification of Vertical Use cases and Experimentation plan

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1.0	Final review and submission to the EC	Jesús Gutiérrez (**IHP**)	30.11.2018

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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 will be carried out through a set of planned use cases that will 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 D6.1 reports on the detailed specification and planning of the use cases and demonstrations that will take place in the course of the project. The specifications include description of the current infrastructure in the demo sites, the deployment of new developed 5G-PICTURE technologies, the definition of the test scenarios and a detailed timeplan for implementing the demos.

Results stemming from the final 5G-PICTURE demonstrators will be reported in deliverables D6.2 and D6.3 accordingly.

1 INTRODUCTION

The 5G-PICTURE solution involves network 'softwarization', migrating from the conventional closed networking model to an open reference platform, supported through hardware (HW) programmability, where HW is configured directly by network functions, to provide the required performance. This will enable provisioning of any service by flexibly mixing-and-matching network, compute and storage resources without sacrificing performance and efficiency, as is the case in today's Network Function Virtualization (NFV)-based solutions. To validate these capabilities, 5G-PICTURE will validate and demonstrate converged fronthaul (FH) and backhaul (FH) services and end-user services in these different demonstration sites:

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

5G-PICTURE Work Package (WP) 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.

The approach for evaluating the proposed solution 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. The results from the lab tests and from initial-deployment demos will be reported in deliverable D6.2.

In this context, this deliverable D6.1 reports on the definition and planning of the use cases to be demonstrated in the 4 available demonstration sites mentioned above. The use cases are 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.

Organisation of the document

This deliverable is structured in six main sections. Following the introduction section, Section 2 provides a high-level presentation of the NITOS testbed in UTH and describes the specific network topology and scenario set up for the dynamically orchestrated functional splits experiments and demos. Section 3 concentrates on the smart city related demos to take place in the 5GUK testbed in Bristol. First, the developed 5G-PICTURE technologies to be deployed are presented namely the millimetre wave (mmWave) nodes from IHP, the Massive MIMO Radio from Airrays. Then the scenarios are presented ranging from converged FH and BH related ones to the smart-city end-user services such as public safety and VR. Section 4 presents the deployment in phases and the use case scenarios to be executed in the rail environment in Barcelona. The exact network architecture and the deployment of technologies are specified in detail including mmWave, WDM-PON, as well as Open Packet Processor (OPP) and Software Defined Networking (SDN). A timeplan also with different phases is provided. Section 5 describes the Stadium demo to be showcased in Bristol. The planned network setup and deployment is the stadium is presented as well as the control plane components are described. The use case scenario including a crowdsource media application is presented and a detailed timeplan is also provided until the end of the project lifetime when the demo will be performed. Finally, Section 6 provides a summary and the main conclusions of the deliverable.

2 Testbed Demonstrations and Experiments

2.1 Current Infrastructure Description

NITOS is an integrated facility with heterogeneous testbeds that focuses on supporting experimentation-based research in the area of wired and wireless networks. The NITOS facility is open to the research community 24/7 and it is remotely accessible through the NITOS reservation tool. Parallel experimentation of different users is enabled, through the utilisation of the NITOS scheduler SW. The testbed is based on open-source SW that allows the design and implementation of new algorithms, enabling new functionalities on the existing HW. Users can perform their experiments by reserving slices (nodes, frequency spectrum) of the testbed through the NITOS scheduler for repeatable experimentation and evaluation of protocols and applications under real world settings.

NITOS facility is comprises three wireless testbeds for experimentation with heterogeneous technologies. For the 5G-PICTURE experimentation, one of these testbeds is utilised, namely the indoor RF isolated testbed, consisting advanced powerful nodes, featuring WiFi, mmWave and LTE support. A brief description of this testbed is presented in section 2.1.1, as well as detailed descriptions of several key components they use, like the wireless interfaces and the OpenFlow switches.

2.1.1 NITOS indoor (RF isolated) testbed

The NITOS indoor testbed consists of 50 Icarus nodes and is deployed in an isolated environment at one of the University of Thessaly's campus building. Experimenters are able to run and evaluate power demanding processing algorithms and protocols in a large-scale testbed.

Icarus Node

Icarus nodes have been developed by UTH. They are equipped with 802.11a/b/g and 802.11a/b/g/n wireless interfaces and feature new generation Intel 4-core CPUs and new generation solid state drives. Figure 2-1 illustrates the Icarus node and more details about its specification can be found in Table 2-1.

Figure 2-1: Icarus Node.

Table 2-1: Icarus nodes' specifications.

Component	Description
Motherboard	2 Gigabit Ethernet interfaces and 2 wireless interfaces
CPU	Intel Core i7-2600 Processor, 8M Cache at 3.40 GHz
RAM	4G HYPERX BLU DDR3
Wireless interfaces	Atheros 802/11 a/b/g & Atheros 802.11 a/b/g/n (MIMO), Huawei E3372 LTE dongles, USRP B210 Software Defined Radio (SDR) devices
Storage	Solid State Drive (SSD)
Power supply	350 Watt mini-ATX
Antennas	Multi-band 5 dBi, operates both on 2.4 GHz & 5 GHz. Quad-band 4dBi antennas on the SDR nodes
Pigtails	High quality pigtails (UFL to RP-SMA)

Server machine

The NITOS indoor testbed is provided through a portal server machine, illustrated in Figure 2-2. It is an HP ML350p G5, more details about its specification can be found in Table 2-2.

Figure 2-2: NITOS indoor testbed's server machine.

Table 2-2: NITOS indoor testbed's server specifications.

Component	Description
Processor	Intel Xeon E5-2609(4 core, 2,40 GHz)
Memory	8 GB (2 x 4 GB)
Hard Drive	2 x 500 GB SATA HDD 7200 rpm
Network Controller	1Gb 331i Ethernet Adapther 4 ports per Controller
Storage Controller	Smart Array P420i/ 5120 MB FBWC
Power Supply	460W power supply

2.1.2 OpenFlow Switches

NITOS indoor testbed operates two HP 3800 OpenFlow switches depicted in Figure 2-3, which interconnect the Icarus nodes of the NITOS indoor testbed through a wired OpenFlow network. Each Icarus node has one of its Ethernet interfaces connected to the OpenFlow switch, which is also connected with the server machine, mentioned above. The OpenFlow controllers of these switches can be located at the server machine, where a variety of OpenFlow controller frameworks have been installed, such as POX, Trema, Ryu, etc.

Figure 2-3: NITOS indoor testbed's OpenFlow switch.

2.1.3 Wireless interfaces

NITOS uses several WiFi interfaces in order to provide many capabilities to NITOS users. Each WiFi interface has unique characteristics since it operates with different drivers and supports different features. To this end, UTH has acquired and equipped NITOS with the most practical and advantageous WiFi interfaces, capable to operate with open-source drivers. Bellow we list the three types that are supported for experimentation from NITOS users.

Wistron CM9 – Atheros AR5213A chip

CM9 [1], shown in Figure 2-4, is an IEEE802.11a/b/g 108 Mb/s WiFi mini-pci module in type IIIB. Built on Atheros® AR5213A chipset, CM9 is designed to IEEE802.11a/b/g standards, is compatible with all IEEE802.11b/g and IEEE802.11a WLAN and is ideally suited for integration in a wide range of OEM devices.

CM-9 runs with the MadWifi [2] driver as well as with the MadWifi-old [3] driver, which supports special features such as the support of the Click modular router.

Figure 2-4: Wistron CM9.

Figure 2-5: Atheros 9380.

Atheros AR9380

Atheros offers the industry's most innovative and complete portfolio of 802.11n wireless LAN chip solutions. This generation of Atheros' XSPAN 802.11n technology builds upon the company's XSPAN leadership, with enhanced performance, higher integration, smaller form factors and lower overall cost, to meet the needs of the rapidly growing 802.11n market.

AR9380 [4], shown in Figure 2-5, is the single-chip, dual-band (2.4 / 5 GHz), 3-stream 11n solution with PCIe interface. It packs the breakthrough Signal Sustain Technology 3 (SST3) technology that enhances the rate-over-range (RoR) performance. SST3 is a set of advanced technologies and features enabled by 802.11n including LDPC, TxBF and MLD. This interface runs the Atheros ath9k driver, which is included in the open-source compat-wireless drivers [4]. It is installed in Grid nodes of NITOS testbed with 3 multi-bands antennas, in the mini-pcie slot of the Commell motherboards.

2.1.4 mmWave nodes in NITOS

Within the framework of 5G-XHaul, six mmWave nodes from Blu Wireless Technology (BWT) have been deployed at the NITOS indoor testbed. The nodes have been installed at the same level than the NITOS nodes, in the topology depicted in Figure 2-6.

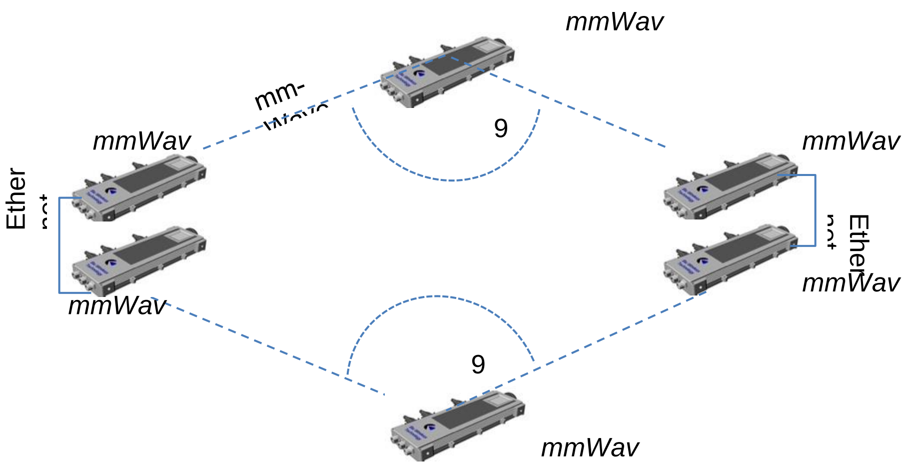


Figure 2-6: BWT nodes topology in NITOS indoor testbed.

Figure 2-7 shows some snapshots taken during the deployment of the BWT nodes at the NITOS indoor testbed.

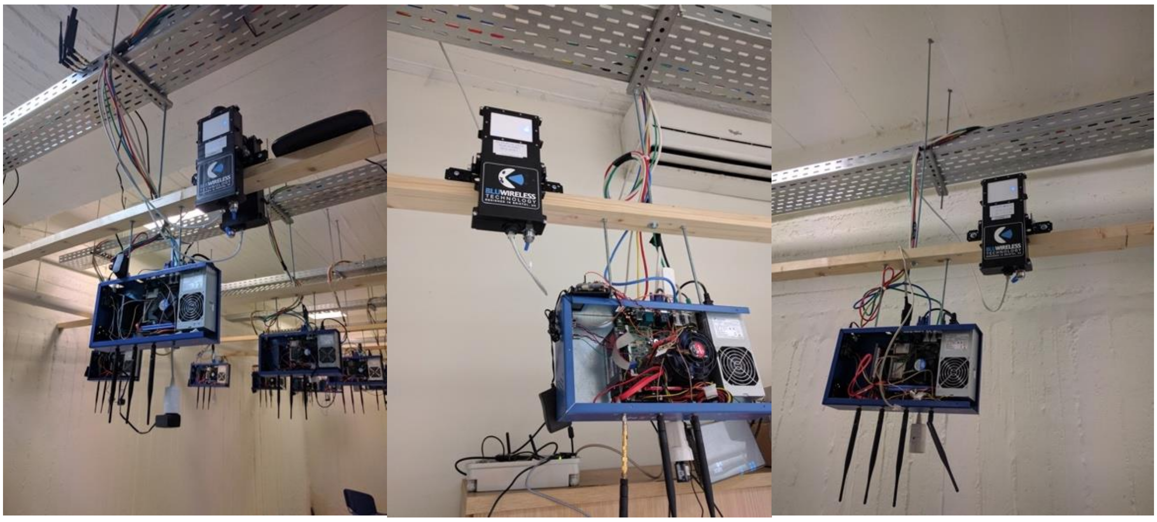


Figure 2-7: Deployment of BWT nodes at NITOS indoor testbed.

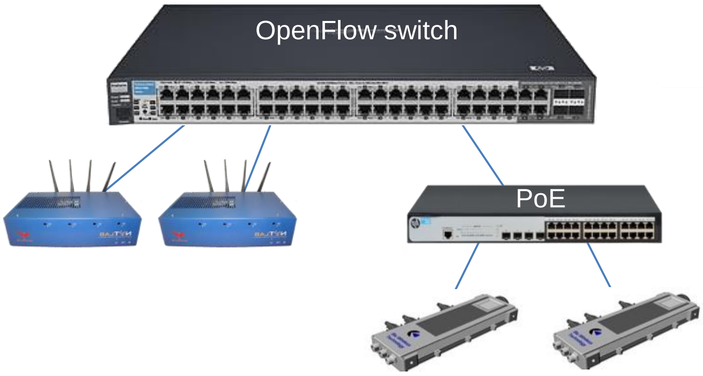


Figure 2-8: Network topology of mmWave nodes.

Each BWT node has a Power over Ethernet (PoE) interface that is connected to an HPE 1920 PoE switch, that is also connected to the HP 3800 OpenFlow switch (described before in section 2.1.2), as it is depicted in Figure 2-8. The PoE switch has been sliced with use of the VLAN technology into 6 separated broadcast domains, so that BWT nodes cannot see each other through the PoE switch. If two BWT nodes ping each other through their Ethernet interfaces, the ping packets will go through the controlled OpenFlow switch. The reason for this deployment is that BWT nodes may have bridged their PoE and wireless interfaces, which could easily produce a switching loop, if the wireless interfaces of the two nodes are configured to see each other and their Ethernet interfaces were into the same broadcast domain through the PoE switch. On the other hand, the SDN control offered by the OpenFlow switch and the BWT virtual bridges enables the loop-free management of the network traffic. Each BWT node has its own static IP address and hostname, *mmWave1* to *mmWave6*.

2.1.5 LTE infrastructure in NITOS

NITOS testbed is providing a small-scale LTE network, similar to an operator's network. Two femtocells are installed in the testbed, whereas a commercial Evolved Packet Core (EPC) is installed at a dedicated server of the testbed. A complete list of the features of the LTE equipment is provided in Table 2-3. The LTE femtocells in NITOS make use of a programmable attenuator at each antenna output, allowing the configuration of the attenuation level at each antenna separately by the experimenter. Figure 2-10 shows the attenuators installed at one of the femtocells, and shows the mobility emulation platform; through this platform, the experimenters can replicate a real pattern of series of Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) on each node of the testbed, extracted from a real trajectory in the city of Volos.

Table 2-3: LTE Equipment in NITOS.

Component	Description
LTE femtocells	ip.access 245F
Supported Bands	FDD Band 7, FDD Band 13
MIMO mode	2x2 MIMO
Method of configuration	Broadband Forum TR-169
Core Network	SiRRAN Communications LTEnet
Release Compatibility	Release 10
Method of Configuration	Web Interface & JSON API
User Equipment	Huawei E3372s-153
Category	Cat 4: 150Mb/s DL, 50 Mb/s UL
Supported Bands	4G (LTE) Frequency Band 1/3/7/8/20 (800/900/1800/2100/2600 MHz)
Method of Configuration	AT Commands / Web interface

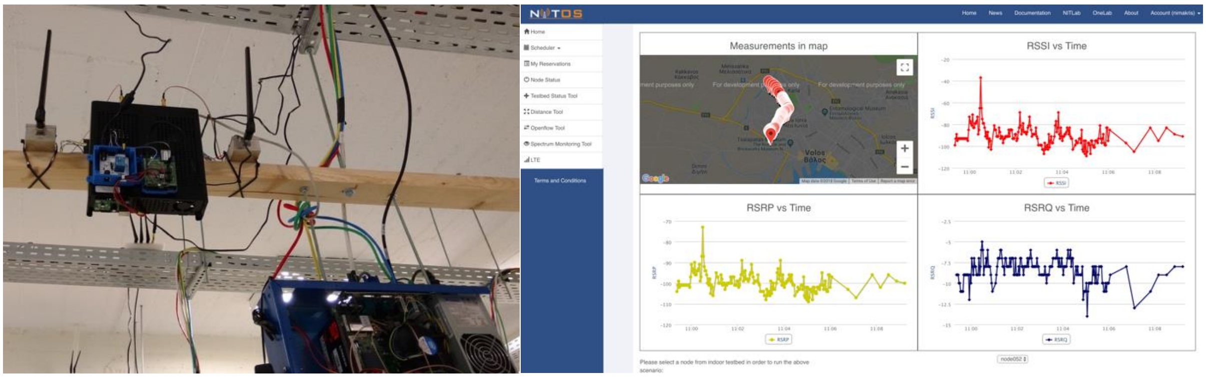


Figure 2-9: Femtocell installed in NITOS with programmable attenuators, and mobility emulation platform (right).

2.1.6 NITOS indoor testbed architecture

In this section, the network architecture of the NITOS indoor testbed is described, as illustrated in Figure 2-10. Two Gigabit (non-OpenFlow) Ethernet switches interconnect the nodes with NITOS Indoor server. The one is the Control switch that provides for control of experiment execution and measurement collection, and the other is the Chassis Manager (CM) switch that is dedicated in controlling the operational status of the nodes through their CM cards, which are attached on each node. The Experimental switch depicted in Figure 2-10 abstractly represents the two OpenFlow switches described before.

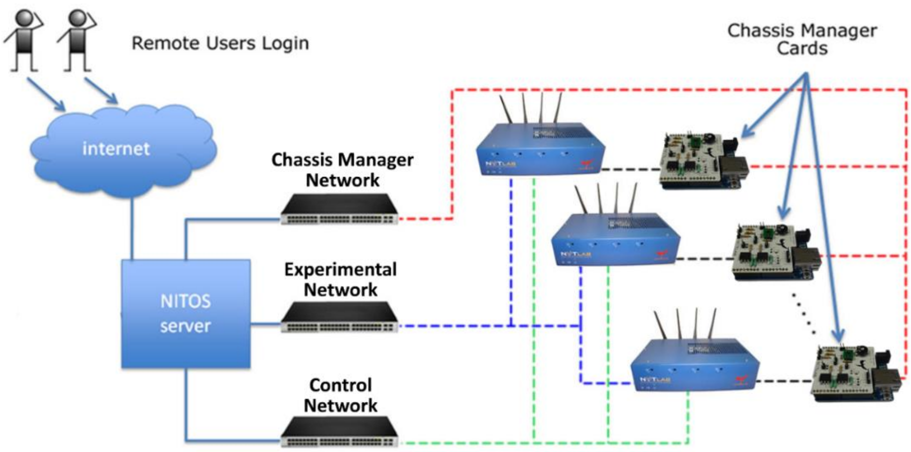


Figure 2-10: NITOS indoor testbed network architecture.

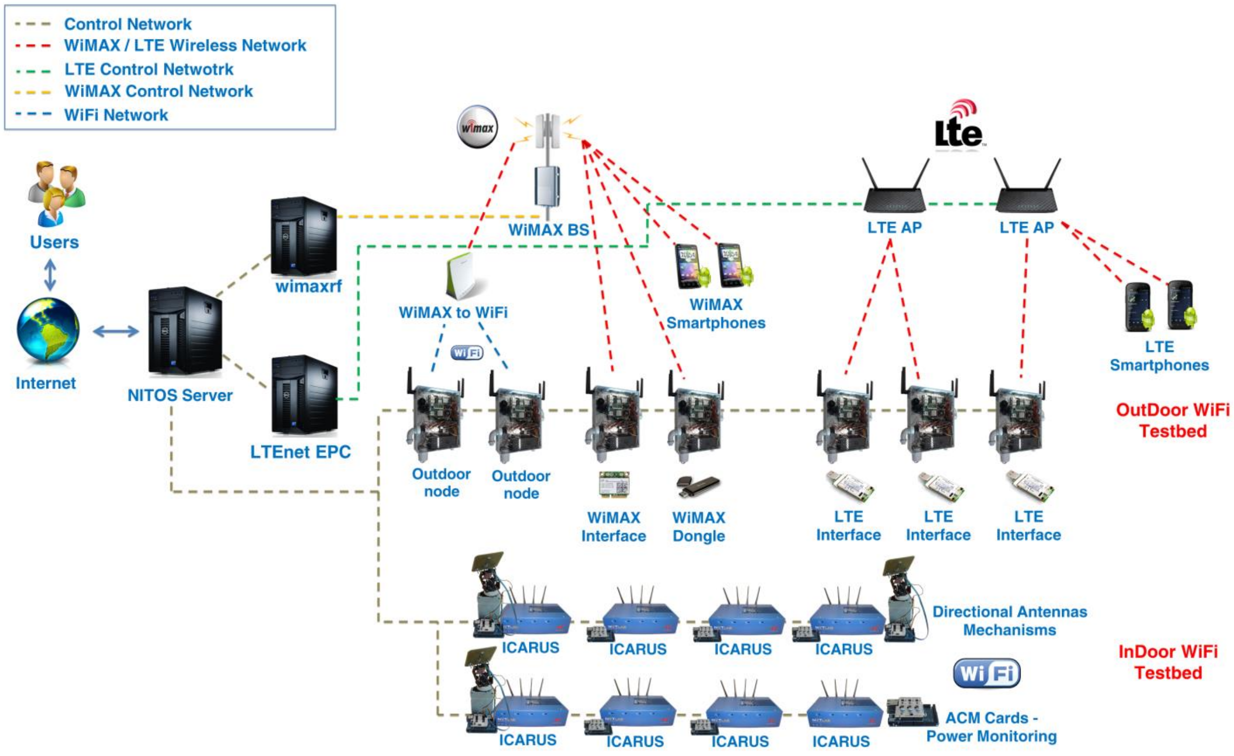


Figure 2-11: NITOS facility architecture.

The overall architecture of the NITOS facility is shown in Figure 2-11.

2.1.7 NITOS software

The control and management of the testbed is done using the cOntrol and Management Framework (OMF) [5] open-source software. Users can perform their experiments by reserving slices (nodes, frequency spectrum) of the testbed through the NITOS Scheduler that together with OMF framework, support ease of use for experimentation and code development. In this section follows a detailed description of the basic software tools utilised by UTH in NITOS testbed.

cOntrol and Management Framework - OMF

The management of several heterogeneous resources is a significant issue for a testbed operator. The wireless testbeds of OpenLab are putting all their resources under a common management framework called OMF for effective management and control. OMF was initially developed in ORBIT by Winlab [6], and currently its development is being led by NICTA along with the contributions of other institutions like Winlab and UTH.

NICTA released a major update in OMF migrating from version 5.4 to version 6, which introduced radical changes in the architecture and philosophy of the framework. The main concept of the new architecture is that everything is being treated as a resource and for every resource there is a dedicated resource controller responsible for controlling it. OMF 6 moves towards to an architecture which incorporates loosely connected entities, that communicate with a “publish-subscribe” mechanism by exchanging messages that have been standardised.

In overall, OMF 6 aims to define the communication protocol between all the entities rather than their specific implementation. The messages of this communication protocol that are being exchanged are defined in the Federated Resource Control Protocol (FRCP). This novel protocol defines the syntax of the messages, but not the semantics that are subject to the different implementations concerning the various kinds of resources.

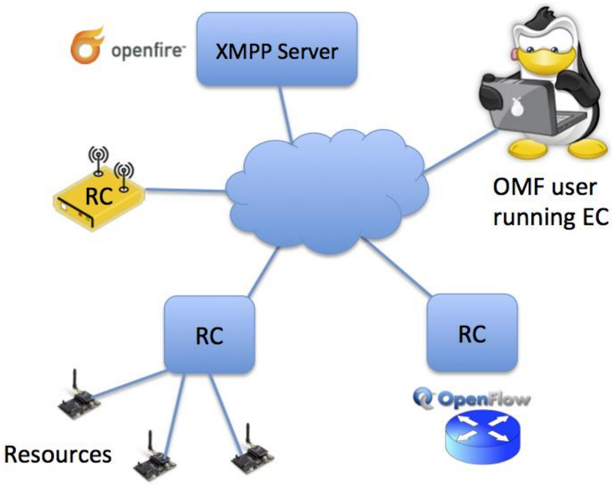


Figure 2-12: OMF 6 Architecture.

The architectural components of OMF 6 can be seen in Figure 2-12, where several RCs are deployed and an experimenter using an EC communicates with the support of Openfire XMPP server. The true power of OMF's new version comes from the capability to easily introduce new resources that are currently not supported by the existing resource controllers. If someone brings a new resource to the community, then he is free to develop an RC responsible for controlling the new resource and share it with the community. This way, OMF can be maintainable and being extended by its users, according to their needs and their different use cases.

NITOS Scheduler

Another tool responsible for managing the testbed's resources is the NITOS Scheduler developed by UTH. It is developed in the spirit of serving as many users as possible without any complicated procedures and relies its functionality on the OMF architecture. NITOS resources, namely nodes and channels, are associated with the corresponding slice during the reserved time slots, in order to enable the user of the slice to execute an experiment. UTH has enabled spectrum slicing support in NITOS, meaning that various users may use the testbed at the same time, without interfering with each other, since each one of them is using different spectrum.

As depicted in Figure 2-13, the wireless nodes and the spectrum channels that a user is going to use are declared during the reservation process and the scheduler does not allow for a user to choose any other resource during the execution of his/her experiment.

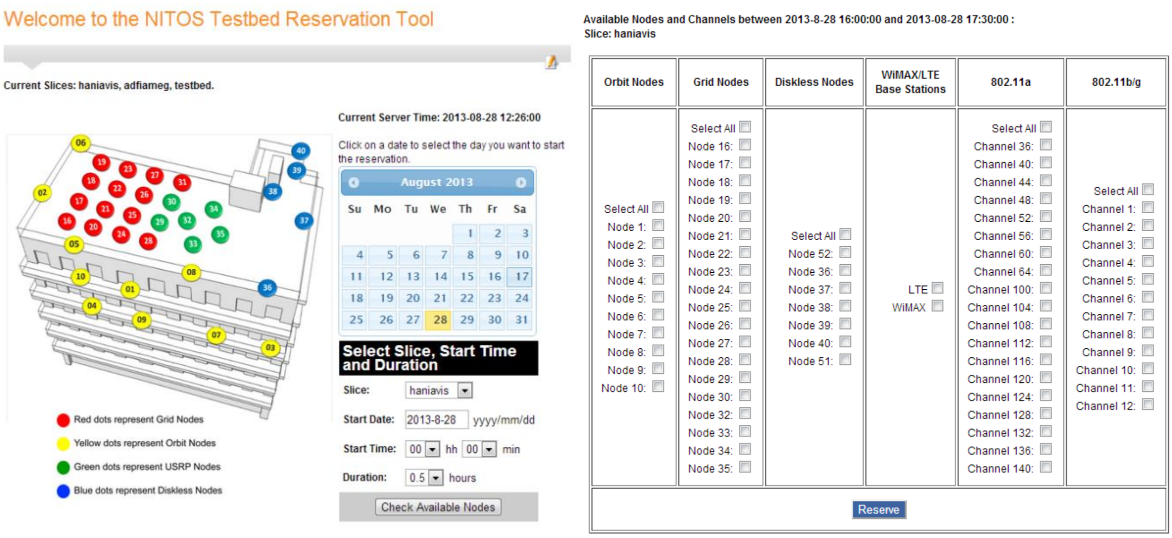


Figure 2-13: NITOS Scheduler user interface.

2.2 Demo and Experiment Scenarios Description

2.2.1 5G-PICTURE orchestration of VNFs in the testbed

The NITOS testbed is hosting an Open Source MANO (OSM) installation for managing the testbed components, using the nodes of the testbed as the compute nodes. OSM is an NFV-MANO compliant orchestrator. The NFV-MANO architecture is providing the necessary abstractions of the underlying hardware equipment, and concentrates only on the orchestration, provisioning and cross- interaction of the deployed functions, taking care of all the low level configurations for setting up end-to-end paths between the functions. Nevertheless, NFV-MANO is mainly addressing datacentre (DC) resources, with the networking being programmed through the SDN concept, whereas services are deployed using either virtual machines or lightweight containers. This approach can extend to generic networking devices (e.g. like the ones that are present in NITOS testbed) as long as they are organised in a distributed fashion, which includes other technologies (such as wireless) that are not currently addressed by SDN through production grade SW.

Nevertheless, the heterogeneous wireless technologies that exist in the testbed (e.g. mmWave, LTE, WiFi) are not inherently supported by OSM. To this aim, the VIM instance that is installed in NITOS testbed is using an updated syntax for the VDU components of the Virtual Network Functions (VNFs), supporting the configuration of the wireless interfaces of the nodes. These interfaces are subsequently bridged with the actual interfaces that are used in the provisioned VNFs. Using this approach, the experimenters are able to access the testbed by using only OSM and depicting the interconnection of the VNFs, even in the wireless domain. To this aim, the NITOS VIM instance is able to consume VNF Descriptors (VNFDs) that are augmented with configuration parameters for wireless networks as well. The following figures present the VNFDs supporting configuration of the WiFi and LTE networks of the testbed.

```
---
id: "vnf_lte"
name: "vnf_lte"
short-name: "vnf_lte"
vendor: "OSM"
logo: "cirros-64.png"
description: "Simple VNF example with a cirros"
version: "1.0"
vnf-configuration: {}
mgmt-interface:
  cp: "eth0"
connection-point:
  -
    name: "eth0"
    type: "VPORT"
  -
    name: "eth1"
    type: "VPORT"
vdu:
  -
    id: "cirros_vnfd-VM"
    name: "cirros_vnfd-VM"
    description: "cirros_vnfd-VM"
    count: 1
    vm-flavor:
      vcpu-count: 1
      memory-mb: 256
      storage-gb: 2
    guest-epa:
      cpu-pinning-policy: "ANY"
    image: "ubuntu1404"
    vdu-configuration: {}
    supplemental-boot-data:
      boot-data-drive: "false"
    interface:
      -
        name: "eth0"
        type: "EXTERNAL"
        external-connection-point-ref: "eth0"
        virtual-interface:
          type: "OM-MGMT"
          vpci: "0000:00:0a.0"
          bandwidth: 0
        floating-ip-needed: "false"
      -
        name: "eth1"
        type: "EXTERNAL"
        external-connection-point-ref: "eth1"
        virtual-interface:
          type: "LTE"
          vpci: "0000:00:0b.0"
          virtual-apn:
            -
              id: "virtual-apn-1"
              name: "TEST_SS"
              qci: 5
              ulambr: 50000000
              dlambr: 50000000
          virtual-cluster:
            -
              id: "virtual-cluster-1"
              name: "virtual-cluster-1"
              cluster-client:
                -
                  id: "cluster-client-1"
        floating-ip-needed: "false"
service-function-chain: "UNAWARE"
```

```
---
id: "test_wifiAP"
name: "cirros_wifiAP"
short-name: "cirros_wifiAP"
vendor: "OSM"
logo: "cirros-64.png"
description: "Simple VNF example with a cirros"
version: "1.0"
vnf-configuration: {}
mgmt-interface:
  cp: "eth0"
connection-point:
  -
    name: "eth0"
    type: "VPORT"
  -
    name: "eth1"
    type: "VPORT"
vdu:
  -
    id: "cirros_vnfd-VM"
    name: "cirros_vnfd-VM"
    description: "cirros_vnfd-VM"
    count: 1
    vm-flavor:
      vcpu-count: 1
      memory-mb: 256
      storage-gb: 2
    guest-epa:
      cpu-pinning-policy: "ANY"
    image: "ubuntu1404"
    supplemental-boot-data:
      boot-data-drive: "false"
    interface:
      -
        name: "eth0"
        type: "EXTERNAL"
        external-connection-point-ref: "eth0"
        virtual-interface:
          type: "OM-MGMT"
          vpci: "0000:00:0a.0"
          bandwidth: 0
        floating-ip-needed: "false"
      -
        name: "eth1"
        type: "EXTERNAL"
        external-connection-point-ref: "eth1"
        virtual-interface:
          type: "WIFI-ACCESS-POINT"
          vpci: "0000:00:0b.0"
          virtual-access-point:
            -
              id: "virtual-access-point-1"
              ip: "192.168.10.1"
              bss: "virtual_wlan0"
              essid: "test1"
              mode: "g"
              channel: 1
        floating-ip-needed: "false"
service-function-chain: "UNAWARE"
```

```
---
id: "wifi-client"
name: "cirros_wifi-client"
short-name: "cirros_wifi-client"
vendor: "OSM"
logo: "cirros-64.png"
description: "Simple VNF example with a cirros"
version: "1.0"
vnf-configuration: {}
mgmt-interface:
  cp: "eth0"
connection-point:
  -
    name: "eth0"
    type: "VPORT"
  -
    name: "eth1"
    type: "VPORT"
vdu:
  -
    id: "cirros_vnfd-VM"
    name: "cirros_vnfd-VM"
    description: "cirros_vnfd-VM"
    count: 1
    vm-flavor:
      vcpu-count: 1
      memory-mb: 256
      storage-gb: 2
    guest-epa:
      cpu-pinning-policy: "ANY"
    image: "ubuntu1404"
    supplemental-boot-data:
      boot-data-drive: "false"
    interface:
      -
        name: "eth0"
        type: "EXTERNAL"
        external-connection-point-ref: "eth0"
        virtual-interface:
          type: "OM-MGMT"
          vpci: "0000:00:0a.0"
          bandwidth: 0
        floating-ip-needed: "false"
      -
        name: "eth1"
        type: "EXTERNAL"
        external-connection-point-ref: "eth1"
        virtual-interface:
          type: "WIFI-CLIENT"
          vpci: "0000:00:0b.0"
          wifi-client:
            -
              id: "wifi-client-1"
              client-ip: "192.168.10.2"
              interface: "wlan0"
              essid: "test1"
        floating-ip-needed: "false"
service-function-chain: "UNAWARE"
```

Figure 2-14: NITOS VNFDs for empty VNFs with an experimental LTE link (left), WiFi in AP configuration (middle) and WiFi station mode (right).

Based on the available tools that are operating in NITOS, the project's VNFs will be able to be hosted over the testbed. The VNFs will be able to be instantiated on top of the NITOS nodes, depending on their network configuration. Qemu will be used as the hypervisor installed on the NITOS nodes, aiming at a setup as shown in the Figure below. Depending on the network configuration by the experimenter, the data plane of the VNF will be either routed or bridged with the respective networking interface.

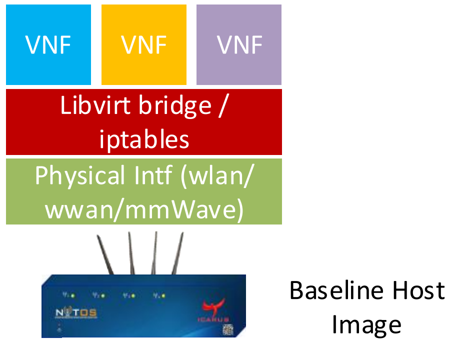


Figure 2-15: VNF provisioning on top of NITOS nodes.

The NITOS configuration of VNFs supports the following features:

- Each testbed node is a compute node. Three DCs are available, depending on the different equipment as follows:
    - LTE DC, including all the nodes with LTE connectivity.
    - SDR DC, with the nodes equipped with USRP devices.
    - Generic DC, including all the nodes with WiFi and mmWave connectivity.
- Each node can use one of the two physical Ethernet interfaces for its control (mgmt. interface).
- New network configurations to support connection to the physical network interfaces of either LTE, WiFi or mmWave technologies.
- Upon reception of a VNF configuration requiring the setup of an LTE network or a WiFi AP, calls are made to testbed dedicated services for configuring either the LTE infrastructure network (base stations and Core Network), the WiFi APs or the mmWave nodes.
- Virtual Deployment Units (VDUs) are able to be provisioned regarding the LTE UEs with guarantees on the maximum achievable aggregate bandwidth on UL and DL per each client, WiFi Access Point VDUs per each physical virtual access point provisioned through the Virtual Access Point functionality of the drivers used in the testbed, and WiFi station VDUs.

2.2.2 5G-PICTURE Orchestration and control of wireless transport technologies to support functional splits.

This demonstration will illustrate the implementation of functional splits as VNFs orchestrated and automatically deployed by the 5G-PICTURE OS and the impact of heterogeneous wireless transport technologies in NITOS with setups as the one shown below.

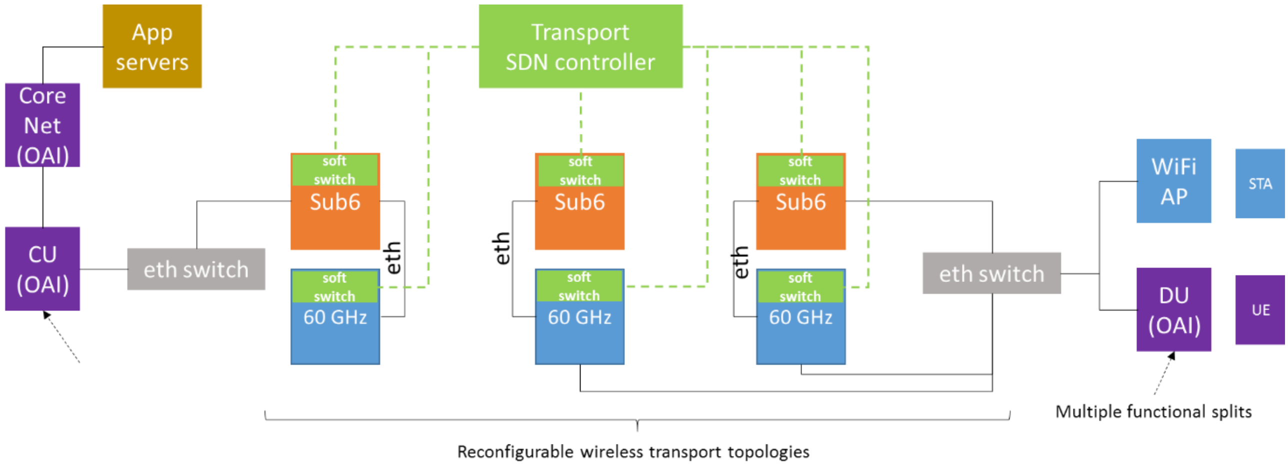


Figure 2-16: Experiment Setup in NITOS.

The experiment will be developed around the following units:

- 2x mmWave nodes/ 2x Sub-6 nodes used for creating the transport network with redundant links.
- 1 node with an SDR front-end, used to execute the VNF containing the cellular network DU.
- 3 generic NITOS nodes, used to run the CU of the network, the WiFi DU and the Core Network.
- 1 UE interfacenode with both LTE and WiFi interfaces to connect to the DUs.

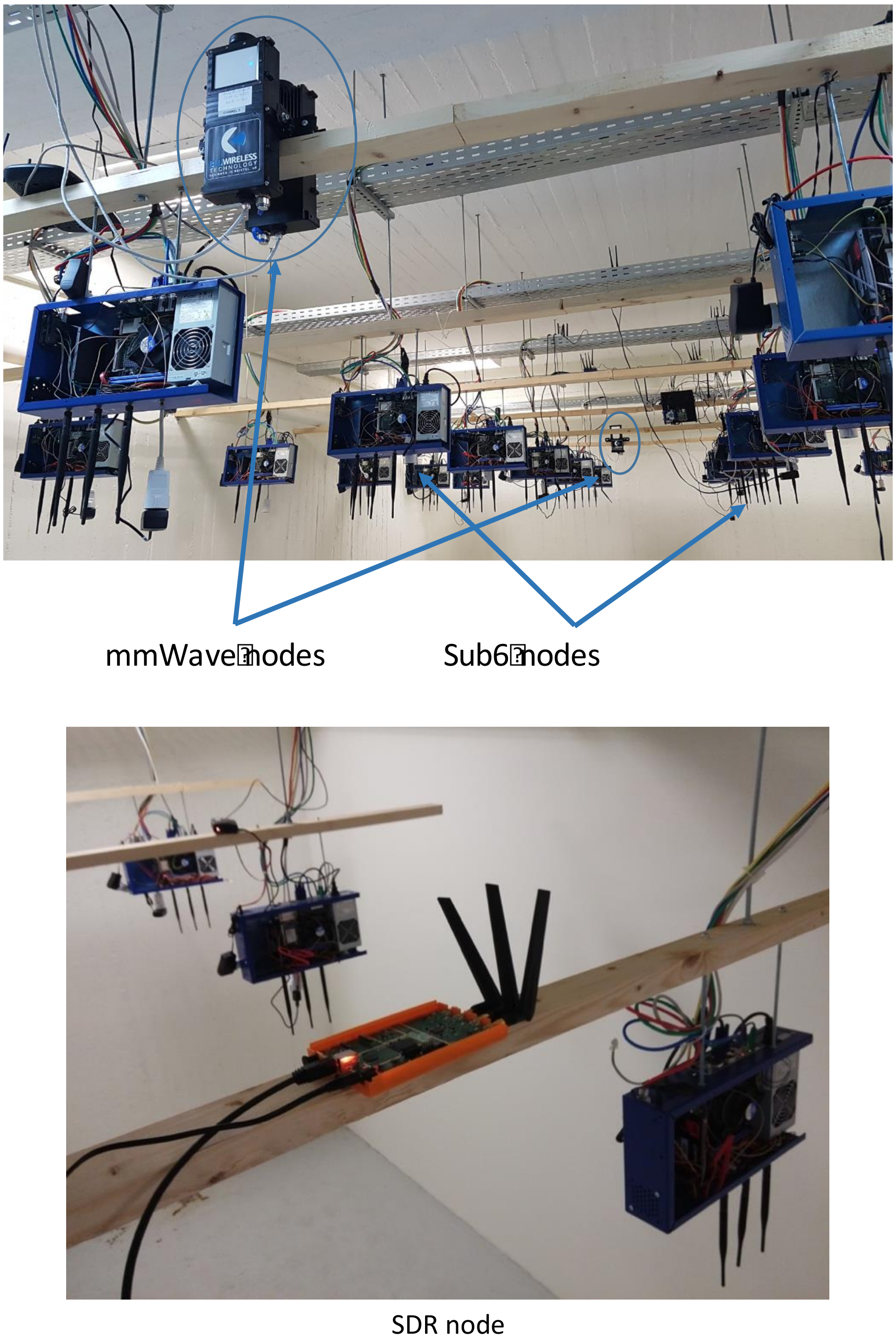


Figure 2-17: NITOS nodes used in the experiments.

In terms of SW, the project will use the OSM tools provided by the testbed. OSM will manage the deployment of the software VNFs to the nodes. It will distinguish the nodes with the SDR frontend for deploying only the Remote Radio Unit to it, and the node with the UE interface for deploying the UE VNF. Two nodes will be running the disaggregated core network setup – Mobile Management Entity (MME), Serving/PDU Gateway (S/P-GW), Home Subscriber Server (HSS) – and the Radio Cloud Controller interface.

The link between the Remote Radio Unit (RRU) and the Remote Cloud Center (RCC) will be running over the mmWave/Sub-6 network. Different scenarios for reconfiguration will also be showcased, e.g. load balancing, backup paths, etc. For running the disaggregated base station, the **OpenAirInterface** platform will be used. For running the disaggregated core network, **OpenAirCore Network** will be used. The following figures show how the network service description looks like before being on boarded to OSM for deploying it in the testbed.


```
nsd:nsd-catalog:
    nsd:
    -   id: disaggregated-het-dus-ns
        name: disaggregated-het-dus-ns
        short-name: oai-ns
        description: NSD to create a software based disaggregated base station system (RAN + EPC) based on OpenAirInterface. Consists of 3 VNFs for the RAN and the EPC
        version: '1.0'
        version: '1.0'
        logo: osm.png
        constituent-vnfd:
        -   vnfd-id-ref: oai_cu-vnf
            member-vnf-index: '1'
        -   vnfd-id-ref: oai_du-vnf
            member-vnf-index: '2'
        -   vnfd-id-ref: wifi_du-vnf
            member-vnf-index: '3'
        -   vnfd-id-ref: oai_cn-vnf
            member-vnf-index: '4'
        vld:
        -   id: mgmtnet
            name: mgmtnet
            short-name: mgmtnet
            type: ELAN
            vim-network-name: provider
            vnfd-connection-point-ref:
            -   vnfd-id-ref: oai_cu-vnf
                member-vnf-index-ref: '1'
                vnfd-connection-point-ref: vnf-mgmt
            -   vnfd-id-ref: oai_du-vnf
                member-vnf-index-ref: '2'
                vnfd-connection-point-ref: vnf-mgmt
            -   vnfd-id-ref: wifi_du-vnf
                member-vnf-index-ref: '3'
                vnfd-connection-point-ref: vnf-mgmt
            -   vnfd-id-ref: oai_cn-vnf
                member-vnf-index-ref: '4'
                vnfd-connection-point-ref: vnf-mgmt
        -   id: datanet
            name: datanet
            short-name: datanet
            type: ELAN
            vim-network-name: provider2
            mgmt-network: false
            vnfd-connection-point-ref:
            -   vnfd-id-ref: oai_cu-vnf
                member-vnf-index-ref: '1'
                vnfd-connection-point-ref: vnf-data
            -   vnfd-id-ref: oai_du-vnf
                member-vnf-index-ref: '2'
                vnfd-connection-point-ref: vnf-data
            -   vnfd-id-ref: wifi_du-vnf
                member-vnf-index-ref: '3'
                vnfd-connection-point-ref: vnf-data
            -   vnfd-id-ref: oai_cn-vnf
                member-vnf-index-ref: '4'
                vnfd-connection-point-ref: vnf-data
```


Figure 2-18: NSD description for supporting the disaggregated heterogeneous RAN VNFs (developed in WP4) in OSM.

Demo workflow:

The VNFs will be organised in the OSM canvas, and then instantiated over the testbed in a fully automated manner. During the demo, we will reconfigure the network to use a WiFi network for the FH interface. The functional split that will be examined are Option 2 and Option 7-1 splits, according to the 3GPP split options.

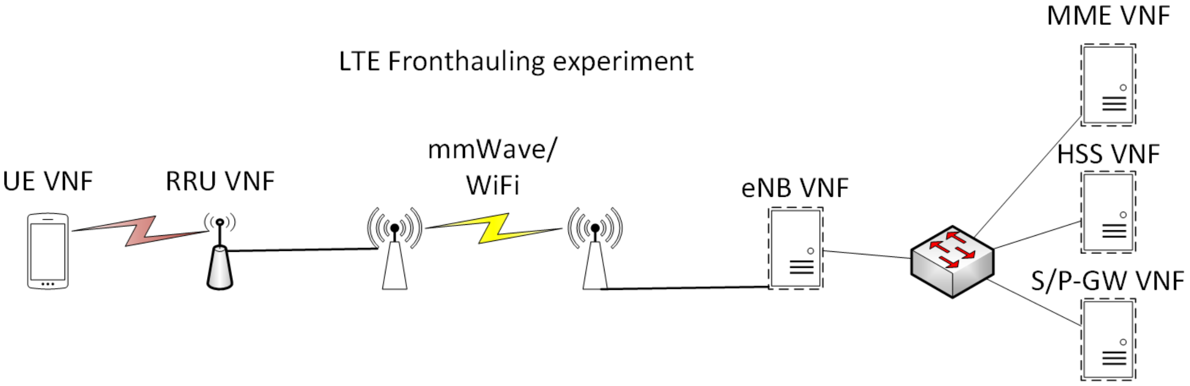


Figure 2-19: Fronthaul experiment.

3 Smart City Use Case

3.1 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 3-2. 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 3-1, 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 3-1: Distribution of the testbed access technologies.

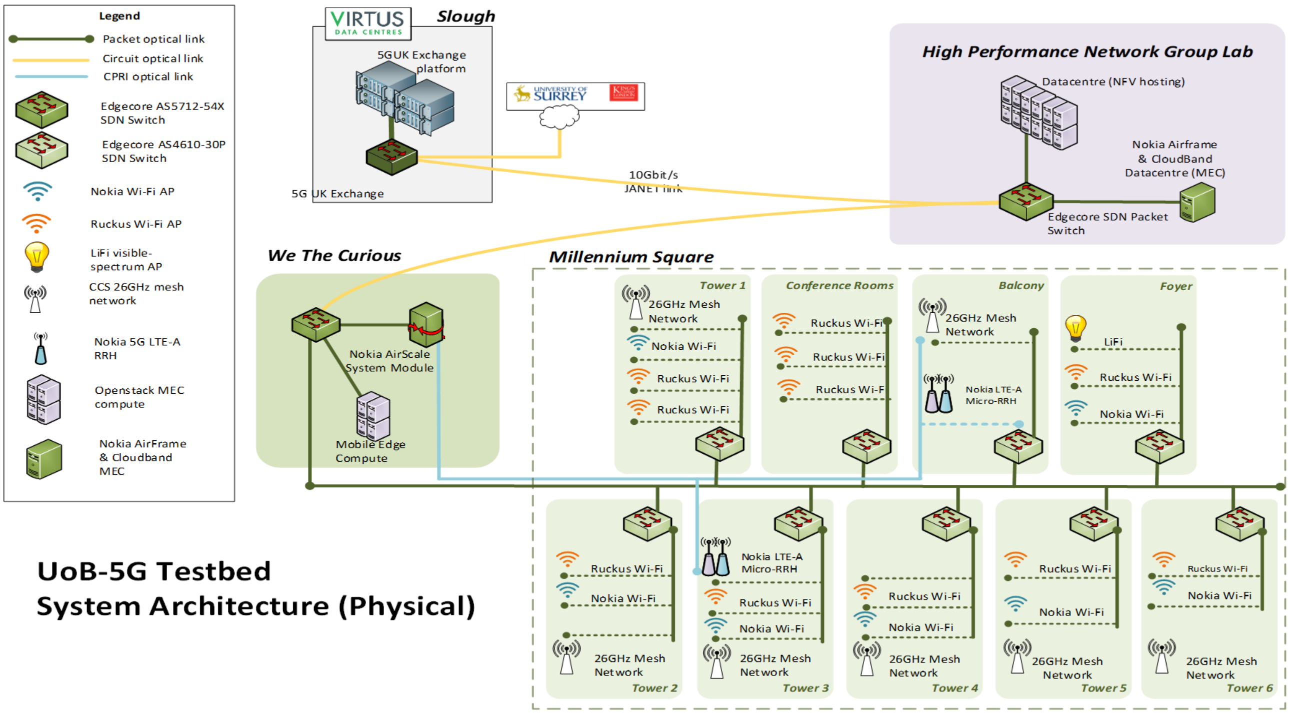


Figure 3-2: University of Bristol top level system architecture.

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 at 3.5 GHz; with 20MHz T&D licence) The project expected availability after November 2018 Handset availability is beyond January 2019.
- 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 3-3) 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.

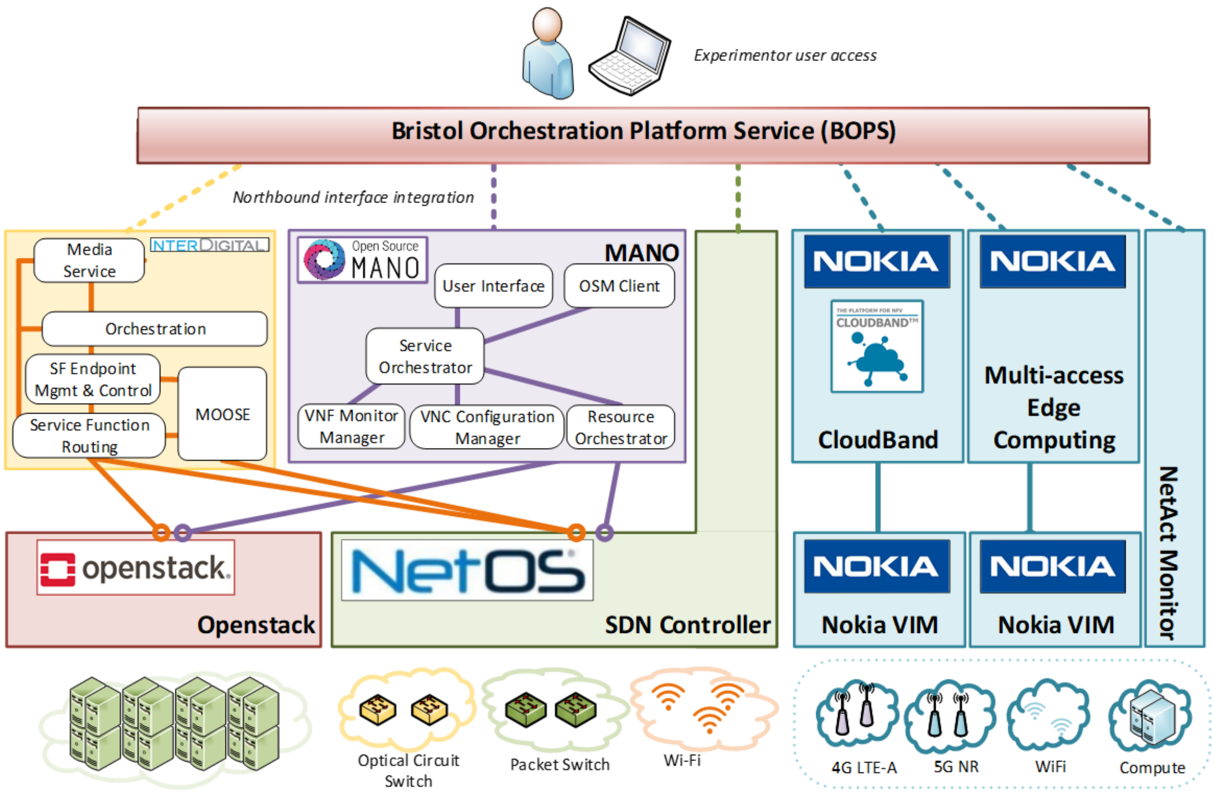


Figure 3-3: Software used for management and orchestration of the testbed resources.

Within any of our projects, the aforementioned structure 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 networkintensive 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.

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.

3.2 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:

3.2.1 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 3-4).

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.

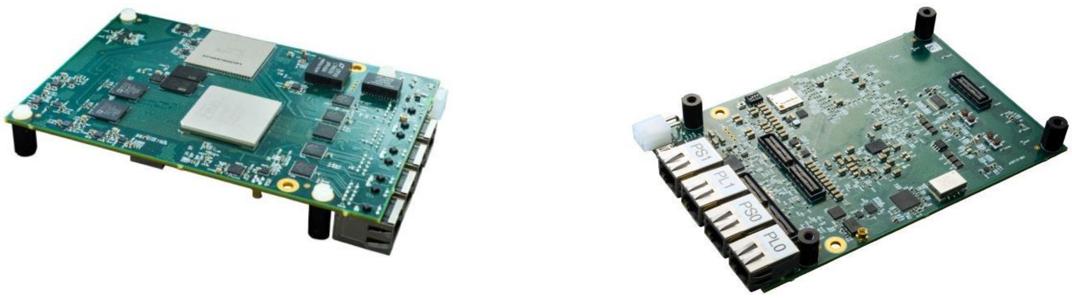
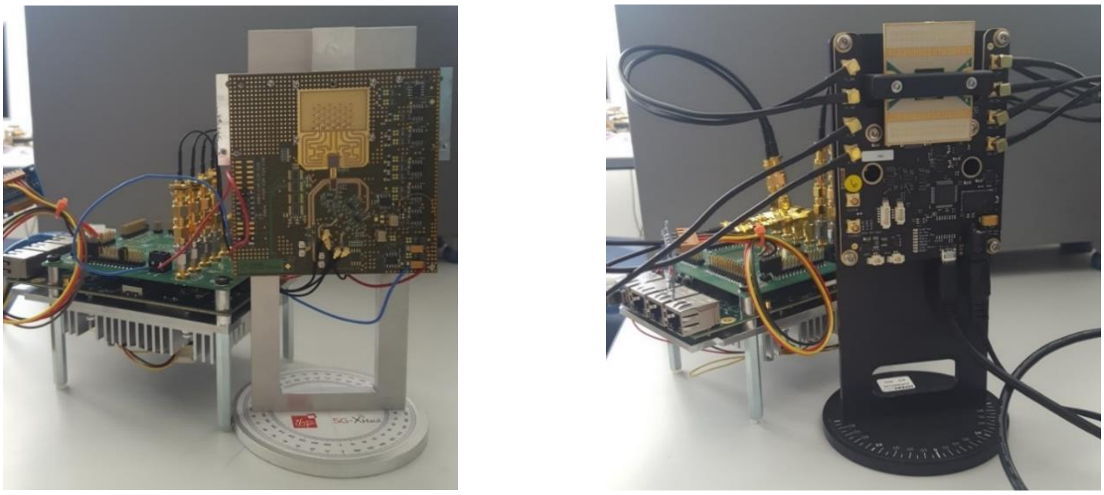


Figure 3-4. IHP's FPGA platform for mmWave baseband processor and MAC implementation.

For integration with abovementioned FPGA platform, IHP has developed its own mmWave RF-frontend beamforming solution (Figure 3-5 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 3-5 b). This is the case of Sivers IMA RF beamforming modules.



a) b)

Figure 3-5: a) IHP's RF Front-End, b) COTS RF Front-End attached to the FPGA boards.

3.2.2 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 received air interface signals from the antenna. An overview of the targeted setup is shown in Figure 3-6:

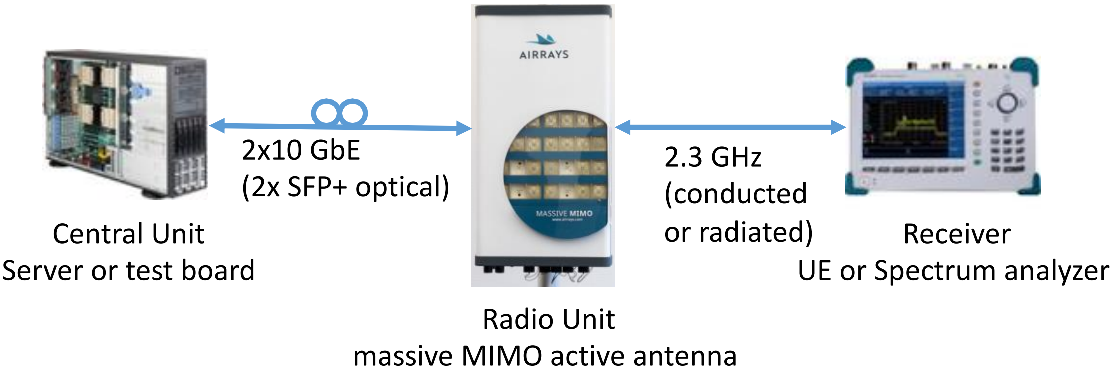


Figure 3-6: Targeted Setup.

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, Transpacket, 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 3-7: 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).

3.3 Demo and Experiment Scenarios Description

As discussed in detail in deliverable D2.2 [7], 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.

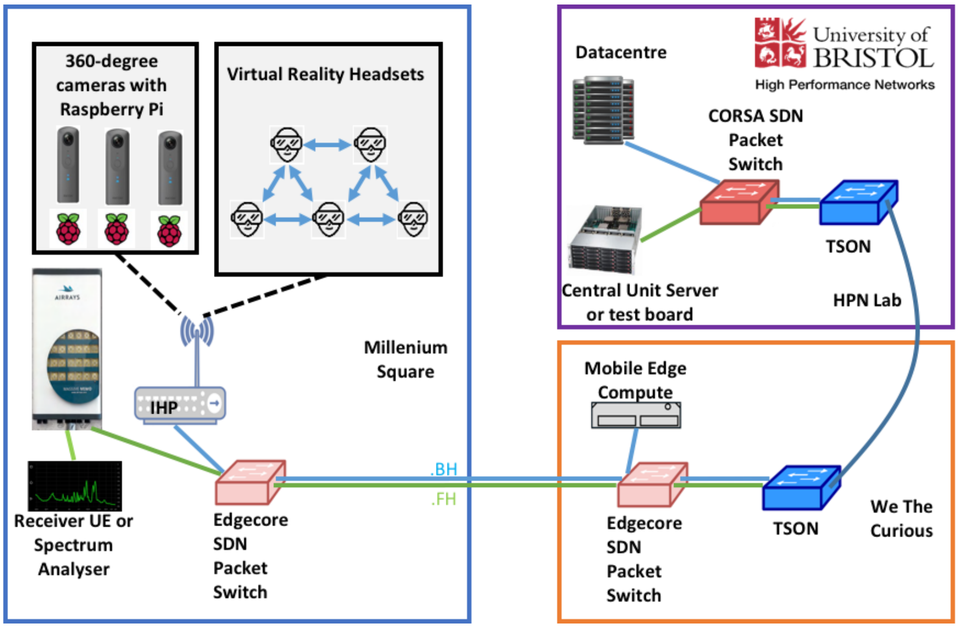


Figure 3-8: 5G-UK test bed architecture for the 5G-PICTURE demonstrations.

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.

3.3.1 Use Case: VR Dance

Service description: Audience capacity per experience: 10 people 'playing', up to 50 people watching, lasting 5 to 10 minutes, and can be repeated as part of the day time activity.

This is a so called social virtual reality piece, where players are working collectively towards a common goal. A member of the public stands on a coloured mat in Millennium Square and plays a VR game or completes a task, wearing headsets. They are in public, along with 9 other players. The game/task in their Gear VR headset is absorbing, fun and physical. An audience looks on and makes sense of the movements of the VR players as a choreography. One participating audience is being puppeteer for another – both unsighted from each other's worlds.

Figure 3-9: VR dance service delivery at Millennium Square, Bristol.

3.3.1 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.

3.3.1 Use Case: FH services

TSON supports Ethernet natively and can also transport CPRI as a FH service either natively or through packetised versions. In this context, it should be noted that evolving FH standards such as eCPRI and the xRAN FH standard utilise Ethernet framing and, hence, will be also natively supported by TSON. At the same time, the xRAN standard defines a management plane that also uses Ethernet packets to configure and control Radio Units (RUs) and Central Units. This configurability of RUs enables a dynamic adaptation of RAN capacity, by e.g. enabling/disabling additional carriers, changing carrier bandwidth, or increasing/decreasing carrier power. The management traffic can be also multiplexed into a FH/BH Ethernet stream. The mMIMO Radio Unit provided by AIR, supports the state-of-the-art xRAN interface (based on eCPRI) low layer split 7.2x, both in term of FH and management data. With this platform, FH services and RU management will be demonstrated over the 5GUK test-bed described above, showing both the versatility of TSON to transport different types of FH, BH and management data, as well as the ability of the network to dynamically adjust to different requirements.

Alternatively, end-to-end Ethernet-based FH services for a system integrating the Airrays platform can be demonstrated with TransPacket FUSION IP Core implementing Ethernet Time-Sensitive Networking. This platform supports all mobile transport functional splits framed and carried through Ethernet as a transport technology. The aggregation of three base service classes into 10GE client wavelengths/channels and further aggregated into 100GE transport wavelength will enable seamless convergence of the FH services with backhaul and fixed access. Three main FUSION classes of services are integrated on the same 10GE wavelength channels to fully support the Airrays xRAN interface communication and a FH service which require time-sensitive user and control plane data transport, synchronisation and management/OAM:

1. FH traffic transport with low and bounded delay through the Bounded Delay Transport (BDT) service. The packet delay variation (PDV) introduced by packet switching needs to be smoothed, i.e. compensated at the receiver side by a playout buffer. TP's low and bounded delay thus simplifies the dimensioning and relaxes the requirement on the buffer size - especially important on the RU side as defined in the new xRAN specification to be able to support multiple types of RUs with fixed buffer size. In the integration scenario with Airrays platform, the PDV and delay will thus be dimensioned for their RU unit.
2. Transparent timing transport of IEEE 1588 PTP packets with ultra-low PDV is aggregated/broadcasted through the same wavelength/channels as the FH to the RUs. The target performance should enables 3GPP Time alignment error (TAE) requirements at antenna ports of 130 ns for class A (Time Error |TE| of maximum 70 ns) and related 3GPP features for carrier aggregation.
3. Statistically Multiplexed (SM) service for lower priority traffic as e.g. management Ethernet frames and OAM packets in the RU-CU transport channel.

In addition, ADVA's G.metro passive WDM system, demonstrated in 5G-XHaul [D5.2] can be utilised to distribute the services to the outdoors access sites and connect directly to Airrays RUs and other client units already deployed in Millennium Square.

The performance of the services will be monitored through traffic generators and analyzers implemented by TP within the FPGA and also with external Anritsu MT1000A tester.

The system will be first evaluated/demonstrated first in a lab environment and further in the UoB 5G testbed. Two or three FUSION nodes can be placed respectively in the HPN IT Room and Watershed (possibly We The Curios as well, demonstrating also add/drop functionality) and connected through dark fiber with off the shelf grey 100G transceivers (Lumentum CFP4 10GBase LR-4) for distances shorter than 10 km between the nodes. Furthermore, BH traffic and fixed access 10GE client channels can be further aggregated on this 100GE transport link between the different sites. This can be the current WiFi fixed access and/or Nokia's LTE-A small cell system currently on the testbed. Thus demonstrating the maturity of the product and interoperation with current technologies, an important use case for the brownfield 5G deployments.

For supporting IHP's platform with 4 x 1Gb/s Ethernet interfaces, it is possible to utilize the 10GE FUSION version, H1, implemented in Xilinx Virtex 6 platforms, aggregating 10 x 1GE into 2 x 10GE interfaces. In this setup 2 x H1 nodes would be clients of the 100GE nodes in a tree structure.

The possible architecture is illustrated in Figure 3-10.

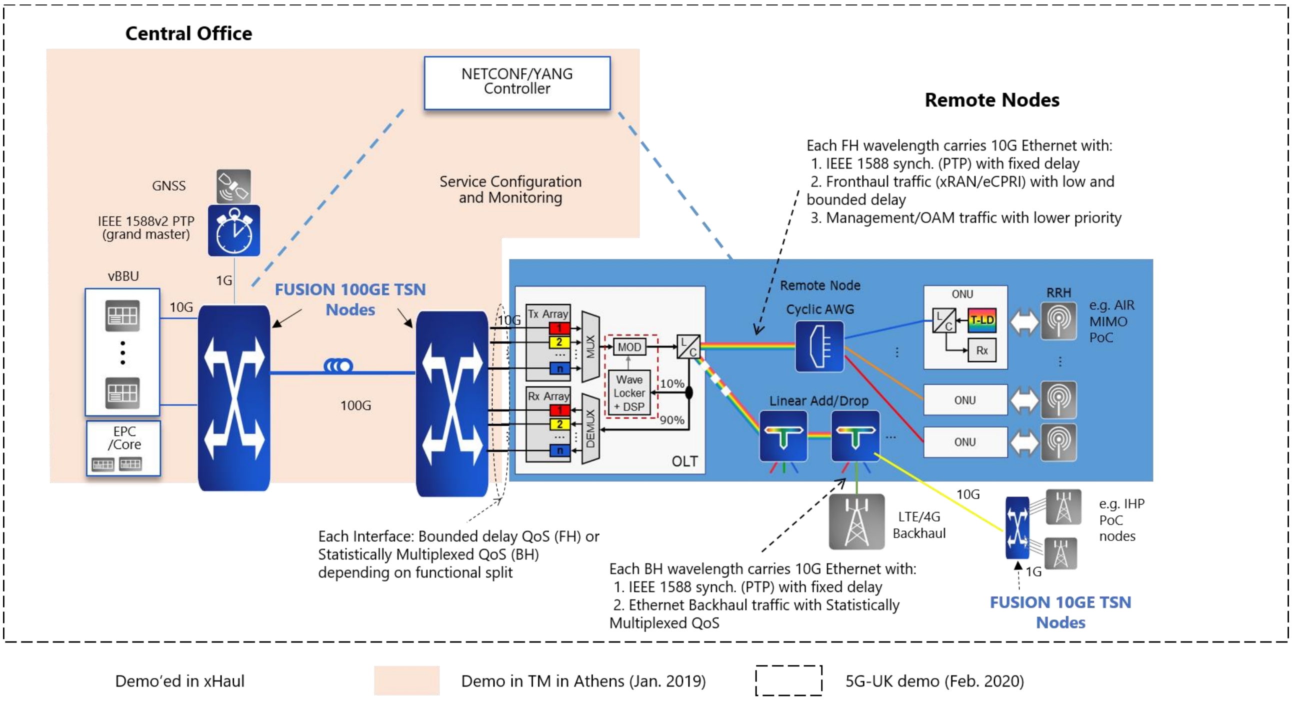


Figure 3-10: Integrated System with two FUSION 100G nodes from TP, ADVA's G.metro WDM and Airrays RU/CU platform.

4 Rail Use Case

4.1 Network Architecture for Railways

The combination of mmWave radio links (as a channel for high quality mobile broadband) and passive WDM (which provides point-to-point logical connections through a physical point-to-multipoint network topology) results in the most appropriate technology for building a new communications infrastructure for railway infrastructures. The Train Access Network (henceforth abbreviated as TAN), mainly targets to offer a broadband transparent connection between the railway track and the trains passing through it. This new network must solve the traditional limitations in performance (throughput, latency) related with train mobility.

As a result, a new and faster on-board communication network (traditionally named as Train Communications Network, TCN) must also be developed to take advantage of the capabilities of this new TAN, allowing aggregated traffic of the order of Gb/s.

In the medium term, this model aims to resolve any generic railway deployment, regardless of the type or nature of the different types of rail services (from High Speed Long Distance to High Frequency Urban Metro), is dedicated to both passenger and freight transport and aims to prove itself valid for all types of environments (including tunnels and adverse weather situations).

However, in the short term, 5G-PICTURE must necessarily limit these ambitious objectives due to the novelty of the technology used and the logical limitations of available resources, given the wide variety of possible environments and situations. The project, therefore, aims to show the enormous potential of this new architecture but within a limited environment.

4.1.1 General Description

As it was explained before, TAN must provide a robust integration scheme between mmWave Access Points backhauled along the track using fibre infrastructure and the mmWave modems on-board connected to the TCN.

4.1.1.1 Train Acess Network

Table 4-1 shows TAN main components:

Table 4-1: Train Access Network Components.

Component name	# boxes	Locations	Considerations
mmWave AP	as required	on suitable trackside infrastructure (e.g. stanchions).	Mounted in pairs, facing opposite directions
G.metro passive WDM system	1 or 2 (for redundancy)	Stations and trackside infrastructure	Single fibre working (SFW) configuration (up to 10 km reach) with a maximum of 20 DWDM channels per fibre
Head-end equipment (HEE)	1 or 2 (for redundancy)	Stations	5-Port 10G optical transponder card with pay-as-you-grow G.metro T-SFP+s.
Remote node (RN)	1 or 2 (for redundancy)	Trackside infrastructure	Passive optical add/drop filters mounted in a water-proof enclosure
Tail-end equipment (TEE)	As required	mmWave AP	Essentially a G.metro T-SFP+ possibly plugged into the mmWave AP
Ethernet switch	WDM HEE co-located	Stations	Conform an Ethernet ring along the trackside

- mmWave Access Points (APs), as many as range and visibility conditions requires. This equipment is intended to be mounted on suitable trackside infrastructure (e.g. stanchions). At a given moment, a mmWave AP provides up to a 4 Gb/s TDD clear channel connection with the mmWave unit on top of the train (it is to say, a 4 Gb/s throughput clear pipe – adding incoming and outgoing train traffic). Furthermore, at some locations the train can connect to multiple APs at the same time to add resilience against fading and increased throughput.
- G.metro passive WDM link: The HEE is intended to be located at railway stations and supports a maximum of 20 10GbE channels per fibre. At medium term, there will be possibility to use tuneable SFP+s for 10, 20 and 40 km. The Barcelona demo will only deploy HEE with SFP+s for 10 km. A second HEE can be used to provide channel redundancy (see later).
- Ethernet switches: Depending on several considerations (length of the track, train number and frequency, network availability, etc.), a 10/100 G Ethernet ring will be placed along the track to aggregate all the traffic originated by the HEE's. In fact, we can imagine the TAN as a LAN in which any attached device corresponds to a HEE channel.

TCN must be complemented with a Handover Management Network Function for Session Continuity. This network function can be built in many ways and with different degrees of sophistication. For this preliminary version of the network has been built in a simple way, allowing the set of elements defined for the Barcelona demo, as described in section 4.1.4.

It is possible to use some PON free channels to connect trackside additional equipment to the TAN (directly, as CCTV cameras, small cells, ATC interlocking elements, sensor networks, etc., or using an intermediate switch). Of course, the environmental conditions introduce special requirements for these devices.

4.1.1.2 Train Communications Network

Typically, a "classical" TCN has a hierarchical structure with two levels of network, a train backbone (for interconnecting vehicles in trains) and a consist network (for connecting standard on-board equipment inside a vehicle). However, this new architecture proposes a flat, simplified version of the TCN, postponing the TCN final design to new future projects. The TCN proposed has a very simple structure:

- mmWave Train Units: Each train unit consists of two components: Antenna Module fixed to the train roof and Host Processor Module fixed inside the train. A separate Host Processor Module is required for each Antenna Module. The antenna module has two mmWave modems (each supporting a tx and rx antenna). The modems can independently connect to two APs.
- TCN Ethernet switches: a 10Gb/s Ethernet ring allows the connection of different devices along the train, allocating an Ethernet switch in each train vehicle.

Service equipment detailed in section 4.2.2 will be attached to the TCN.

All on-board equipment must fit a specific set of train standards (referred to size restrictions, vibrations, etc.), the EN 50155 rugged-railway Ethernet portfolio. Despite this, this not will be a requirement for the equipment to be installed in the demo.

4.1.1.3 Railway Operator Network Components

A generic railway operator network will be composed by several LANs:

- each railway station has their specific LAN to connect different devices and provide the telecommunication based-services portfolio detailed in 5G-PICTURE's D2.1 deliverable [8]. Other locations, as depots or maintenance facilities can support their own LANs.
- each track has their specific TAN providing access to the their passing TCNs along it and its devices directly attached.
- Railway Operational Control Centre(s).

To interconnect all these elements, a Railway Operator Network will need a backbone level. Depending on the footprint of the Railway Operator, several network types can be used: for a local one it may be sufficient to interconnect LANs via a private MAN, while a regional Operator will surely need to interconnect LANs with a private WAN. Since some of the telecommunication-based services provided by this type of networks are classified as safety-critical (as explained in deliverable D2.1), these wide area networks will typically be owned by the Railway Operator. In any such case, this backbone must be able to support IEEE 1588 for clock synchronisation and fit the requirements detailed in the referred document.

4.1.1.4 Network Virtualisation and prioritisation

The network will be shared between the rail operator's traffic and the passengers' traffic, so that the former is prioritised, by defining two VLANs, one for each of these two services, and prioritizing one of them (named "railway operator VLAN"). To test this, the assigned bandwidth on the train-to-ground connection of the other VLAN ("passengers VLAN") would be reduced in some tests until Internet Access packets were discarded, showing that the camera continues to display remote images of the same quality. The network will be configured accordingly to this schema.

4.1.2 mmWave Architecture

BWT's trackside units (APs) will be fixed to stanchions. With the actual antennas, the access points are mounted in pairs. In a pair, one unit faces up the track whilst the other faces in the opposite direction. Blu Wireless product name for these unit is DN-101LC.

Each train unit consists of two components: Antenna Module (fixed to the train roof) and Host Processor Module (fixed inside the train). A separate Host Processor Module is required for each Antenna.

Each train is equipped with 2 TN-201LC Typhoon devices, mounted at the front and rear of the train and connected to the TCN.

The mmWave train to track BH is sketched in Figure 4-1.

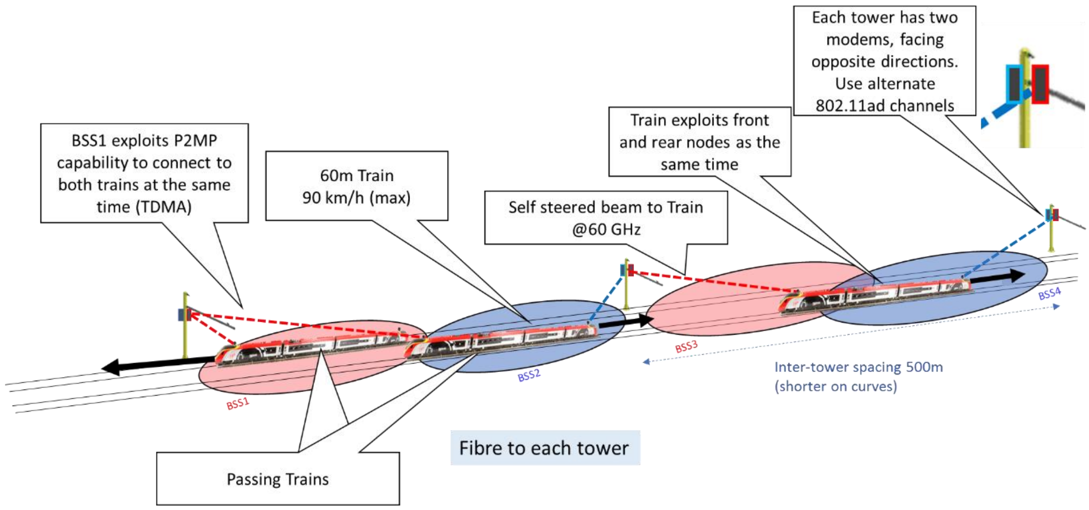


Figure 4-1: Beam management a train passes between masts (each mast holds two APs, one facing up and one facing down the track.

4.1.3 TAN Passive WDM-PON (G.metro) Architecture

The passive metro wavelength division multiplexing (WDM) technology can efficiently provision the optical infrastructure to backhaul the mmWave APs. Since both optical upstream and downstream are independently multiplexed on different wavelength grids, resulting in a single trunk fibre in the field, such a WDM link can significantly save the fibre resource. The remote node that de-/multiplexes different channels is purely composed of passive optical filters, and ideally should be installed close to the mmWave APs. Moreover, the tuneable wavelength-agnostic tail-end transceivers (in an SFP+ form factor) facilitate an auto-configuration of the optical layer and substantially reduce inventory sparing and operational efforts. An out-of-band communication channel is implemented on both HEE and HEE sides, which enables auto-tuning of TEE's wavelength according to the connected port at the remote filter node.

Figure 4-2 depicts the proposed deployment of passive WDM system along the railway track. The TEE at the station consists of all the provisioned SFP+s and one central de-/multiplexer. A single fibre link connects the station with the first stanchion, as well as two adjacent stanchions. At each stanchion, the RN drops the downstream wavelength at the connected filter port and at the same time adds the upstream wavelength from the TEE, which is autonomously tuned as per the downstream wavelength. The maximum distance between the HEE and the furthest TEE is 10 km at 10 Gb/s.

4.1.3.1 Redundancy Consideration

The redundant HEE is installed at the neighbouring station on a dedicated fibre link, which may be deployed on the opposite side of the primary link along the track. The complete passive WDM system with redundancy is illustrated in Figure 4-3.

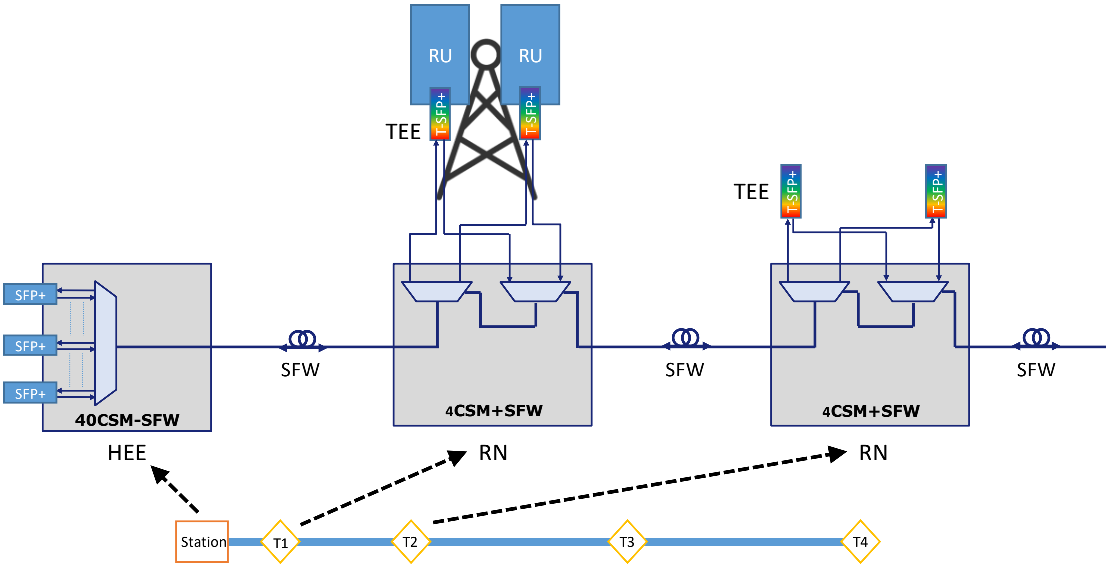


Figure 4-2: Passive WDM deployment for TAN.

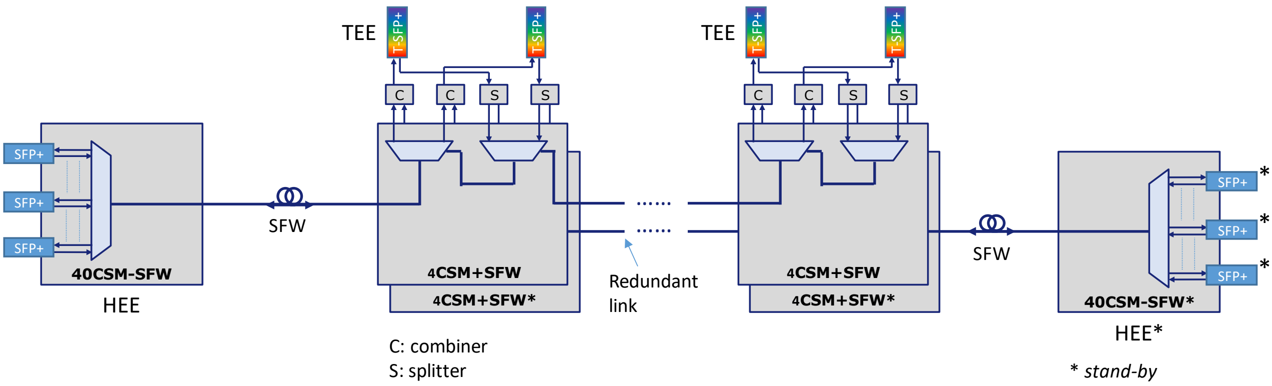


Figure 4-3: Link protection using the dedicated redundant link.

During the normal operation, the redundant HEE is deactivated, while the redundant add/drop filters are always connected to the TEEs together with the primary filters. Given the fact that the filter does not have any active protection switch, each TEE receives the downstream and transmits the upstream through a power combiner and a power splitter, respectively. Additional insertion loss from the passive combiner and splitter must be taken into the link budget consideration

4.1.4 TAN 100G Ethernet Aggregation

To aggregate and transport the TAN data traffic to the remote operation centre, a pair of 100G Ethernet aggregators are commissioned at the station and the operation centre over a duplex fibre link, as shown in Figure 4-4.

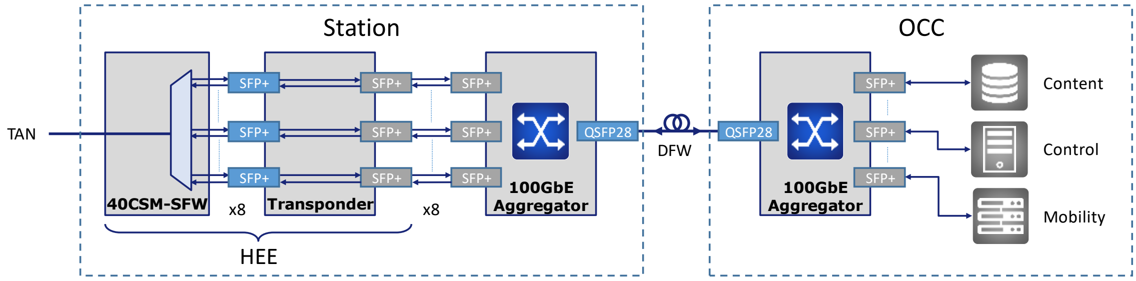


Figure 4-4: Aggregation between the HEE and the control centre.

The interface between the HEE transponder and the 100GbE aggregator is 1310 nm single mode optics at 10GbE, and on the network transmission side, the aggregated traffic is transmitted using a QSFP28 pluggable. At the control centre, correspondingly, 100GbE traffic is disaggregated into multiple 10GbE client ports, which is connected to all the services, i.e. content, control and mobility servers, via the 1310 nm single mode optics.

4.1.5 Handover Management Network Function for Session Continuity

Figure 4-5 shows a high-level picture of the network infrastructure that will be used a general case. Due to the movement of the trains, the connection between the Antenna Module (fixed to the train roof) and trackside units will continuously change over time. This represents a problem for the network functionalities since the return paths of the packet replies dynamically change. Thus, it not possible to preserve network sessions if no handover management functions are implemented. There are several methods to provide handover management, depending on the network layer at which the network function operates and on the scenario characteristics. For this demo we will implement a fast-data path solution that exploits the OPP technical component developed by CNIT in the 5G-PICTURE project, as described in deliverable D4.2 section 3.6.

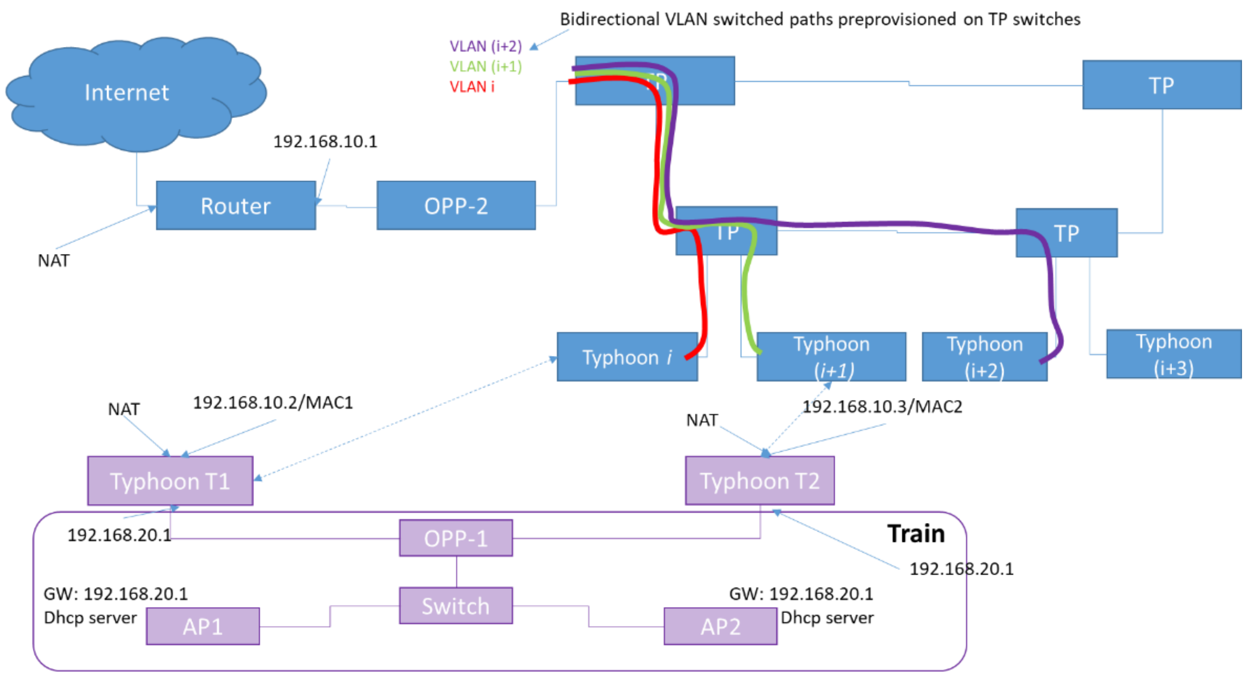


Figure 4-5: deployment of OPP nodes for handover management.

The users travelling in the train can connect to the internet using the Access Points (APs) deployed in the train. The Various APs are connected to a switch that should forward the traffic to the two Typhoon nodes (T1 and T2). The T1 and T2 nodes are connected to some of the Typhoon i nodes deployed close to the railway. These nodes are connected using the TP switches to a router via the OPP-2 node.

The OPP-1 node monitors the connection state of the two typhoon nodes and forward the traffic. It periodically sends probes packets (e.g. ICMP ping) toward the OPP-2 node to detect if the connection of a specific Typhoon node link is active and performs the load balancing of the incoming traffic. When only one link is active, it sends all the traffic to the active link, otherwise it split the traffic between the two active connections. It is worth to notice that this node can be removed if all the traffic is forwarded to both the front and rear Antenna Module. It is also possible to deploy, using the OPP-1 node, a Quality of Service (QoS) functionality that duplicate only a subset of the outgoing traffic (i.e. the traffic of critical applications such as the CCTV service) thus increasing the fault tolerance for this traffic class.

Each of the Typhoon i nodes deployed close to the railway belong to a different VLAN network, thus allowing to the OPP-2 node to detect from which link the packet arrive. The OPP-2 node is therefore able to associate the MAC addresses of T1 and T2 to a specific VLAN and send to this VLAN network the packets arriving from the router. Thus OPP-2 can send the replies to the correct Typhoon nodes maintaining the network session continuity.

The two OPP nodes are implemented using the FPGA based prototype boards (namely a NetFPGA SUME) [9] equipped with four 10 GbE interfaces. The OPP-1 nodes will use thre 10 GbE links: two of them connect the node to the two Antenna Modules and the third one connects the node to trains users through a standard access point.

The OPP-2 node uses only 2 10GbE links. One for the traffic coming from the train, which is forwarded to the outside internet domain, and one from the outside toward the train.

The main functionality of the OPP-2 node for the traffic coming from the train is to learn, for each MAC address of the Antenna Modules, the VLAN tag associated to the packet. Moreover, depending on the behaviour (and on the presence) of the OPP-1 node, a deduplication function can be enabled. The deduplication avoids sending duplicate packets that are generated by the train sending the data to both the front and rear Antenna Modules.

For the traffic coming from outside the OPP-2 node simply pushes the specific VLAN label learned by the packet coming from the other direction.

As OPP-1 is not strictly necessary in the Barcelona Demo it might be removed, sending all the traffic to trough both nodes.

4.2 Barcelona Railway Demo Description

Testing will be carried out in the *Llobregat–Anoia* line. This line has a freight historical origin, as it was constructed to transport mining products from *Súria* mines and textile products from the Llobregat and Anoia basins. The first section of this line was constructed in 1893. Due to this origin, it has metric track gauge of 1.000 mm. Over the years, different passenger and goods lines have been opened in Barcelona and the surrounding areas. Nowadays the line has mixed traffic, passengers and different freight among them cars, car pieces or salt. Along the line there are different train services, some of metro inside Barcelona, some suburban services connecting Barcelona and surrounding areas, and some commuter trains which connect more distant areas of Catalonia. The rail line is depicted in Figure 4-6.

4.2.1 Track section description

The section of the demonstration track is about 2 km long, located next to *Olesa de Monserrat* station, in direction to *Abrera*, and its main characteristics are detailed on Table 4-2. As the speed of commercial trains is above 60 km/h, this means a maximum of two minutes of demonstration each time the train crosses this section.

One commercial train with 5G TCN equipment will pass through this section twice an hour. It is possible to make some specific journeys at night through the section when there are no commercial trains running on it.

Figure 4-6: Llobregat – Anoia rail line.

Table 4-2: Martorell Enllaç – Olesa section characteristics.

Characteristics	Open air	
	Curves with big radius	
	Without surrounding obstacles	
Stations	Martorell Enllaç	Pk. 28.696
	Abrera	Pk. 33.158
	Olesa de Montserrat	Pk. 35.942

Figure 4-7: Section image.

4.2.2 Services to be demonstrated

In addition to the different tools that will be used to for measuring the performance of the on-board solution, the Barcelona demonstration shows two services that have benefited from the capabilities of this new communications infrastructure.

4.2.2.1 Internet Access for Passengers

The train equipped with the new 5G TCN will provide an Internet access "service" for passengers connecting to the on-board Wi-Fi network, although this connectivity will only be available in the section with mmWave coverage.

4.2.2.2 On-board CCTV

The train equipped with the new 5G TCN will be provided with an on-board CCTV 4K camera that will send its images to a video recorder located in Martorell. These recordings will also be seen live displayed in a screen in the Martorell station (again, will only be available in the section with mmWave coverage.)

4.2.3 Deployment of hardware/software

Figure 5 describes the complete scenario for the demonstration of the new railway network, as described in section 4.1. Four stanchions, near the *Olesa de Monserrat* station, are equipped with a pair of mmWave AP's each one. While the location of T1 and T2 must be considered definitive, that of T3 and T4 will be confirmed after a future on-site inspection. The distances between the towers and the area to be provided with mmWave coverage are shown in Figure 4-8.

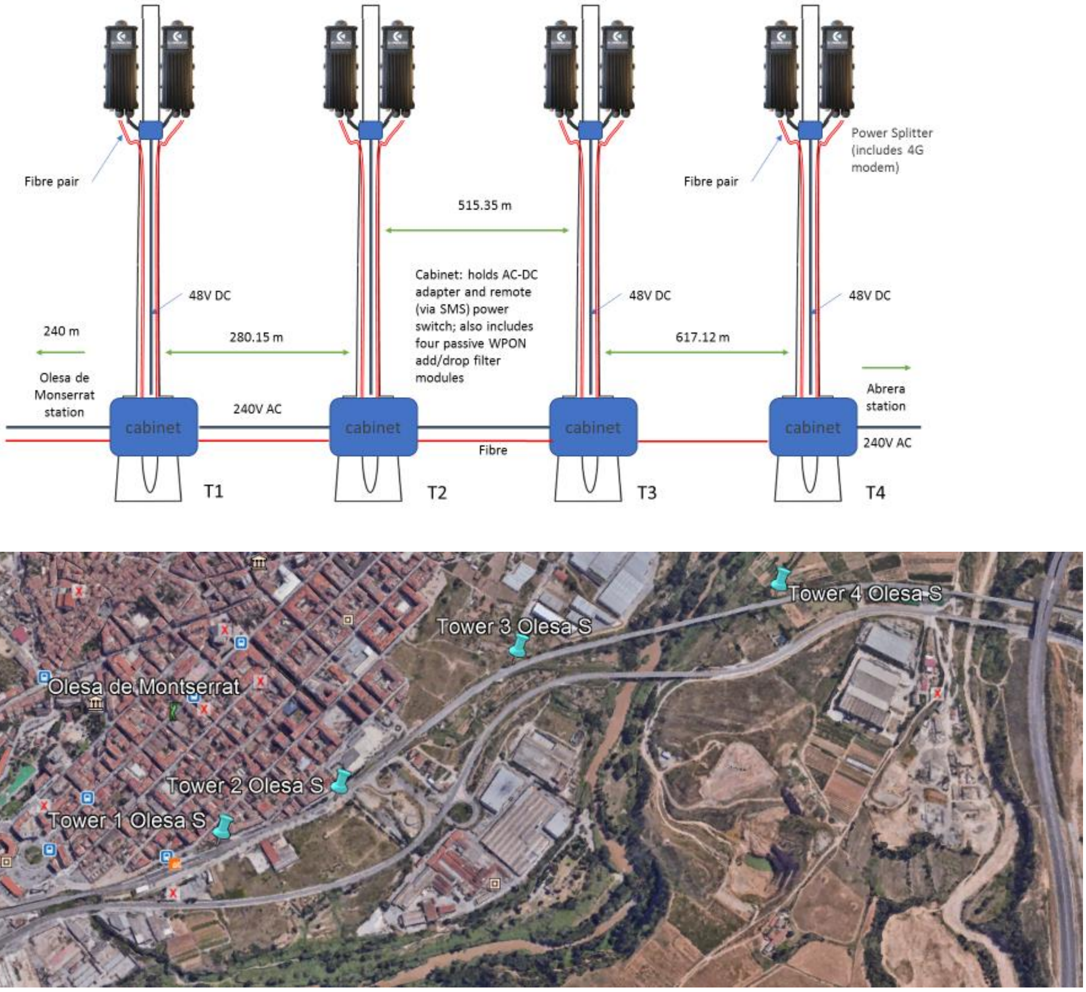


Figure 4-8: Location of the towers.

Martorell station simulates a small OCC: has its own Internet Access and will host the video recorder and the CCTV screens, as well as all the equipment needed to perform the Handover Management Network Function for Session Continuity (see section 4.1.5).

Thus, the primary HEE will be located at Olesa the Monserrat, co-located with the Ethernet aggregator. Martorell station will host the back-up HEE, co-located with its respective Ethernet aggregator.

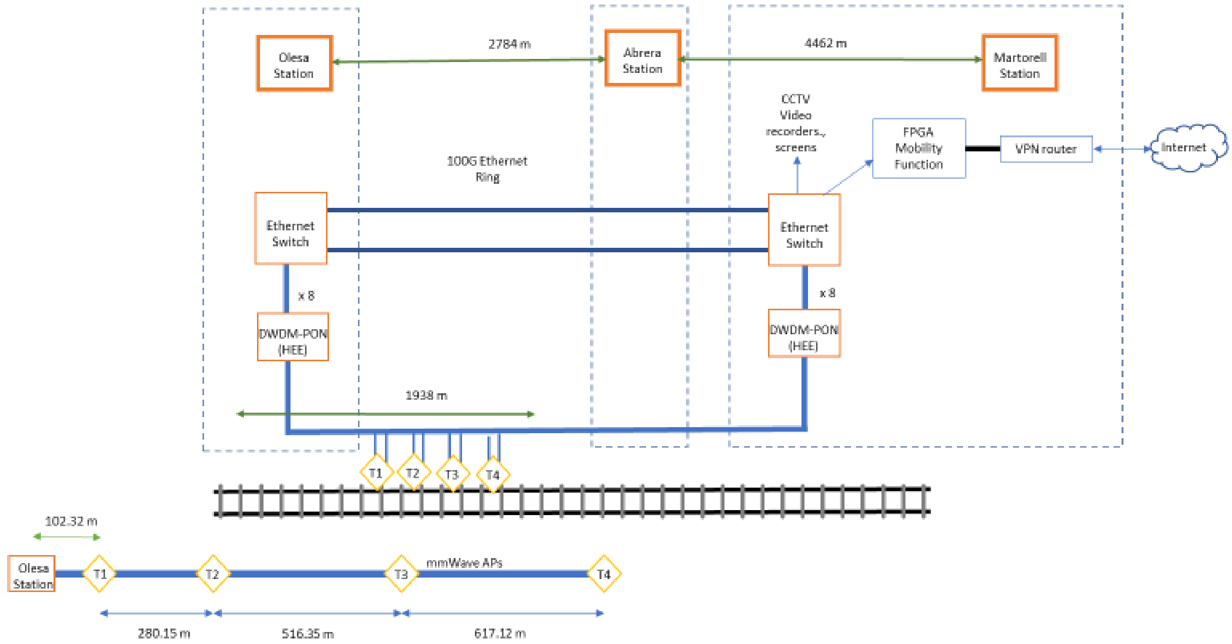


Figure 4-9: Railway Demo: Network Components.

One FGC train will be equipped with a TCN: two on-board mmWave units (see Figure 4-10), mounted at the front and rear of the train. Their Host Processor Modules will be connected to both ends of the 10G Ethernet ring.

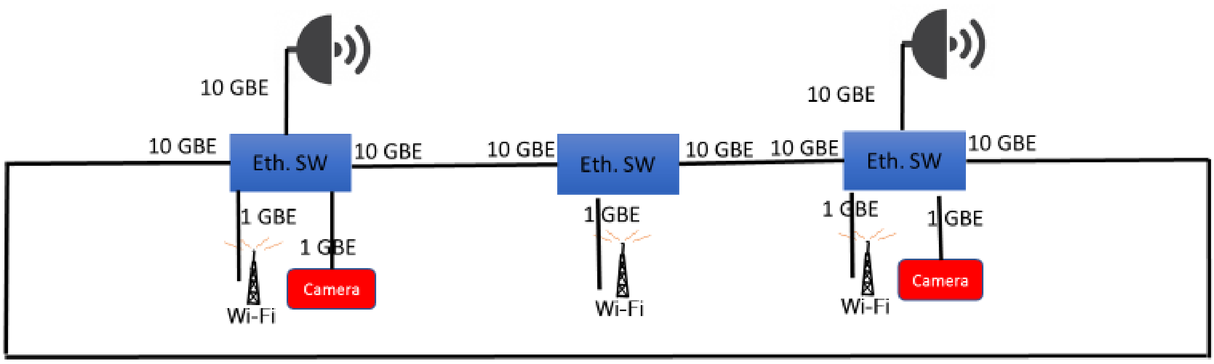


Figure 4-10: On board equipment.

This 10G ring will be consist of three Ethernet switches interconnected by two fibres; each of them in a vehicle. One Wi-Fi AP will be connected to each switch to provide the Internet Access service to passengers. A CCTV camera will be connected at some point of the TCN.

Table 4-3 shows the equipment needed to build the demo:

Table 4-3: Equipment needed.

Equipment	# units	Location	Partner
DN-101LC.	8	T1-T4	BWT
HEE	2	Martorell and Olesa	ADVA
TEE	8	T1-T4	ADVA
SFP+	27	Martorell and Olesa	ADVA
TAN Ethernet aggregators	2	Martorell and Olesa	ADVA
TN-201LC	2	Train	BWT
TCN Ethernet switches	3	Train	ADVA
FPGA OPP-2	1	Martorell	CNIT
Wi-Fi APs	3	Train	COMSA
CCTV camera	1	Train	COMSA
CCTV video recorder	1	Martorell	COMSA
CCTV screen	1	Martorell	COMSA
Internet Connection	1	Martorell	FGC
Stanchion power splitter	4	T1-T4	BWT
Stanchion bottom cabinet	4	T1-T4	COMSA
Cellular Dongles	8	T1-T4	BWT
GSM Power Socket Switch	4	T1-T4	COMSA

4.3 Barcelona Demo Planning

Referred to Task 6.3, the Barcelona Demo installation is planned in several phases:

1. Phase 1 encompasses the initial deployment of a couple of APs DN-101 LC in 2 stanchions and a train with a single train unit (TN-201LC) mounted on the front of the roof. These two towers have power feeding but remain disconnected from fibre. Thus, APs will be remotely managed with LTE dongles. The main objective of the initial deployment is to determine the throughput (i.e. rate in Gb/s and many other parameters) of UDP downlink traffic from the APs to the train as a function of train position with the train travelling at normal operating speed and adjust de units to improve the KPIs.
2. Phase 2 encompasses the rest of the components: complete the remaining APs, in the other two stanchions; build the passive WDM and the Ethernet Aggregation Level to finish the TAN between Olesa de Monserrat and Martorell.
3. In Phase 3, the TCN must be finished, including the on-board equipment related with the services defined in section 4.2.2; terminating the installation of service equipment and the access to Internet Connection in Martorell Station and commissioning of the entire installation, verifying that there is Internet Access inside the train and the CCTV circuit works properly (of course, in the track section with mmWave coverage).
4. Phase 4 consist of Test plan execution and writing the deliverable with results and conclusions.

Planning of this activities is showed in Table 4-4.

Table 4-4: Planning of activities (Gantt chart) of the Rail demo.

	Title	leaders	Nov M18	Dec M19	Jan M20	Feb M21	Mar M22	Apr M23	May M24	June M25	July M26	Aug M27	Sep M28	Oct M29	Nov M30
Ph 1	**Detailed design & preparation**														
T6.3.1	Track Section Inspection & Ultimate Decision for Emplacements	BWT, COMSA	■	■											
T6.3.2	Constructive Project	COMSA		■	■										
Ph 2	**TAN Installation & setup**														
T6.3.3	Electrical installation (including stanchions' cabinets and power splitters)	COMSA				■	■								
T6.3.4	Typhoon nodes installation, set up & testing (T1 & T2)	BWT, COMSA				■	■								
T6.3.5	DWDM-PON & Ethernet switches installation, set up & testing	ADVA, COMSA						■							
T6.3.6	Typhoon nodes installation, set up & testing (T3 & T4)	BWT, COMSA						■							
T6.3.7	Mobility Function installation & VLAN provisioning	CNIT, COMSA							■						
T6.3.8	TAN final setup & testing	COMSA							■						
Ph 3	**TCN Installation & Setup**														
T6.3.9	10 G Ethernet ring (fibre & switches)	ADVA, COMSA		■	■	■									
T6.3.10	mmWave on-board units connection	BWT, COMSA				■									
T6.3.11	TCN set-up & testing	COMSA					■								
T6.3.12	Wi-Fi & Internet Access for Passengers	COMSA						■	■						
T6.3.13	CCTV setup & testing	COMSA							■						
Ph 4	**Trial execution**	UBRIS													
T6.3.14	Test plan elaboration	All							■	■					
T6.3.15	Tools for KPIs (?) ready	???							■	■					
T6.3.16	Test plan execution	COMSA									■	■	■	■	■
Ms															M29-IR
T6.3.17	Overall analysis of the trial results and D6.3 elaboration	All												■	■
Ds															D6.3

5 Stadium Use Case

The objective of the various demonstrations in the mega-event/stadium vertical is to address the following 5G themes:

1) Application aware network (i.e. programmable network) over heterogeneous HW.
2) Differentiated treatment of the application using slices.
3) Service resilience using slices – in a multi-connectivity link scenario for WiFi.
4) High capacity wireless access technologies: Massive MiMo (physical).

5.1.1 Approach

An incremental approach is planned:

1) Demonstration over existing network (without 5G)
2) Demonstration over 5G network
    a. Using high capacity wireless access technologies (Massive MIMO).
    b. Application aware network – differentiated service slice for applications.
    c. Network aware application – application uses programmable network features.

Note: No demo will take place on or the day before a match-day. This is to ensure the availability of the Stadium infrastructure (e.g. network, rooms etc.) for the match.

5.1.2 Overview of Demonstration Metrics and KPIs

The traffic type most suited for this demonstration is high definition video stream which requires low jitter and low latency variations. User Metrics to be evaluated are: Quality of Experience (QoE) of App user via the Media KPIs. Network Metrics to be evaluated are: jitter, latency, utilisation and congestion. The target KPIs are: Low jitter, low latency variation and low congestion. User Metrics are described in the next.

- User Metrics: QoE (Quality of Experience) of App user, Media KPIs.
- Network Metrics: jitter, latency, utilisation and congestion.
- KPI Target: Low jitter, low latency variation and low congestion.

5.1.2.1 User Metrics: Application Related KPIs

User Metrics are application related, they are critical for a good quality of experience. For example, if there is massive frame loss then the video will not be uninterrupted and therefore will lead to a bad quality of experience. The full set of KPIs to be measured are. The full set of KPIs to be measured are:

1. delay (per client & medium).
2. jitter (per client & medium).
3. bandwidth consumption (individual per client/ aggregated on server).
4. packet loss (on server, per incoming stream).
5. frame loss (on server, per incoming stream).
6. stream synchronisation (on server, per incoming stream).

5.2 Application Overview

Given that one of the objectives is to demonstrate a programmable network, it becomes important to have an external client that can be modified to interact with such a network. For the demonstration, i2Cat (Media) are providing access to Watchity[1]. Application that works on standard smart phones and provides a platform for crowdsourced video.

Typical usage scenario:

1) A Watchity event is created for a given 'mega-event'.

[1] https://www.watchity.com

2) Spectators, fans and other interested parties download the Watchity App on their phone.
3) People wanting to share their video from the event stream video from their phone to the corresponding Watchity event, via the App.
4) All video streams are aggregated in the Cloud (video processing server) where they are also curated – which involves removing streams that violate terms of use.
5) Approved streams are published and viewable by the wider public.

The Watchity event can be created by the venue owner or the event organiser or by a member of the public.

5.3 Demonstration Use-cases

This section describes the uses-cases that are part of the Stadium Demo. The plan is to incrementally do the demos. 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. As a stretch goal we plan to make the network more aware of the application requirement.

Figure 5-1 provides a component and deployment view of the different use cases.

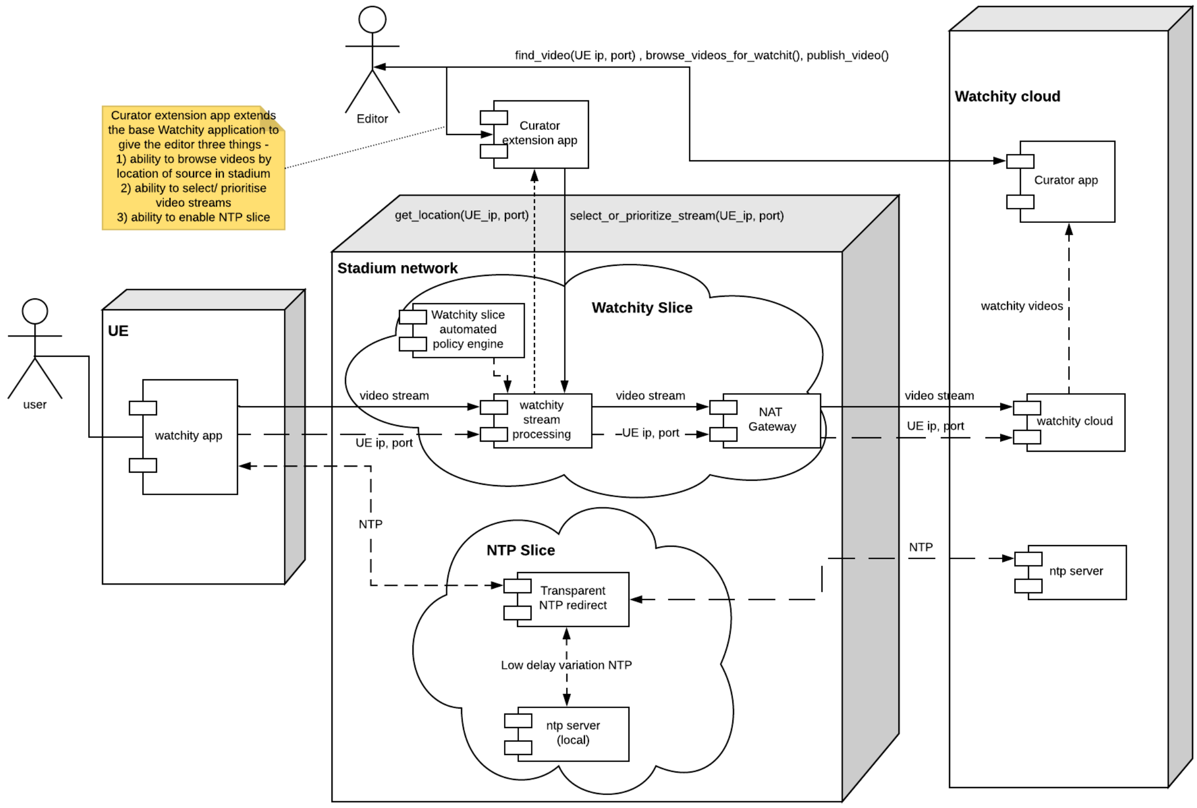


Figure 5-1: Component and Deployment view of the Use-cases.

1) <u>Application as it is over stadium network (base line - no slicing, no QoS)</u>
   a. Application is run over the current stadium network.
   b. Base line results collected (including Quality of Experience) including for the Wifi access network.

   KPIs to be measured: delay (per client & medium), jitter (per client & medium), bandwidth consumption (individual per client/ aggregated on server), packet loss (on server, per incoming stream), frame loss (on server, per incoming stream), stream synchronisation (on server, per incoming stream).

Objective: To provide the ground truth of the system. This use case will help us to define a basic starting point that represents how Watchity application performs in current networks.

Expected results: similar delay, jitter, packet & frame loss in each client. Small desynchronisation.

2) Application as it is over 5G network in stadium (only QoS + Slicing for video)
   a. Application traffic emulation over a Massive MIMO access network.
   b. Application is run over a 5G network in the stadium within its own slice optimised for video traffic.
   c. Results are collected and compared with the base line.

KPIs to be measured: delay (per client & medium), jitter (per client & medium), packet loss (on server, per incoming stream), frame loss (on server, per incoming stream), stream synchronisation (on server, per incoming stream).

Objective: Evaluate the improvement in quality of service and synchronisation thanks to the use of 5G slicing.

Expected results compared with firs case: delay reduction, jitter reduction, packet & frame loss reduction. Minor synchronisation improvement expected.

3) Interaction between application and network (e.g. IP address from device present in editor view - simple API not real application development – allow application streams to be localised and selected – via AP information)
   a. Network is aware of the application and provides location information based on wireless access points the client is connected to – so that streams can be localised and selected or deselected depending on location of the handset in the stadium.
   b. Editor can prioritize streams coming from specific sections of the stadium.
   c. Using the user equipment IP address the network can be programmed to drop streams not selected by the editor, ensuring available capacity for streams of interest.
   d. Results for Quality of Experience and network utilisation are collected.

KPIs to be measured: delay (per client & medium), jitter (per client & medium), bandwidth consumption (individual per client/ aggregated on server), packet loss (on server, per incoming stream), frame loss (on server, per incoming stream), stream synchronisation (on server, per incoming stream).

Objective: Evaluate if and to what extend image quality improves applying stream prioritisation and bandwidth allocation.

Expected results: Higher bandwidth consumption and better image subjective quality. For the rest of parameters only minor improvements.

4) Application requests dedicated NTP slice to improve synchronisation
   a. Timing and synchronisation are an important aspect of transmitting video streams and there is an existing problem with NTP reliability, this can be improved by putting NTP in its own slice with strict QoS.
   b. Results for Quality of Experience are collected.

KPIs to be measured: Stream synchronisation.

Objective: Evaluate the synchronisation improvement thanks to the use of NTP slice.

Expected results: a fine-grained synchronisation is achieved, relevant improvement if compared with all 3 previous tests.

5) Stretch Goal: Automatic function and network management on behalf of the application: where the application delegates function of filtering streams to the network via IP address of the stream source.

KPIs to be measured: delay (per client & medium), jitter (per client & medium), bandwidth consumption (individual per client/ aggregated on server), packet loss (on server, per incoming stream), frame loss (on server, per incoming stream), stream synchronisation (on server, per incoming stream).

Objective: Depending on the functions incorporated to the network testbed, evaluate improvement on the different QoS and QoE parameters.

Expected results: no improvements expected in comparison with cases 2, 3, and 4, only with case 1. Even worst performance depending on the deployment scenario selected and network functions deployed.

5.3.1.1 NTP Service

The NTP service will be used to demonstrate 'time as service' for the network slice, which is required by the Crowdsourced Video application. There are several options for implementing this:

1) As a VNF dependent on the application – implemented using PNF functions e.g. OpenFlow rule-based header rewrites.
2) As a VNF independent of the application – pure service with application configuration-based setup.
3) As a PNF using physical clock source (e.g. via GPS).

The plan is to experiment using option 1 to start with, as that requires the least amount of work in terms of application changes (compared to option 2 and 3). As application changes are outside the scope of the project, we want to minimise effort spent on it.

5.4 Current Infrastructure Description

5.4.1 I2Cat Wireless Testbed

I2CAT will provide for the stadium scenario WiFi Small Cells with joint access and BH capabilities, for which various components are being developed in WP3 and WP4. The left part of Figure 5-2 depicts an example use case, where WiFi Small Cells are deployed in an outdoor area mounted on lamp-posts, and various slices composed of a set of dynamically instantiated virtual Access Points delivering a specific connectivity service. This functionality is considered for various applications in a stadium scenario, such as providing connectivity services in the Fan Zone. In the right part of Figure 5-2 we illustrate the software architecture of the WiFi controller that will be integrated with the overall 5G OS to orchestrate the various services deployed in the stadium.

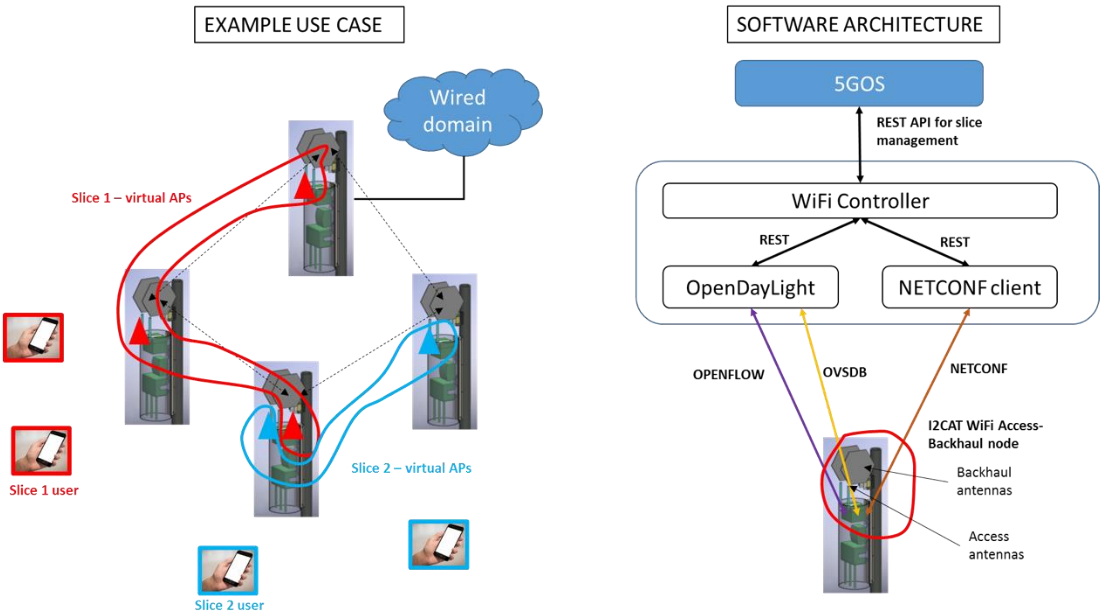


Figure 5-2. Joint Access+BH WiFi use case and architecture.

5.4.2 Stadium Testbed Deployment

The Ashton Gate Stadium in Bristol has a fixed as well as a wireless network currently installed. The fixed network consists of 75 OpenFlow switches from two different vendors. The wireless infrastructure consists of 150 WiFi access points also from two different vendors. These allow the access network to be sliced based on SSIDs.

5.4.2.1 Stadium Layout and Infrastructure Details

In Figure 5-3 the Stadium's ground level can be seen. Also indicated are the available connectivity (switches) and power supply.

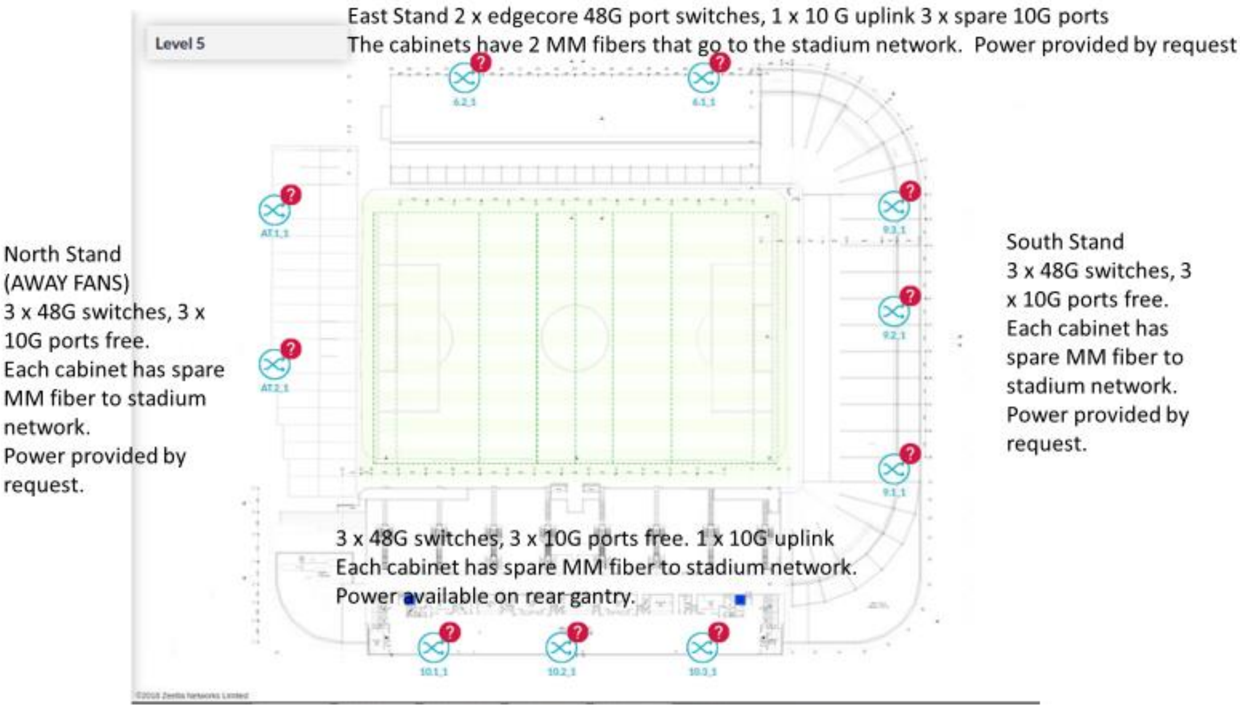


Figure 5-3: Stadium floorplan (Level 1 only) with Switches.

Figure 5-4: Fan Zone area.

Each Switch is mounted in a small cabinet with spare fibre and spare ports on the switch. Access points are mounted on the roof overhang in the bowl or along the walls in the concourse and cabled back to the switches. Power is provided via a new spur to the closest distribution board. The stadium core is 15 cabinets with OpenFlow switches connected hub and spoke at 10G or 20G (except the North Stand, which runs at 1G).

Apart from this, there are several Intel NUCs and Dell servers available for running applications locally.

There is also space available just outside the main stadium, called the Fan Zone, where additional screens and visitor facilities are provided during match days.

In addition to this i2Cat will provide five integrated WiFi Access Point and Backhaul nodes to be deployed at the Stadium. Each i2Cat Access Point can cover an area of radius 200 m, which may be reduced by reducing the power level of the Access Points.

5.4.2.2 Deployment

The plan is to use the concourse on the ground level (depicted in Figure 5-5) for all demonstrations as it provides easy access to connectivity and power supply as well as has enough room to deploy any equipment.

Figure 5-5: Concourse area with power (left) and existing WiFi AP (right).

Apart from the existing infrastructure, at least one WiFi access point and backhaul device will be deployed by i2Cat in the concourse area. It is planned to provide dual connectivity to these WiFi access points (via existing fixed infrastructure at the stadium). This will allow Service resilience scenarios to be demonstrated by disrupting one of the links to the access points.

The massive MIMO demonstrator will be setup here as well.

The remaining i2Cat devices will be deployed at the Fan Zone to provide additional wireless access coverage.

The two locations will also be used to test the Watchity app and show application aware network and programmable network concepts.

Alternative option if the concourse is not suitable for i2Cat WiFi APs is to restrict them to the Fan Zone and provide either wired or wireless (backhaul) connectivity between the Stadium's WiFi APs (only inside the stadium) and i2Cat Wifi APs.(only outside the stadium).

5.4.3 Massive MIMO Testbed Deployment

The Massive MIMO testbed, depicted in Figure 5-6, comprises of a base station (BS) and up to 24 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 can serve, simultaneously: a) up to 24 users with single antenna from 12 USRPs, or b) up to 12 users with two antennas, 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.

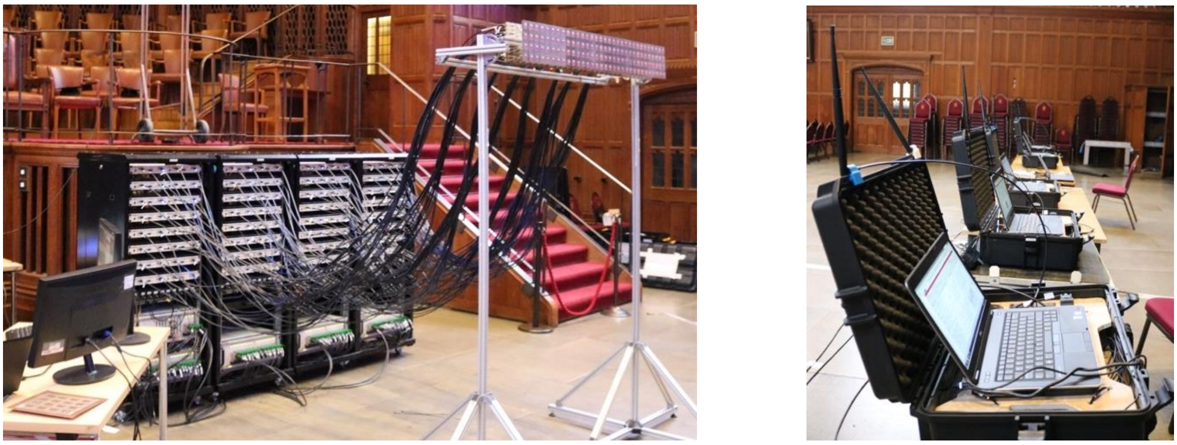


Figure 5-6: Massive MIMO Testbed: (left) Base station end, (right) Users end.

The main aim of the demo is to demonstrate the superiority, in terms of bandwidth and spectral efficiency of a Massive MIMO deployment, with the least possible latency. Two scenarios/deployments are considered.

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 5-7, with users employed on the opposite side. Next, following a distributed Massive MIMO approach, 2 racks will be placed into area L1 and 2 racks into L2. In this case, users will be distributed in between the two areas.

Figure 5-7. Scenario 1: West End Indoors Scenario.

Scenario 2: Stadium Bowl Outdoors

In the outdoors scenario, we are planning to first deploy the 4-racks BS on one balcony (A1 or A2 in Figure 5-8), with users employed on the opposite side. In the second phase, 2 racks will be deployed on A1 and two on A2, in order to deploy a distributed Massive MIMO configuration. Users will be distributed in the seats in between the two balconies.

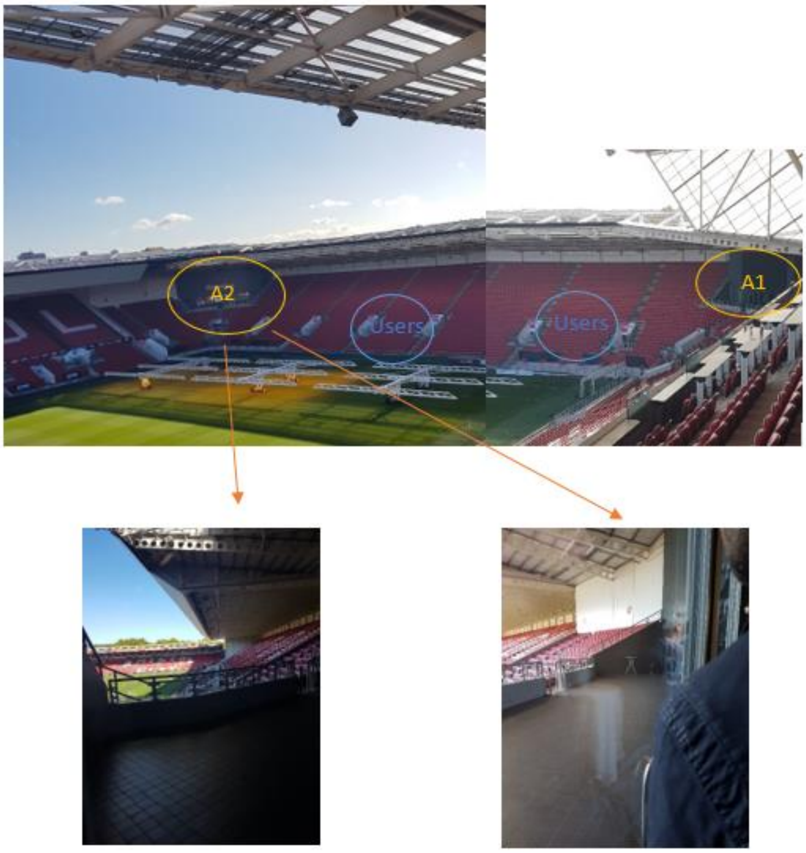


Figure 5-8. Scenario 2: Stadium Bowl Outdoors Scenario.

5.5 Demo and Experiment Scenarios Description

5.5.1 Massive MIMO Testbed Demo

The Massive MIMO Demo will be separate from the main Stadium demo. The expected outcomes are to demonstrate the superiority of a Massive MIMO deployment, compared to Wi-Fi, in terms of bandwidth and spectral efficiency, maintaining latency at the lowest possible levels. The main idea is to have the central BS mounted at the most appropriate place and several distributed users around the stadium.

As for the nature of the demo, in both scenarios, users will upload video streams, i.e. raw UDP streams, to the BS through wireless access. Results will be compared to the results of a similar architecture with Wi-Fi access, as Wi-Fi APs are already installed in the areas considered as our two proposed scenarios. A possible way of running the demo would be to start with one user in the uplink and follow on with adding more users in the network, to examine the aggregate bandwidth, as well as throughput and spectral efficiency.

5.5.2 Stadium Testbed Setup

5.5.2.1 Software and Interfaces

Figure 5-9 shows the different software components, networks and interfaces between them. Network slicing will be the responsibility of the NetOS Orchestrator. This communicates with three different controllers that look after different networks over the 5G OS DC-DO interface. The three different controllers in turn communicate with other controllers via DC-DC interface.

The NetOS Controller is responsible for the existing stadium network which includes OpenFlow Switches and WiFi APs and it provides a REST-based NBI.

The i2Cat WiFi Access Controller is responsible for the i2Cat WiFi Access Points and it provides a REST-based NBI.

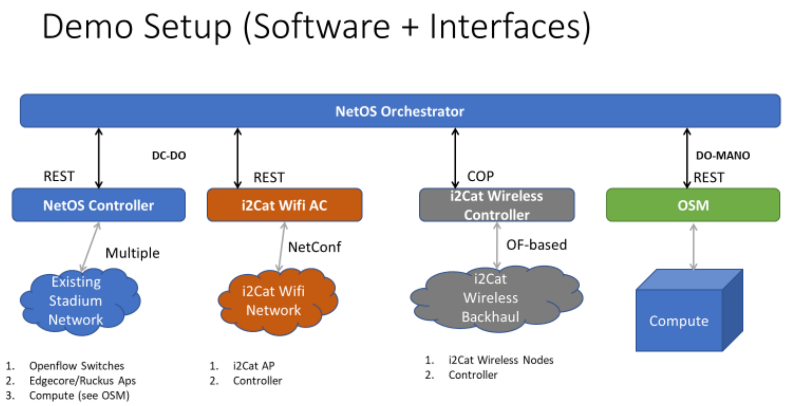


Figure 5-9: Software and Interfaces for the Stadium Demo.

The i2Cat Wireless Controller is responsible for the i2Cat Wireless BH nodes and it provides a COP [10] NBI for configuring Wireless BH Links.

In addition, the NetOS Orchestrator also communicates with a Compute provider (in this instance OSM) via the 5GOS DO-MANO interface to provision services using local compute. There are also some other compute alternatives to OSM being looked at that provide the ability to deploy functions on demand such as Apache OpenWhisk (FaaS). This is being done to align with with the 5G-PPP Software Networks WG.

5.5.2.2 Control and Data Plane Setup for the Demo

Figure 5-10 illustrates the planned control plane for the demo at the stadium. The existing Stadium network will be used to provide connectivity between the controllers and the devices.

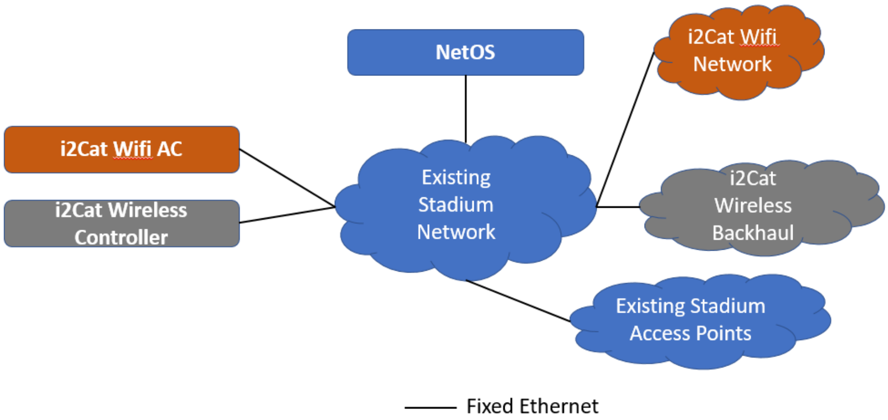


Figure 5-10: Control Plane for the Demo.

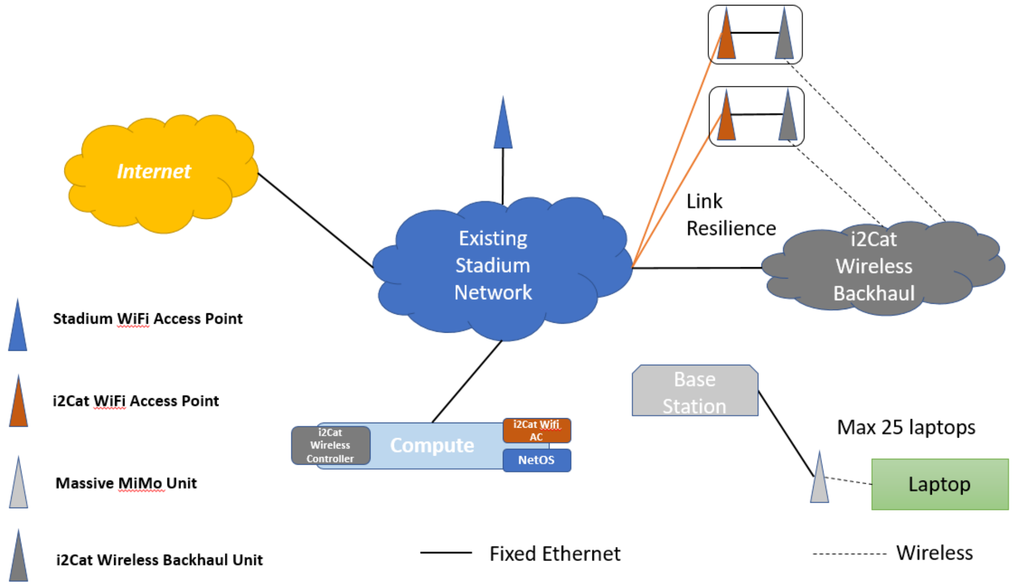


Figure 5-11: Data Plane for the Demo.

Figure 5-11 shows the Data plane for the demo. The existing stadium network will provide the aggregation capability for all Internet traffic as well as between the existing WiFi network and the i2Cat installed WiFi network. It is planned that at least one i2Cat node will be placed in the concourse and dual connected to the existing stadium network via fixed (orange links) and wireless backhaul to demonstrate Service resilience. The wireless backhaul will also connect the i2Cat access points in the Fan Zone to the rest of the network.

The existing stadium network will also provide connectivity to the compute infrastructure.

Another thing to note is the Massive MIMO base-station, which will be deployed at the stadium to compare the access network with existing WiFi solution. The Massive MIMO base-station can work with up to 25 laptops and requires considerable space and access to power. Therefore, the plan is to deploy it in the concourse.

The Massive MIMO and i2Cat WiFi/BH links this demo with Work Package 3 (Data Plane Programmability and Infrastructure Components) of the project. The i2Cat functions for wireless backhaul and WiFi link this demo with Work Package 4 (Physical and Virtual Programmable Functions) of the project – by providing functions that enable connectivity and wireless access point virtualisation over their nodes.

5.5.2.3 Component and Partner Responsibilities

This section provides an overview of components and responsible partners.

Table 5-1 provides a high-level project plan for the demo.

Table 5-2 provides the list of components and responsibilities of the partners.

Table 5-3 provides corresponding Gantt chart.

Table 5-1: Project Plan for Stadium Demo (Zeetta and i2CAT).

		Name	Duration	Start	Finish	
1		5G Picture - Demo Project plan	349 days	01/11/18 08:00	03/03/20 17:00	
2		**1. Detailed Implementation plan and test plan for demos: Dec 18**	**46 days**	**02/11/18 08:00**	**04/01/19 17:00**	
3		Obtain inputs from Partners	8 days	02/11/18 08:00	13/11/18 17:00	
4		Capture Requirements (hardware and Technical)	5 days	14/11/18 08:00	20/11/18 17:00	3
5		Create Project Plan	2 days	21/11/18 08:00	22/11/18 17:00	4
6		Review Project Plan	13 days	23/11/18 08:00	11/12/18 17:00	5
7		Approve Project plan	9 days	12/12/18 08:00	24/12/18 17:00	6
8		Milestone 1	0 days	04/01/19 17:00	04/01/19 17:00	7
9		**2. ZN Internal Lab build**	**110 days**	**02/01/19 08:00**	**04/06/19 17:00**	
10		Obtain Hardware (various sources)	42 days	02/01/19 08:00	28/02/19 17:00	
11		Finalise Experiments for the lab	10 days	01/03/19 08:00	14/03/19 17:00	10
12		Capture and match hardware (switches) models/firmware as per the stadium	11 days	15/03/19 08:00	29/03/19 17:00	11
13		High level Lab design	4 days	01/04/19 08:00	04/04/19 17:00	12
14		Deploy hardware	32 days	05/04/19 08:00	20/05/19 17:00	13
15		Deploy Software	4 days	21/05/19 08:00	24/05/19 17:00	14
16		Capture Configuration (software/Hardware)	6 days	27/05/19 08:00	03/06/19 17:00	15
17		Sign of lab build	1 day	04/06/19 08:00	04/06/19 17:00	16
18		Milestone 2	0 days	04/06/19 17:00	04/06/19 17:00	17
19		**3. Integration Testing and Experimentation in Lab without Watchity**	**63 days**	**05/06/19 08:00**	**30/08/19 17:00**	
20		Testing of indivudual Scenario's	16 days	05/06/19 08:00	26/06/19 17:00	
21		Testing Integration	15 days	27/06/19 08:00	17/07/19 17:00	20
22		RunningExperiments	25 days	18/07/19 08:00	21/08/19 17:00	21
23		Collection of Results	1 day	22/08/19 08:00	22/08/19 17:00	22
24		Collation of Results	3 days	23/08/19 08:00	27/08/19 17:00	23
25		Publish Results	1 day	28/08/19 08:00	28/08/19 17:00	24
26		Sign off Integration Testing in lab without Watchity	1 day	29/08/19 08:00	29/08/19 17:00	25
27		Milestone 3	1 day	30/08/19 08:00	30/08/19 17:00	26
28		**4. Integration Test and Demo validation in Lab with Watchity**	**44 days**	**02/09/19 08:00**	**31/10/19 17:00**	
29		Integration of App	5 days	02/09/19 08:00	06/09/19 17:00	
30		Testing of indivudual Scenario's	7 days	09/09/19 08:00	17/09/19 17:00	29
31		Testing Integration	7 days	18/09/19 08:00	26/09/19 17:00	30
32		RunningExperiments	15 days	27/09/19 08:00	17/10/19 17:00	31
33		Collection of Results	1 day	18/10/19 08:00	18/10/19 17:00	32
34		Collation of Results	3 days	21/10/19 08:00	23/10/19 17:00	33
35		Publish results	1 day	24/10/19 08:00	24/10/19 17:00	34
36		Sign off Integration Testing in lab with Watchity	1 day	25/10/19 08:00	25/10/19 17:00	35
37		Milestone 4	4 days	28/10/19 08:00	31/10/19 17:00	36
38		**5. Initial Stadium Integration Testing without Watchity**	**38 days**	**01/11/19 08:00**	**24/12/19 17:00**	
39		Deploy Hardware	15 days	01/11/19 08:00	21/11/19 17:00	
40		Deploy Software	15 days	01/11/19 08:00	21/11/19 17:00	
41		Test Integration	4 days	22/11/19 08:00	27/11/19 17:00	40
42		Run Experiments	15 days	28/11/19 08:00	18/12/19 17:00	41
43		Collection of Results	1 day	19/12/19 08:00	19/12/19 17:00	42
44		Collation of Results	2 days	20/12/19 08:00	23/12/19 17:00	43
45		Publish Results	1 day	01/11/19 08:00	01/11/19 17:00	
46		Sign off Stadium Integration without Watchity	1 day	23/12/19 08:00	23/12/19 17:00	45
47		Milestone 5	1 day	24/12/19 08:00	24/12/19 17:00	46
48		**6. Demo Validation at Stadium with Watchity**	**22 days**	**02/01/20 08:00**	**31/01/20 17:00**	
49		Deploy Watchity App	2 days	02/01/20 08:00	03/01/20 17:00	
50		Test Integration	2 days	06/01/20 08:00	07/01/20 17:00	49
51		Run Experiments	9 days	08/01/20 08:00	20/01/20 17:00	50
52		Contingency (for multiple iteration of fixes and running experiments	4 days	21/01/20 08:00	24/01/20 17:00	51
53		Collection of Results	1 day	27/01/20 08:00	27/01/20 17:00	52
54		Collation of results	2 days	28/01/20 08:00	29/01/20 17:00	53
55		Sign off Demo Validation	1 day	30/01/20 08:00	30/01/20 17:00	54
56		Milestone 6	1 day	31/01/20 08:00	31/01/20 17:00	55
57			1 day?	29/10/18 08:00	29/10/18 17:00	
58		**7. Final Demo at Stadium**	**20 days**	**03/02/20 08:00**	**28/02/20 17:00**	
59		Demo Preparations (walk Through)	5 days	03/02/20 08:00	07/02/20 17:00	
60		Demo's	10 days	10/02/20 08:00	21/02/20 17:00	59
61		Removal of Hardware from Stadium	5 days	24/02/20 08:00	28/02/20 17:00	60
62		Feedback from partners	10 days	03/02/20 08:00	14/02/20 17:00	
63		Produce Final Report	2 days	17/02/20 08:00	18/02/20 17:00	62
64		Produce Lessons learnt Document	2 days	19/02/20 08:00	20/02/20 17:00	63
65		Project Closure	1 day	21/02/20 08:00	21/02/20 17:00	64

Table 5-2: Component and partner responsibilities.

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

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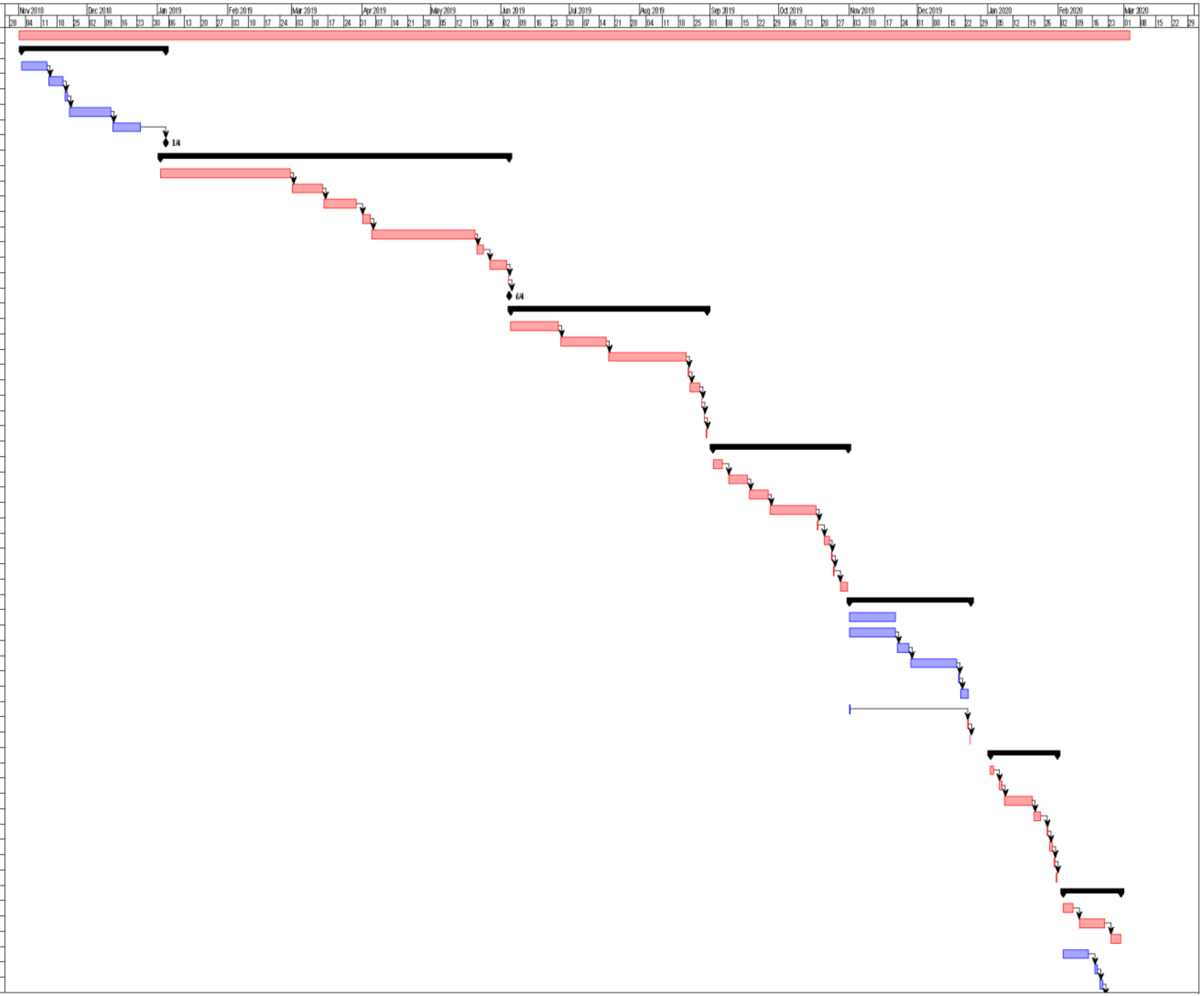
Table 5-3: Gantt chart for the Stadium demo.

	Name
1	5G Picture - Demo Project plan
2	**1. Detailed Implementation plan and test plan for demos: Dec 18**
3	Obtain inputs from Partners
4	Capture Requirements (hardware and Technical)
5	Create Project Plan
6	Review Project Plan
7	Approve Project plan
8	Milestone 1
9	**2. ZN Internal Lab build**
10	Obtain Hardware (various sources)
11	Finalise Experiments for the lab
12	Capture and match hardware (switches) models/firmware as per the stadium
13	High level Lab design
14	Deploy hardware
15	Deploy Software
16	Capture Configuration (software/Hardware)
17	Sign of lab build
18	Milestone 2
19	**3. Integration Testing and Experimentation in Lab without Watchity**
20	Testing of indivudual Scenario's
21	Testing Integration
22	Running Experiments
23	Collection of Results
24	Collation of Results
25	Publish Results
26	Sign off Integration Testing in lab without Watchity
27	Milestone 3
28	**4. Integration Test and Demo validation in Lab with Watchity**
29	Integration of App
30	Testing of indivudual Scenario's
31	Testing Integration
32	Running Experiments
33	Collection of Results
34	Collation of Results
35	Publish results
36	Sign off Integration Testing in lab with Watchity
37	Milestone 4
38	**5. Initial Stadium Integration Testing without Watchity**
39	Deploy Hardware
40	Deploy Software
41	Test Integration
42	Run Experiments
43	Collection of Results
44	Collation of Results
45	Publish Results
46	Sign off Stadium Integration without Watchity
47	Milestone 5
48	**6. Demo Validation at Stadium with Watchity**
49	Deploy Watchity App
50	Test Integration
51	Run Experiments
52	Contingency (for multiple iteration of fixes and running experiments
53	Collection of Results
54	Collation of results
55	Sign off Demo Validation
56	Milestone 6
57	**7. Final Demo at Stadium**
58	Demo Preparations (walk Through)
59	Demo's
60	Removal of Hardware from Stadium
61	Feedback from partners
62	Produce Final Report
63	Produce Lessons learnt Document



5.6 Risks

Given the unique nature of the demo, which involves actual deployment at Ashton Gate Stadium, there are risks associated with it that are not insignificant. In this section we aim to list the more critical ones along with what is being done to minimise them.

1) Massive MIMO Effort Required by University of Bristol CSN – the partner deploying Massive MIMO require additional 4 PM in Work Package 6 to enable them to do the demo.
   Resolution Effort: Evaluating different sources of funding within the Project and partner organisation.

2) Explicit authorisation required from Ashton Gate
   Resolution Effort: This is work in progress. Currently Zeetta have a software and services contract with the Stadium and have discussed the project demonstrations in that context. But there is no explicit authorisation from the Stadium. As the demo scenarios are now finalised, we are in a good position to start the process to obtain explicit authorisation.

3) Facility Availability and Deployment Permissions – Ashton Gate Stadium is an active use facility. The demo is scheduled during the main sports season (February 2020). There are risks associated with availability of the required physical infrastructure. The demo network will need to be logically isolated from the Stadium network. All installation of new equipment will require Risk Assessment to be provided in advance and Stadium authorised contractors may have to be used.
   Resolution Effort: Ongoing discussions with the Stadium to get early buy-in and a clearer idea of available support, worst case the Stadium will have to be hired as a venue for the demo. Early site survey has also been carried out to ensure logistic feasibility. Book 'public' spaces to avoid access issues.

6 Summary and Conclusions

In this deliverable, the specification and planning of the demonstration activities of 5G-PICTURE are presented. More specifically, the description of the available infrastructure and plans for the deployment of the new developed functionality and the test scenarios have been provided for all 4 major demos.

First, in the NITOS testbed demos related to dynamically orchestrated VNF implementations of different functional splits have been presented with specific topology configurations and a variety of wireless technologies namely WiFi and mmWave. Second, a smart city demonstrator has been described in the 5GUK testbed in Bristol, where demonstrations related to converged fronthaul and backhaul demo as well as public safety and VR applications will be demonstrated over a variety of both optical and wireless transport technologies as well as computing facilities. Third, the Rail demo use case has been specified to be deployed in the rail infrastructure available by FGC in Barcelona where scenarios related to mobility and mmWave technologies have been specified while Passive Optical Network technologies will be utilised for the fixed network part. Finally, in the Stadium use case demo, a crowdsource media application will be used and 5G-PICTURE Orchestration and Control functionality will be showcased utilising slicing over a variety of wireless access and transport wireless networks.

7 References

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8 Acronyms

Acronym	Description
5G OS	5G Operating System
AP	Access Point
BH	Backhaul
BDT	Bounded Delay Transport
CU	Central Unit
DC	Datacentre
DU	Distributed Unit
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
PNF	Physical Network Function
PON	Passive Optical Network
PTMP	Point-to-Multi-Point
OSM	Open Source Mano
QoS	Quality of Service
RAN	Radio Access Network
SDN	Software-Defined Networking
SLA	Service-Level Agreement
SM	Statistical Multiplexing
S/P-GW	Serving/PDU Gateway
TSON	Time-Shared Optical Network
TAN	Train Access Network
TCN	Train Communications 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