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Abstract

The present document focuses on a description of the different Proof-of-Concept (PoC) scenarios and their relationships with the use cases developed in WP2 and the features defined in WP3/WP4.

Keywords

Testbed, Proof-of-Concept, eMBB, URLLC, mMTC, Use case, PoC components

[1] CO = Confidential, only members of the consortium (including the Commission Services)

PU = Public

Executive Summary

This report contains the collection of the different Proof-of-Concepts (PoC) as well as the relations with other WPs for the ONE5G (E2E-aware Optimizations and advancements for the Network Edge of 5G New Radio) project.

ONE5G aims at researching advanced link enhancements beyond Release 15, moving 5G to "5G advanced", and developing performance optimization schemes for 5G, to achieve successful deployment and operation, including optimizations for both the network operator and the E2E user-experience performance

The purpose of this report is to define five PoC scenarios and which testbeds will be used, to specify the core ONE5G features to be validated in each PoC and to identify the research inputs coming from WP2, WP3 and WP4. These research inputs are the use cases related to the PoC, in the case of WP2, and the technical components in WP3 and WP4.

First, a brief introduction is presented, in which the different testbeds are summarised reviewing their main attributes. Afterwards, each PoC is described in detail through its corresponding storyline, the related WP2 use cases and the technical components involved in WP3/WP4. Finally, in the annex, the testbeds are described in detail.

The following deliverables will provide additional details about the implementation and integration of PoC components into the PoC (IR5.1 and D5.2).

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List of Acronyms and Abbreviations

Term	Description
3GPP	3rd Generation Partnership Project
APP	Application
AR	Augmented Reality
CE	Computation Engines
CIC	Cascaded integrator-comb
CRAN	Centralized RAN
D2D	Device-to-device
DL	Downlink
DRX	Discontinuous reception
E2E	End-to-end
EC	European Commission
eCNS	Evolved Core Network Solution
eMBB	enhanced Mobile Broadband
eNB	evolved Node B
EPC	Evolved Packet Core
FDD	Frequency División Duplexing
FFT	Fast Fourier Transform
FIFO	First in, first out
FIR	Finite Impulse Response
FPGA	Field Programmable Gate Array
H2020	Horizon 2020
HARQ	Hybrid automatic repeat request
HSS	Home Subscriber Server
ICT	Information and Communication Technologies
IoT	Internet of things
IP	Internet Protocol
IRC	Interference Rejection Combining
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
MAC	Medium Access Control
MCS	Modulation and coding schemes
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications

MR	Mixed reality
MR	Mixed Reality
MRC	Maximum Ratio Combining
OAI	OpenAirInterface
OBU	Control onboard Unit
PCRF	Policy and Charging Rules Function
PGW	Packet Gateway
PHY	Physical
PoC	Proof-of-Concept
PXIe	PCI Express Extensions for Instrumentation
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Block
REST	Representational State Transfer
RF	Radio Frequency
RFID	Radio Frequency Identification
RFNoC	RF Network on Chip
RIO	Reconfigurable I/O
RRM	Radio Resource Management
RSRP	Reference Signal Receive Power
RSSI	Received Signal Strength Indicator
SDR	Software Defined Radio
SGW	Serving Gateway
SIC	Successive Interference Cancellation
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
SON	Self-Organizing Network
TCP	Transmission Control Protocol
ToD	Tele-operated Driving
UE	User Equipment
UL	Uplink
URLCC	Ultra-Low Latency Communications
USRP	Universal Software Radio Peripheral
V2X	Vehicle-to-everything
VHDL	VHSIC Hardware Description Language
VR	Virtual Reality
XML	eXtensible Markup Language

1 Introduction

This is the first public deliverable from Work Package 5 (WP5) of the ONE5G project, where descriptions of the different Proof-of-Concept (PoC) scenarios are provided. Each description is specified through the PoC relationship with the use cases developed in WP2 and the technical components that will be implemented in each PoC defined in WP3 and WP4.

1.1 Objective of the document

The main objective of the present document is to provide a description of the different PoCs that have been defined during Task 5.1. This objective can be divided into some specific goals:

- To provide an understanding of the different PoCs to be developed in the project through a description of each PoC and its constituent testbeds, and a storyline picturing representative applications that the PoC aims at illustrating. Each PoC will be related to one of the two scenarios, Megacities or Underserved Areas [D21], to one or several verticals and to one or several service categories; enhanced Mobile Broadband (eMBB), Ultra-Reliable and Ultra-Low Latency Communications (URLLC), massive Machine Type Communications (mMTC).
- To relate each of these PoCs with the corresponding use cases developed in WP2 and described in Deliverable D2.1, and their main KPIs.
- To provide a list of PoC components from WP3 and WP4 to be integrated and evaluated in the PoC.

This document will serve as a baseline, providing valuable outputs for the next step, the implementation of the enabling technologies and optimization techniques, proposed and designed in WP3 and WP4, in order to serve as PoC components for the realization of the PoC scenarios (T5.2).

1.2 Structure of the document

This document is organised into five sections, one per each PoC. Each section is structured as follows:

- **Storyline**. Brief non-technical story about the potential applications that the PoC could demonstrate. The narration is based on the verticals and use cases related to the PoC.
- **Description**. Summary of the PoC including objectives, constituent testbeds and technical information (e.g. hardware and software components).
- **Related WP2 use cases**. List of the verticals and use cases related to the PoC.
- **KPIs specification aligned with WP2.** Two lists, one including the features and capabilities that the different testbeds support and another with the statistics that are important for the demonstration of the specific PoC.
- **List of PoC components**. List of WP3/WP4 features to be deployed into the PoC. These lists include the technical components to implement in the PoC; the originating task and sub-topic; the technical stream with which it is related the technical component and finally, the testbed where it will be implemented. The term "technical stream" refers to the one of the five technical streams identified during project preparation and adopted by the project, namely: 1) Future proof multi-service access solutions; 2) Massive MIMO enablers; 3) Advanced link management based on multi-cell processing; 4) Optimized multi-link management for improved E2E performance; and 5) Network and user-experienced E2E performance optimization and context awareness.

1.3 Testbeds overview

A brief description of the different testbeds is provided in the following sections. This information is presented in more detail in ANNEX: DETAILED TESTBEDS DESCRIPTION.

1.3.1 Multi-link/multi-node and C-RAN testbed (AAU)

This testbed offers a total of 48 antenna ports which can be grouped or distributed according to the specific application with a minimum granularity of a 2x2 unit. An indicative setup includes 6 access points which are distributed in a certain area and serve 6 user equipment. Each node in the network is composed of a host PC connected with 2 USRP RIO boards (4x4 MIMO configuration). The architecture can be centralized (i.e., a central controller for the access points) or distributed (each access point operates autonomously or coordinates its operations with the other access points). The testbed comprises 24 SDR USRPs, a PXIe-8135 controller, 3 Octoclocks for timing distribution, 17 PCs and a WiFi/Ethernet backhaul network.

Scenario	Megacities
Services	URLLC, eMBB
Capabilities	
PHY implementations	Yes (MIMO transmission and reception of reference sequences)
MAC implementations	They can be emulated
RRM implementations	Yes
e2e optimization implementations	No
Measurement collection	Yes: from layers: PHY
Real-time execution support	No
Interfaces supported	TBD: based on the needs

Table 1 Multi-link/multi-node and C-RAN testbed overview

1.3.2 MIMO Multi-RAT /multi-band (B-COM)

This platform is suited for Megacities scenarios and is based on a custom MIMO Multi-RAT platform composed of 2 boards:

- One RF board supporting the use of multiple bands allowing to perform band aggregation (in both licensed and unlicensed spectrum) with 2x2 full duplex MIMO.
- One digital board with 2 powerful FPGAs, high speed analog-to-digital and digital-to-analog converters, 4GBytes DDR3, and high-speed links (optical link, Ethernet …). On this board baseband algorithms for the PHY layer written in (V)HDL language (or C language if CPU implemented) can be integrated.

The MIMO Multi-RAT platform can be interfaced with other simulators by using the adequate link connection.

Scenario	Megacities
Services	eMBB
Capabilities	

PHY implementations	Yes: using FPGA implementation
MAC implementations	Yes: using OAI (OpenAirInterface)
RRM implementations	Yes : using OAI
e2e optimization implementations	No
Measurement collection	Yes: from layers: PHY, IP, APP
Real-time execution support	Yes
Interfaces supported	Giga Ethernet

Table 2 MIMO Multi-RAT and multi-band testbed overview

1.3.3 Flexible and reconfigurable HW/SW testbed (B-COM)

This platform is more specific to the Underserved Area scenario since it is less data rate constrained. This platform is composed of several ETTUS X310 USRP integrating the RF part (dedicated board with specific frequency carrier and bandwidth; typically, frequency carriers below 4.4 GHz and bandwidth up to 120 MHz are possible in our case). This selected USRP integrates an FPGA where processing can be performed just behind the RF front-end (typically filtering, impairments correction, service/channel detection, system configurability). This USRP uses an Ethernet link for communicating with some tools and/or higher layers and/or core network. Typically, the OpenAirInterface software will be interfaced with this platform.

Scenario	Underserved area
Services	mMTC
Capabilities	
PHY implementations	Yes: using FPGA implementation and/or software
MAC implementations	Yes: using OAI
RRM implementations	Yes : using OAI
e2e optimization implementations	Yes: Using OAI
Measurement collection	Yes: from layers: PHY, IP, APP
Real-time execution support	Yes
Interfaces supported	Ethernet – PCIe

Table 3 Reconfigurable HW/SW testbed overview

1.3.4 Flexible Massive MIMO testbed (HHI)

This testbed comprises 2 massive MIMO cells at 3.5-3.7 GHz in the 5G Berlin Testbed environment, with more than 64 antenna elements connected to a workstation server using 10 Gb. It includes 6 live UEs, while additional UEs can be emulated in software by using stored measurement trial data. A workstation/cloud server is used in order to change the configuration of the SDR platform, while PHY-MAC-layer processing is done in Matlab/Mex. In addition, multiple antenna arrays can be connected to the same workstation in centralized RAN fashion.

Scenario	Megacities
Services	eMBB
Capabilities	
PHY implementations	Yes: offline in Matlab
MAC implementations	Possible: it has to be provided by partner
RRM implementations	Possible it has to be provided by partner
e2e optimization implementations	No
Measurement collection	Yes: Channel coefficients, IQ-samples
Real-time execution support	No
Interfaces supported	Matlab - Quadriga channel Open source implementation in MATLAB available at: http://quadriga-channel-model.de/ Documentation on interface (data format) online available

Table 4 Flexible Massive MIMO testbed overview

1.3.5 5G URLLC V2X testbed (Huawei)

This testbed includes a software defined radio platform with flexible L1/L2 protocol stack as well as the emulated higher layers. The hardware consists of several small form factor UE platform PCs, USRPs and additional power amplifiers, aiming to support carrier frequency from 700MHz up to 3.6 GHz. The UE platform is scalable depending on the required data rate and limitation of the power consumption. On the cellular base station side, multiple antennas are employed. In addition, high precision positioning system will be included. The software implementation carries out 5G baseband processing supporting different numerologies, multiple antenna processing, retransmission mechanism, as well as basic traffic management/control.

Scenario	Megacities
Services	URLLC, limited support to eMBB
Capabilities	
PHY implementations	Yes: in C/C++ with SIMD optimization
MAC implementations	Yes: in C/C++
RRM implementations	Simple fixed resource sharing
e2e optimization implementations	MAC adaptation to Tele-operated driving (TOD) and cloud robot’s application traffic property
Measurement collection	Yes: from layers: PHY, IP.
Real-time execution support	Yes
Interfaces supported	IP data interface to application system

Table 5 5G URLLC V2X testbed overview

1.3.6 Full indoor commercial LTE network: UMAHETNET (UMA)

This testbed is a full indoor LTE network. It comprises 12 picocells, each including a WiFi access point and LTE/WiFi-capable cell phones. Regarding the EPC, the testbed is based on a Huawei solution for private networks, where all the core network elements (HSS, MME, SGW, P-GW and PCRF) are grouped into a single compact equipment, namely, the eCNS (evolved Core Network Solution). A 24-port GB switch is provided in order to interconnect all the elements, while both the picocells and the eCNS are fully configurable.

Scenario	Megacities
Services	eMBB
Capabilities	
PHY implementations	No, but configurable.
MAC implementations	No, but configurable.
RRM implementations	Yes, and also configurable.
e2e optimization implementations	Yes: RESTful API to access configuration parameters in LTE Network
Measurement collection	Yes: from layers: PHY, IP, APP, E2E
Real-time execution support	Yes
Interfaces supported	Restful

Table 6 Full indoor commercial LTE network overview

1.3.7 Smart-City Network (UMA)

This network (under procurement process at the moment) will be available in 2018. The system will be composed of several multi-technologies heterogeneous IoT devices deployed along the university campus implementing a Smart-City oriented area of approximately 2 Km^2. It will consist of an extensive variety and high number of MTC devices (sensors, cameras, phones, etc.) and actuators. It will also include their complete interconnecting network, with gateways, repeaters, servers and its management platform.

1.3.8 Platform for vertical service delivery through 5G – IoT and big data – technologies (WINGS)

This testbed comprises 6 USRPs based on OpenAirInterface framework and a Cloud based IoT platform which support network measurement collection, analysis, knowledge building, predictions generation based on stored knowledge and network optimization support. The testbed also includes different IoT devices: a) Arduino Uno with DHT11 Temperature and Humidity sensors, LDR Analogue Luminosity sensors, Motion detection sensors, LED actuators and buzzer, b) Libelium WaspMote with Libelium Temperature Sensors and LDR Analogue Luminosity sensors and c) SparkFun FIO board with DHT22 Temperature and Humidity sensors, LDR Analogue Luminosity sensors, LED actuators and buzzer.

Scenario	Megacities, undeserved areas
Services	mMTC, URLLC
Capabilities	

PHY implementations	No, but configurable.
MAC implementations	Yes: using OAI
RRM implementations	Yes: using OAI
e2e optimization implementations	Yes
Measurement collection	Yes: from layers: PHY, IP, APP, E2E
Real-time execution support	Yes
Interfaces supported	REST, Socket (C/C++, Java)

Table 7 Network optimisation and predictive analytics testbed overview

This has been a brief summary of the testbeds and their capabilities. The project PoCs, to be described in detail in the following chapters, will be built on the aforementioned 8 testbeds, by implementing and integrating selected technical components on them. Using these PoCs/testbeds, the main innovations of the project will be demonstrated and evaluated.

2 PoC#1: Cell-less Megacity Proof-of-Concept - Industrial areas with large factories.

This PoC targets industrial areas with large factories.

2.1 Storyline

Anne works as supervisor of an automotive industrial plant. When arriving to the factory, she picks one of the assistant tablets and a pair of augmented reality (AR) / virtual reality (VR) glasses. These glasses automatically connect to the cloud server and provide her with her personal graphical user interface and the set of applications she needs for today. All the processing and storing is done seamlessly in her company cloud, so she can take any equipment and it always provides her with her files and needed tools for the day.

Crossing the office on her way to the production area, the tablet shows her a summary of her pending emails and daily tasks. Her glasses also show her an AR visual indication of the colleagues around that are currently available and have pending questions to her, in case she might want to go talk to them directly. Before entering production, she stops for a moment and loads in her glasses a virtual reproduction of the new motor system that goes into production today. The 3D model appears to be really floating in front of her eyes and she can see, rotate and manipulate it in order to refresh her knowledge about the component.

After this, during her inspection, she routinely checks the production area of the factory plant, observing the coordinated work of the different robot arms of the assembly line. They all connect between them and with the central cloud by the distributed ultra-dense networks covering the whole factory. Every few meters there is a picocell, roughly similar to a ceiling lamp with respect to size and appearance, providing the high throughput required for the robots' coordination. This includes video recording of their activity for further image processing and monitoring at the cloud, which again is where most of the computation of the process is done. These communications are URLLC, so the different systems are kept at maximum efficiency and the security is guaranteed. Also, full encryption and authentication is performed in all communications to guarantee industry secrecy and avoid malicious hacking.

Also, the ambient sensors that keep track of the factory temperature, humidity and many other parameters make use of the same network. These monitoring applications fit into the mMTC category, implying less stringent requirements on latency and throughput. The network automatically and seamlessly manages how the communication resources are shared between the different terminals and needs, so the service is never degraded and each system has its specific requirements fulfilled.

Therefore, when she walks along the huge machines to check their work, Anne is confident that no robot arm would harm her and that the systems automatically coordinate to let her pass and check the different points of the assembly line. Her equipment keeps a seamless coverage and eMBB service throughout the process. Also, her glasses provide her with a complete augmented reality experience, where she can see superimposed the identification and details of all machines and elements in the production line. Any issue can be immediately identified and possible improvements to the production can be defined and applied in the spot. In this way, Anne is always sure of having smooth operation and full efficiency in the factory.

2.2 Description

The aim of this PoC is to test the E2E performance optimization techniques proposed in WP3 in combination with cell-less technologies proposed in WP4. The vertical scenario is assumed to be an industrial area with large factories.

Three testbeds will be used in this PoC: a) the multi-link/multi-node and CRAN (centralized RAN) testbed (AAU); b) Platform for vertical service delivery through 5G – IoT and big data - technologies (WINGS) and; c) Cloud Robot Testbed (Huawei). In testbed a), 48 antenna ports will be grouped or distributed according to the specific application. The equipment consists of 24 SDR (software defined radio) USRPs (universal software radio peripheral), a PXIe-8135 controller and 3 Octoclocks. The services involved in this testbed are URLLC and eMBB. In the testbed b), the system is composed by 6 USRPs based on OAI and a software platform which will support network measurement collection, analysis, knowledge building, predictions generation. Also, the system comprises a base station (OAI) and the evolved packet core (OAI). The services related to this testbed are URLLC and mMTC. In testbed c), the concept of cloud robot from HWDU is implemented for which the control algorithm of a robot performing challenge task is completely shifted to an independent cloud server behind the BS node. For supporting this, the URLLC connectivity is established with HWDU's 5G testbed with USRP and soft baseband and protocol.

A selected set of technologies and optimization algorithms based on CRAN approach will be implemented and integrated into the PoC. The PHY functionalities will be implemented by AAU, while the RRM (radio resource management) functionalities (centralized), MAC (medium access control) implementations (just emulated in the case b)) and measurement collection will be implemented by both AAU and WINGS. E2E (end-to-end) performance optimization functionalities will be performed by WINGS, as well as the real-time execution support. Concerning the interfaces supported in the testbed a) is a REST interface or socket (C/C++, Java) while in the testbed b) it is still under definition.

For the PoC of cloud robot, a light-weighted version of the Huawei's 5G prototype terminal will be integrated with a mobile robotic platform. The robot will perform a challenging task requiring low-latency sensing and movement reactions, for which the control algorithm is completely shifted to independent computer behind the BS node, which emulates the concept of cloud-controlled.

For all the scenarios, different receiver types will be considered at both UE/BS, e.g., maximum ratio combining (MRC), interference rejection combining (IRC) and successive interference cancellation (SIC). Every node in the testbed will be measuring KPIs such as SINR (signal to interference and noise), throughput, outage probability, and will report those to a remote server via a backhaul network. The server will also act as a testbed controller. The server will perform operations on the received data to obtain network-level KPIs, and display them over a graphical user interface (GUI).

2.3 Related WP2 use cases

- Main use cases:
  - Vertical: Factories, Transport and Logistics
    - Time-critical factory processes and logistics optimisation (industry and smart airports)
  - Vertical: Smart Cities and Energy
    - Non time-critical processes and logistics (factories and smart cities)
- Related use cases:
  - Vertical: Media, Entertainment and eOffice
    - Outdoor hotspots and smart offices with AR/VR and media applications

2.4 KPIs specification aligned with WP2

2.4.1 The multi-link/multi-node and CRAN (centralized RAN) testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the following use cases:

- Time-critical factory processes and logistics optimization
- Non time-critical processes and logistics (factories and smart cities)

Such use cases hold for both “Factories, transport and logistics” and “Smart cities and Energy” verticals.

Statistics (and KPIs) that the testbed supports

The testbed is able to perform instantaneous measurement of the complex channel frequency response between each receiver and all the transmitters. Given such measurements and a certain transmission/reception technique, it is possible to estimate:

- Received Signal Strength Indicator (RSSI)
- Reference Signal Receive Power (RSRP)
- Instantaneous SINR and average SINR (computed over a certain time window)
- Node PHY throughput (obtained by SINR to-throughput-mapping abstraction models, e.g. modified Shannon, AVI curves)
- Network PHY throughput (obtained as a sum of the throughputs of the nodes in the network)
- Reliability (measured as occurrences of SINR outage over time)

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- Experienced data rate: node PHY throughput (defined above)
- Area traffic capacity: network PHY throughput (defined above)
- User plane reliability: reliability (defined above)
- User plane E2E latency: PHY latency can be estimated from SINR (i.e. how many transmissions are needed to decode a packet given a certain SINR). E2E latency not directly measurable.
- Payload size: achievable supported packet size for a given bandwidth and reliability target

2.4.2 Platform for vertical service delivery through 5G – IoT and big data – technologies

Statistics (and KPIs) that the testbed supports

The testbed is based on the OpenAirInterface (OAI) framework, therefore all the statistics already available by OAI are supported in the testbed. In addition, some other higher layer KPIs are collected by the testbed as well.

- PHY layer statistics (for both eNB and UE): received signal power, channel impulse response, channel frequency response, LLRs, throughput and I/Q components (e.g. constellations)

- MAC/PHY layer statistics: successful transmissions, errors per HARQ per round, average throughput, ULSCH/DLSCH errors per HARQ process (8 in LTE FDD) per round (4 is maximum).
- Experienced data rate (IP, TCP and APP layers)
- User plane E2E latency (IP, TCP and APP layers)

Visualization:

- Visualization of allocated slices
- Visualization of critical events
- Visualization of predictions
- Visualization of real-time data
- Visualization of historical data

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

The statistics and KPIs presented in the following can be used for assessing the performance of the following use cases:

- Time-critical factory processes and logistics optimization
- Non time-critical processes and logistics (factories and smart cities)

The statistics that are important for the demonstration of PoC#1 are:

- Experienced data rate: experienced data rate (IP, TCP and APP layers)
- User plane E2E latency: user plane E2E latency (IP, TCP and APP layers)
- Control latency for the creation of a new network slice: to be implemented during the project
- Control latency for the update of a current network slice: to be implemented during the project
- Area traffic capacity: experienced data rate of all users
- Reliability: estimated as occurrences of measured SINR outage over time

2.4.3 5G URLLC V2X testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the cloud controlled robot use case. Such use case holds for “Factories, Transport and Logistics” vertical.

Statistics (and KPIs) that the testbed supports

This radio testbed supports the TDD connection between one terminal and cloud side services, with different latency, reliability and bandwidth requirements. The following features are supported:

- PHY data throughput ranging from 300kbps ~ 5Mbps
- Latency ranging from 1ms to 5ms
- 99.999% PHY reliability achievable at SNR as low as 1dB
- 1 Tx by 2 Rx with receive diversity for reliability enhancement
- Signal bandwidth: 1MHz to 10MHz
- Frame length: 0.25ms ~ 5ms
- Subcarrier spacing: 30kHz, 60kHz, 120kHz
- Reference signal density: every 2 to 12 OFDM symbols

- Cyclic-prefix ratio: 0.08 ~ 0.5 length of DFT window
- ZF or MMSE channel equalization
- Coding rate 1/9 ~ 0.9
- Live query of SNR, BLER
- Live display of QAM constellation and signal PSD
- PHY parameter reconfiguration on-the-fly
- Defining and simulating frame structures in Matlab reference chain
- PDCP size: 42 ~ 600Bytes
- PCAP & IP tunnel based interface
- Diagnostic with self-transmitted signal

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- IP packet drop rate: PHY reliability, coding rate, subcarrier spacing, CP length, Rx diversity, reference signal density
- Video codec throughput: PHY data throughput, coding rate, CP length, reference signal density
- Controlling latency: frame length, PHY data throughput
- IP packet MTU size: PDCP size

2.5 List of PoC components to be implemented

PoC#1 "Cell-less Megacity PoC" will demonstrate FoF applications using the advantages of a cell-less environment by supporting both URLLC and mMTC services. In this direction, we select, for implementation, integration and demonstration, technical components which support:

- Dynamic multi-link/multi-node connectivity (as an enabling technology for supporting high reliability and availability of URLLC services)
- Optimization of network resources in an end-to-end manner by appropriate creation, configuration and management of network slices (which relies under the topic mobility and load balancing of T3.2)
- Solutions for URLLC services (e.g. macroscopic transmit diversity, packet duplication at physical layer with single-frequency-network (SFN) type of transmission, coordinated cell muting etc.)
- Multi-node cooperation in a cell-less environment in order to increase the reliability and availability, as well as, the capacity.
- Prediction and learning as the tools to enhance the network decisions in a cell-less environment and as an enabler for forecasting vertical requirements and critical events (e.g. fires, floods in agricultural areas).

The table below characterizes the selected technical components.

Technical Component	Originating task and sub-topic	Technical stream	Targeted testbed
Macroscopic transmit diversity (i.e. multiple base stations transmitting the same signal)	**T3.2**: Dynamic multi-link/multi-node connectivity **T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Optimized multi-link management for improved E2E performance	Multi-link/multi-node testbed
Packet duplication at PDPC level	**T3.2**: Dynamic multi-link/multi-node connectivity **T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Optimized multi-link management for improved E2E performance	Multi-link/multi-node testbed
Packet duplication at physical layer, with single-frequency-network (SFN) type of transmission	**T3.2:** Dynamic multi-link/multi-node connectivity **T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Optimized multi-link management for improved E2E performance	Multi-link/multi-node testbed
Coordinated cell muting, i.e. neighbour cells may be asked to mute transmissions over a set of radio resources in order to avoid interference to a specific user	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Advanced link management based on multi-cell processing	Multi-link/multi-node testbed
Cell selection (according to receive signal strength) or coherent/non-coherent receive combining of the signals received by multiple cells	**T4.1:** Solutions for Ultra Reliable and Low Latency Communication	Advanced link management based on multi-cell processing	Multi-link/multi-node testbed
Maximum Ratio Combining (MRC) vs. interference suppression receivers	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Advanced link management based on multi-cell processing	Multi-link/multi-node testbed
Acquisition of downlink channel state information by means of low-overhead non-orthogonal reference sequences, and	**T4.3**: Multi-node cooperation and cell-less design **T4.3**: Prediction and learning	Advanced link management based on multi-cell processing	Multi-link/multi-node testbed

compressed sensing algorithms at the user			
Translation of FoF specific requirements into network requirements	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Network slice creation supporting the FoF requirements in an area-based and time-based manner	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Creation of end-to-end network slices (5G network and cloud resources)	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Implementation of slice negotiator entities both on Factory owner and Operator sides	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Activation of mMTC network slices for non critical tasks inside the factory	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Activation of URLLC network slices in cases of emergencies	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Distributed decision making of slice activation in a cell-less FoF environment	**T4.3**: Multi-node cooperation and cell-less design	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Flexible short frame structure and frequency bandwidth	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Future proof multi-service access solutions	5G URLLC V2X testbed
Flexible pilot pattern	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Future proof multi-service access solutions	5G URLLC V2X testbed
Multi-antenna enhancement of reliability	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Optimized multi-link management for improved E2E performance	5G URLLC V2X testbed

Table 8 List of potential PoC components PoC#1

3 PoC#2: Smart-Megacity Proof-of-Concept

This PoC targets smart-megacity with a large number of users, a diversity of services and high cell densities.

3.1 Storyline

Anne also loves walking around the city after work. She leaves her car parked at home and takes the bus to go downtown. During the travel, she usually checks her emails or watches some high-quality videos. Without even noticing, her terminal changes from one serving base station to the other, providing seamless eMBB coverage.

The bus itself, as well as the traffic lights and sensors are continuously monitoring the status of the traffic. This information is sent to the central traffic city control, being afterwards shared directly between vehicles and the road infrastructure. Also without noticing it, city lights, water meters and pollution sensors along the way also provide information to the smart city centre for improved monitoring of the city status and the definition of possible improvements in routes, vehicle use and general well-being of its citizens.

From the bus window, Anne wonders about the increasing number of automatic vehicles without driver, that populate the streets bringing passengers across the roads. URLLC links connect all these vehicles together, making them even safer than human drivers.

After arriving to her stop, Anne puts her AR/VR glasses on. Although she usually walks around without any specific objective, today she will probably do some interesting social activities. Therefore, she activates the events recommendation App. As it keeps track of her interests, the application immediately recommends her the concert of folk music nearby. After selecting it, her glasses show her the way to go through the streets with an arrow and a path superimposed in front of her eyes. This AR guidance allows her to reach the place without getting lost, as she did not know the location of the square where the concert takes place.

In her way, her smartphone advises her of a close “minimonster”. It is part of a collaborative online game she has been playing. This makes her to stop for a while trying to “catch” it. Her trophy is immediately registered by the App and uploaded to the cloud, where she increases a little her rank in the game.

Once arrived, the place is crowded. Hundreds of people watch the concert. While the band plays, many spectators record the experience in high definition with their glasses or smartphones. Online video is also streamed by TV reporters and drones flying around. Although the data traffic demand is at its peak, network resources have been provided to the surrounding cellular bases station. They serve all the users in the area without issue, allowing Anne to automatically upload her video stream to their social network and share the experience with her friends around the world.

3.2 Description

The aim of this PoC is to test the E2E performance optimization and multi-node/multi-link techniques proposed in WP3, as well as to assess some E2E and context-aware KPIs defined in WP2. The vertical scenario is assumed to be a smart-megacity with many users, services and cell densities.

Four main testbeds are envisaged: (a) the MIMO multi-band testbed (B-COM); (b) Platform for vertical service delivery through 5G technologies (Wings) (c) the commercial LTE network (UMA).

The last one (c) will be mainly used for field trials, whereas the others will be used in a lab environment. Some foreseen ONE5G innovations to be tested are described below.

In case a), the testbed includes a MIMO Multi-RAT - OAI platform that supports band aggregation (in both licensed and unlicensed bands), with high powerful FPGA and optical/Ethernet links. The service involved is eMBB. The testbed b) includes different IoT devices: Arduino Uno with DHT11 Temperature and Humidity sensors, LDR Analogue Luminosity sensors, Motion detection sensors, LED actuators and buzzer; Libelium WaspMote with Libelium Temperature Sensors and LDR Analogue Luminosity sensors and SparkFun FIO board with DHT22 Temperature and Humidity sensors. In case c), the testbed is a full indoor LTE network that comprises 12 LTE picocells, each including a WiFi access point and 12 LTE/WiFi-capable cell phones. The service involved is eMBB. The target services will include mainly mMTC and also URLLC.

Firstly, multi-link and multi-band service aggregation will be evaluated on PHY level, using abstractions on higher levels of the RAN to approximate the E2E effects. Aspects such as separation of UL and DL, and multi band (licensed/unlicensed) will be implemented and tested. Hardware accelerators allowing the integration of flexible and fast reconfigurable digital processing functionalities will be used to reinforce these techniques. Secondly, functionalities for creation and management of network slices will be developed and mechanisms for the translation of high level vertical requirements into network requirements and resources will be implemented. Lastly, E2E and context-aware KPIs will be assessed in a real scenario. Subsequently, the E2E performance optimization will be studied, with a focus on novel mobility optimization techniques. These techniques will use E2E KPIs and optimize RAN parameters that mostly influence them taking also into account the context.

In relation to the capabilities of the testbeds the PHY and MAC functionalities will be implemented by BCOM. RRM functionalities and measurement collection will be performed by the UMA and BCOM, although the data will be obtained from different layers in the distinct testbeds. Network slice management functionalities will be performed by WINGS. E2E performance optimization functionalities will be performed by UMA. Lastly, functionalities related to the real-time execution support will be performed by BCOM and UMA.

Concerning the interfaces supported in the testbed a) and b), they are being defined while in the testbed c) it is a REST interface.

3.3 Related WP2 use cases

- Main use cases:
    - Vertical: Smart Cities and Energy
        - Non time-critical processes and logistics (factories and smart cities)
    - Vertical: Media, Entertainment and eOffice
        - Outdoor hotspots and smart offices with AR/VR and media applications
        - Live Event Experience – massive number of users with video sharing
- Related use cases:
    - Vertical: Smart Cities and Energy
        - Smart grid, connected lighting and energy infrastructure

3.4 KPIs specification aligned with WP2

3.4.1 The MIMO multi-band testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the following use cases:

- Non time-critical processes and logistics (factories and smart cities)

- Outdoor hotspots and smart offices with AR/VR/MR (Mixed Reality) and media applications
- Live Event Experience

Such use cases hold for the following vertical "Smart Cities and Energy, Media and Entertainment and eOffice".

Statistics (and KPIs) that the testbed supports

Since the platform is not operational yet, no statistical figures nor KPIs are available so far. However, the following metrics will be considered:

- Number of simultaneously addressed services with regular multi-band multiplex;
- Ability to reject out-of-band interferers;
- End-to-end signal processing latency;
- Low-latency reconfiguration capabilities.

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- Frequency UL/DL separation;
- URLLC improvement metrics;
- E2E performance evaluation;
- Generic Multiband aggregation performance;
- Analog performance (SNR, bandwidth, …)

3.4.2 Platform for vertical service delivery through 5G – IoT and big data – technologies

Statistics (and KPIs) that the testbed supports

The testbed is based on the OpenAirInterface (OAI) framework, therefore all the statistics already available by OAI are supported in the testbed. In addition, some other higher layer KPIs are collected by the testbed as well.

- PHY layer statistics (for both eNB and UE): received signal power, channel impulse response, channel frequency response, LLRs, throughput and I/Q components (e.g. constellations)
- MAC/PHY layer statistics: successful transmissions, errors per HARQ per round, average throughput, ULSCH/DLSCH errors per HARQ process (8 in LTE FDD) per round (4 is maximum).
- Experienced data rate (IP, TCP and APP layers)
- User plane E2E latency (IP, TCP and APP layers)

Visualization:

- Visualization of allocated slices
- Visualization of critical events
- Visualization of predictions
- Visualization of real-time data
- Visualization of historical data

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

The statistics and KPIs presented in the following can be used for assessing the performance of the non time-critical processes and logistics (factories and smart cities) use case.

The statistics that are important for the demonstration of PoC#2 are:

- Experienced data rate: experienced data rate (IP, TCP and APP layers)
- User plane E2E latency: user plane E2E latency (IP, TCP and APP layers)
- Control latency for the creation of a new network slice: to be implemented during the project
- Control latency for the update of a current network slice: to be implemented during the project

3.4.3 Commercial LTE network

The statistics and KPIs presented in the following can be used for assessing the performance of the following use cases:

- Non time-critical processes and logistics (factories and smart cities)
- Outdoor hotspots and smart offices with AR/VR/MR and media applications
- Live Event Experience

Such use cases hold for the following vertical “Smart Cities and Energy, Media and Entertainment and eOffice”.

Statistics (and KPIs) that the testbed supports

UMA HetNet is a real LTE commercial network and as such, it is possible to collect information related with configurable parameters and indicators (traces, counters and KPIs). The LTE network provides many counters that represent the performance of the network. The counters may be related to one or more features or functionalities of the network (e.g., mobility, voice…). These available features are gathered in the table aside.

Feature name
Coverage-based Inter-frequency Handover
Coverage-based Intra-frequency Handover
DRX
Dynamic Downlink Power Allocation
Emergency Call
Inter-RAT Mobility between E-UTRAN and UTRAN
None
RAN Sharing
Random Access Procedure
Security Management
SON Self-Optimization
System Capability
Voice Services
Warning Broadcasting System

Table 9 Features of UMA HetNet

Besides the KPIs that can be obtained from the UMA HetNet, others are going to be obtained in the UE by using TCAP, TEMS, Wireshark and other open source drive test tools e.g Mobile Insight.

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- Service setup time

Average service setup time = L.RRC.ConnSetup.TimeAvg + L.E-RAB.Est.TimeAvg
Maximum service setup time = L.RRC.ConnSetup.TimeMax + L.E-RAB.Est.TimeMax
Where:
L.RRC.ConnSetup.TimeAvg: *Average RRC connection setup duration*
L.RRC.ConnSetup.TimeMax: *Maximum RRC connection setup duration*
L.E-RAB.Est.TimeAvg: *Average E-RAB setup duration in a cell*
L.E-RAB.Est.TimeMax: *Maximum E-RAB setup duration in a cell*

- U-plane maximum UL/DL radio latency (ms)

L.Traffic.DL.PktDelay.Time.QCI.X (DL): *Total processing delay of* ***downlink*** *PDCP SDUs for DRB services with the QCI of X in a cell*

- U-plane reliability

L.Traffic.DL.PktDelay.Num.QCI.X/ L.Traffic.DL.PktUuLoss.Tot.QCI.X*100
Where:
L.Traffic.DL.PktDelay.Num.QCI.X: *Number of successfully transmitted downlink PDCP SDUs for DRB services with the QCI of X in a cell*
L.Traffic.DL.PktUuLoss.Tot.QCI.X: *Total number of transmitted downlink PDCP SDUs for DRB services with the QCI of X in a cell over the Uu interface*

- Positioning accuracy

RRC Idle: Tracking Area-level
RRC Connected: Cell-level

- U-plane maximum E2E latency (ms)

TCP (UL/DL): C/S first payload
C first payload: *Client first segment with payload since the first flow segment (ms)*
S first payload: *Server first segment with payload since the first flow segment (ms)*
[TSTAT]

- U-Plane packet/frame loss (%)

DL: (L.Traffic.DL.PktUuLoss.Tot.QCI.X - L.Traffic.DL.PktDelay.Num.QCI.X)/ L.Traffic.DL.PktUuLoss.Tot.QCI.X*100

Where:
L.Traffic.DL.PktUuLoss.Tot.QCI.X: *Total number of transmitted downlink PDCP SDUs for DRB services with the QCI of X in a cell over the Uu interface.*
L.Traffic.DL.PktDelay.Num.QCI.X: Number of successfully transmitted downlink PDCP SDUs for DRB services with the QCI of X in a cell.

- Average End User Throughput (Mbps)

UDP/TCP User Average Throughput (UL/DL) = Data bytes/Completion time
Where:
Data bytes: *Number of bytes transmitted in the payload, including retransmissions (bytes).*
Completion time: *Flow duration since first packet to last packet (ms)*
[TSTAT]

- Video startup time

Youtube Information Set: Begin Offset (*Playback offset for the Youtube video*)
[TSTAT**]**

- Mean/5-ile video bitrate (Mbps)

Video information set: Video total datarate.
[TSTAT]

3.5 List of PoC components to be implemented

The "Megacities" scenario is a highly populated metropolitan area with a dense deployment of radio nodes (of heterogeneous technologies). In this environment, the very high area throughputs and connection densities are of highest importance. In this direction, in PoC#2 "Smart-Megacity PoC", we will implement technologies for increasing capacity and density, in terms of multi-link and multiband service aggregation and mobility and load balancing optimisation. In addition to persons using smartphones, the "Megacities" scenario in the near future will include large quantity of wireless connected machine type communication (MTC) devices. Therefore, we decided to demonstrate in PoC#2 smart-megacity IoT (mMTC) and URLLC applications, in addition to eMBB, in order to demonstrate multi-service innovations which are of paramount importance in a Megacity environment. In detail, PoC#2 will implement, integrate and demonstrate technical components which support:

- Multi-link and multiband service aggregation
- Context-aware multi-service solutions (e.g. RRM optimization)
- Solutions for URLLC services by utilizing advanced link management based on multi-cell processing (including also solutions for the topic "Advanced connectivity: D2D, multicasting, network coding")
- Enhancement of traditional load balancing techniques, service-differentiated load balancing and traffic steering management.
- Creation, configuration and management of network slices (from the topic Mobility and load balancing optimizations)

The table below characterizes the selected technical components.

Technical Component	Originating task and sub-topic	Technical stream	Targeted testbed
Multi-link service aggregation	**T3.2:** Dynamic multi-link/multi-node connectivity	Optimized multi-link management for improved E2E performance	MIMO Multi-RAT /multi-band testbed
Multiband service aggregation	**T3.2:** Dynamic spectrum aggregation mechanisms	Network and user-experienced E2E performance optimization and context awareness	MIMO Multi-RAT /multi-band testbed
URLLC Link Adaptation	**T4.1**: Solutions for Ultra Reliable and Low Latency Communication	Advanced link management based on multi-cell processing	MIMO Multi-RAT /multi-band testbed
	T4.3: Advanced connectivity: D2D, multicasting, network coding		
Enhancement of traditional load balancing techniques	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Full indoor commercial LTE network
Prediction of network performance degradation	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Full indoor commercial LTE network
QoE-to-KQI and KQI-to-KPI metrics mapping	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Full indoor commercial LTE network
Service-differentiated load balancing	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Full indoor commercial LTE network
Traffic steering management using context, user and cell level information	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Full indoor commercial LTE network
Translation of vertical (high level) requirements into network requirements	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies

Creation of new network slices (including 5G network and cloud resources) in order to support the vertical end-to-end requirements	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness / Future proof multi-service access solutions	Platform for vertical service delivery through 5G technologies
Management of already established slices in order to continuously fulfill the vertical requirements	**T3.2:** Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies

Table 10 List of potential PoC components PoC#2

4 PoC#3: Enhanced massive MIMO Proof-of-Concept

This PoC targets the increased User Experience for new media.

4.1 Storyline

Peter is on his way to a concert. He is travelling by metro. On his cell phone he gets the latest news about the upcoming event. The massive MIMO cells are tracking him and sending him directed beams with his own data. If Peter wants to have a look to what is happening live at the venue, which is in the city centre, he opens a high-resolution stream on his phone and the massive MIMO cell makes sure the SNR is good enough for high data-rate downlink transmission.

The lack of coverage in the narrow tunnels of the metro is not a problem for the enhanced massive MIMO technology and Peter can have a look before he arrives. At his station he leaves the metro and a massive MIMO macro-cell is taking over. He is forming a cluster with other people heading in the same direction. More massive MIMO cells form a collaborative beam towards his cluster of people to increase SNR and MCS level to satisfy the high data-rate demand of the users. While the crowd Peter is in is moving, the massive MIMO technology tracks the cluster so that no handover is needed. All the people want to see a high definition video teaser for the concert and more and more metro trains arrive at the venue.

Blocks of people are moving towards the concert side. Each block is tracked individually and the massive MIMO cells form complex beam patterns so that each block of users is in its own virtual cell. Thanks to enhanced massive MIMO the user experience is always perfect.

At the venue the live concert starts. Peter is very far away from the stage. He cannot see very well. Fortunately for him the host organized a special service for the guests. He can see a high-definition live stream on his mobile. Thanks to massive MIMO he gets his own personal beam with high data-rate to see the direct camera feed from the stage. The picture on his phone is crystal clear and real-time. He feels like he is on stage.

4.2 Description

The aim of this PoC is to assess and demonstrate the potential performance gains of the massive MIMO technology in a multi-user and multi-cell environment. The targeted vertical scenario is the smart-megacity with a large number of users and dense cell deployment. The massive MIMO BS can adapt between single or few spatial beams with high receive SNR, due to the beamforming gain and power only divided to one or few beams, and a high number of spatial beams for users in high SNR regime increasing the cell-throughput by spatial multiplexing.

This PoC will be based on the flexible massive MIMO testbed (HHI). In order to demonstrate the effects on PHY and MAC layer, this PoC will introduce a new evaluation methodology by combining hardware proof-of-concept with radio network evaluations. In this direction, the cloud server will change the configuration of the SDR platform, while PHY-MAC-layer processing will be done in Matlab/Mex based on channel estimates. The PoC will include a system-level simulation tool engine for precoding, user grouping and SINR processing, while different KPIs such as SINRs, interference conditions, sum and user data rates (L2S interfaces), localization accuracy will be calculated directly in the workstation.

The goal of this PoC is to implement key components of massive MIMO concepts in hardware and software to allow evaluating and visualizing its behaviour and performance in real-time conditions. As a result, ONE5G will develop a massive MIMO hardware-in-the-loop platform which directly combines system-level simulations such that concepts from WP4 will be evaluated in a hybrid fashion.

4.3 Related WP2 use cases

- Main use cases:
  - Vertical: Media, Entertainment and eOffice
    - Outdoor hotspots and smart offices with AR/VR and media applications
    - Live Event Experience – massive number of users with video sharing

4.4 KPIs specification aligned with WP2

4.4.1 The flexible massive MIMO testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the following use cases:

- Outdoor hotspots and smart offices with AR/VR and media applications
- Live Event Experience – massive number of users with video sharing

Such use cases hold for the following vertical “Media, Entertainment and eOffice”.

Statistics (and KPIs) that the testbed supports

The testbed radio equipment can connect to a subset of eight antennas for example from a massive MIMO patch array per SDR module. The industrial I/O interface provides RX and TX stream buffers, which contains one IQ time vector for each of this eight antenna ports in time domain.

By filling the buffer on transmit side with up to eight orthogonal sounding sequences, which offers the possibility for synchronization and channel estimation, we are able to perform complex channel frequency response between each transmitter and receiver pair on the resource elements where reference symbols (pilots) are present.

This channel information can be used in connection with the MATLAB toolbox QuaDRiGa (QUAsi Deterministic RadIo channel GenerAtor) version 2.0.0, to estimate the complex-valued channel coefficient as well as the delay for N strongest paths of the channel impulse response and, from this, an interpolated version of a channel frequency response for all resource elements in frequency domain can be derived.

- Received Signal Strength Indicator (RSSI) – (direct from SDR)
- Massive MIMO beamforming KPIs - (based on QuaDRiGa MIMO antenna model)
  - 3dB beamwidth
  - Azimuth and elevation angle range
  - Gain
- Further statistics and KPIs can be measured by additional code parts in MATLAB - (from HHI or partners)
  - Direct from raw time or frequency domain complex valued signal vector
  - Based on channel measurements inside QuaDRiGa channel model

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- Examination of massive MIMO beamforming parameter changes
- Signal to interference noise ratio (SINR) between massive MIMO beams to several users channel estimation and virtual users channel (QuaDRiGa based simulation) for investigation on sectorization topics.

- User throughput (Derived from QuaDRiGa SINRs and mapped to a throughput abstraction model)
- Total system throughput (Sum of user throughputs)

4.5 List of PoC components to be implemented

In PoC#3 "Enhanced massive MIMO PoC" innovative massive MIMO technologies for increasing capacity and connection density will be implemented and integrated as enablers of the smart-megacity applications, covering, as illustrated in the table below, many of the topics of WP4. PoC#3 will demonstrate technical components which support:

- Non-orthogonal multiple access and code design
- Multiple data path transmission and multi-source synchronization
- Array design (e.g. MIMO planar antenna arrays and subarrays)
- Sector and Beam management (under the topic Beam management and multi-service enablers)
- Enhanced CSI acquisition techniques for mMIMO

Technical Component	Originating task and sub-topic	Technical stream	Targeted testbed
Sector and Beam management	**T4.2**: Beam management and multi-service enablers	Massive MIMO enablers	Flexible Massive MIMO testbed
Phase coherent reception (multiple software-defined-radios)	**T4.2**: Beam management and multi-service enablers	Massive MIMO enablers	Flexible Massive MIMO testbed
Non-orthogonal multiple access and code design	**T4.1**: Design of non-orthogonal multiple access and code design	Massive MIMO enablers	Flexible Massive MIMO testbed
Multiple data path transmission and multi-source synchronization	**T4.1**: Design of non-orthogonal multiple access and code design	Massive MIMO enablers	Flexible Massive MIMO testbed
MIMO planar antenna arrays and subarrays	**T4.2:** Array design	Massive MIMO enablers	Flexible Massive MIMO testbed
Channel coefficient estimation in frequency domain	**T4.2**: CSI acquisition for mMIMO	Massive MIMO enablers	Flexible Massive MIMO testbed
Change the configuration of the SDR platform using M-MIMO simulations based on QuaDRiGa channel model and measurement data	**T4.2**: Beam management and multi-service enablers	Massive MIMO enablers	Flexible Massive MIMO testbed
Transmission of raw I/Q data in time domain over packet based 10G Ethernet	**T4.2**: Beam management and multi-service enablers	Massive MIMO enablers	Flexible Massive MIMO testbed

Table 11 List of potential PoC components PoC#3

5 PoC#4: Underserved areas Proof-of-Concept

This PoC targets large underserved areas with agricultural applications.

5.1 Storyline

Nick is a farmer living with his family, his wife and two daughters in the countryside of North Greece. Their everyday life is very tough since they need to take care of their farmstead, covering a large area of several Km^2, full of plants and livestock. Nick wakes up every day at 5 a.m., he grabs a quick bite to eat, he picks his tablet, in which a set of farming applications are installed and jump on the motorbike to bring in the cows for milking.

The milking shed is equipped with equipment, connected to Internet, for the automation of the milking process. When, a cow is heading through the cowshed, its health and wellbeing are automatically monitored, while the data is communicated to a server located in the cloud. The cow is equipped with a unique RFID tag, therefore this data, is combined with cow specific information, historical data and environmental data in order to produce a full personalized report including the probability of a lame or sick cow, or cows that need special feeding treatment. Nick, by using his tablet can access in real time the results of the reports and the proposed actions and can decide to separate cows for further examination or call the vet automatically through the tablet. Then, Nick by using his tablet is informed about the feeding capability of the available field, while the application makes suggestions for the most appropriate position for feeding the cows. This application makes use of a set sensors and cameras spread along the farmstead.

After taking care of the livestock, Nick opens the field monitoring and management application. The application communicates with a cloud server in which several data from sensors spread along the farmstead are stored in a real-time manner. In case of very sensitive plants (like grapes) cameras are located near the plants in order to monitor data not covered by simple sensors (e.g. fruit maturing). In the server a process is continuously analysing the available data and the video feeds and create a list of jobs that Nick should do during the day in order to optimize the yield of the crops and avoid any plan diseases. For today, the list contains the following tasks: 1. To spray for weeds in the first 10 lines of the plans in field C using a quantity of 0.2 lt of the pesticide Z; 2. To set up grazing for the herd in field D; 3. To pick up the grapes in field E; etc.

After all these jobs, Nick returns to his home in the afternoon really tired. During his way back, he remembers some years ago, when this automated and connected farming environment was not a reality. He remembers that he had to inspect all the fields day by day, deciding if some of them were facing problems or if the fruits were mature enough, to inspect very thoroughly all the cows in order to check if some of them were affected by a disease, to read a couple of pesticide manuals in order to decide which was the correct amount of pesticide for this specific plant type, season and weeds, to spend a lot of money for unused chemicals, and plant and vet instructions and finally to return home late at night. He signs with relief: "At least now I have prosperous crops and most important I have a couple of hours to spend with my family at home".

5.2 Description

The main objective of this PoC is to design, develop and implement a low-cost network for underserved areas use cases. The targeted vertical scenario is large underserved areas with agricultural applications.

Two testbeds will be used in this PoC: a) Flexible and reconfigurable HW/SW testbed (B-COM); b) Platform for vertical service delivery through 5G – IoT and big data - technologies (WINGS), integrated in a single collaborative PoC. A selected set of technologies and techniques designed in WP3 and WP4 will be implemented either in software or hardware. USRPs equipment will be used that can integrate hardware enablers developed in VHDL, typically performing a part of the baseband processing. Dynamic resources allocation, MAC layer and higher level management and monitoring will be realised in software and interfacing with the USRPs, while the OpenAirInterface framework will be used.

The main requirements of this PoC is to showcase underserved areas scenarios, in which the network should cover large areas (cell of around several Kms radius) with allocation of narrow bandwidth (few RBs), and in a low cost manner, having also a low energy fingerprint. Because of the aforementioned constraints, frequency carriers below 2GHz (in licensed or in un-licensed bands) will be used to optimize the coverage, to be able to dynamically adapt/switch the transmission in narrow bands (optimization of spectrum use) and to aggregate narrow multi-bands for increasing the data throughput (trade-off between coverage and throughput). For that, the receivers should be capable to demodulate signal at low power level, with high frequency agility, and should be easily reconfigurable in terms of hardware and software to address the multi-services transmission.

5.3 Related WP2 use cases

- Main use cases:
    - Vertical: Agriculture
        - Long range connectivity in remote areas with smart farming application
- Related use cases:
    - Vertical: Smart Cities and Energy
        - Non time-critical processes and logistics (factories and smart cities)

5.4 KPIs specification aligned with WP2

5.4.1 Flexible and reconfigurable HW/SW testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the long-range connectivity in remote areas with smart farming application use case.

Statistics (and KPIs) that the testbed supports

Since the platform is not operational yet, no statistical figures nor KPIs are available so far. However, the following metrics will be considered:

- Number of simultaneously addressed services with regular multi-band multiplex;
- Ability to reject out-of-band interferers;
- End-to-end signal processing latency;
- Low-latency reconfiguration capabilities.

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- Radio range
- UE radio consumption (lowest possible)
- Reliability (expected 100% for -100dBm received power)

5.4.2 Platform for vertical service delivery through 5G – IoT and big data – technologies

Statistics (and KPIs) that the testbed supports

The testbed is based on the OpenAirInterface (OAI) framework, therefore all the statistics already available by OAI are supported in the testbed. In addition, some other higher layer KPIs are collected by the testbed as well.

- PHY layer statistics (for both eNB and UE): received signal power, channel impulse response, channel frequency response, LLRs, throughput and I/Q components (e.g. constellations)
- MAC/PHY layer statistics: successful transmissions, errors per HARQ per round, average throughput, ULSCH/DLSCH errors per HARQ process (8 in LTE FDD) per round (4 is maximum).
- Experienced data rate (IP, TCP and APP layers)
- User plane E2E latency (IP, TCP and APP layers)

Visualization:

- Visualization of allocated slices
- Visualization of critical events
- Visualization of predictions
- Visualization of real-time data
- Visualization of historical data

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

The statistics and KPIs presented in the following can be used for assessing the performance of the long-range connectivity in remote areas with smart farming application use case.

Statistics that are important for the demonstration of PoC#4 are:

- Experienced data rate: experienced data rate (IP, TCP and APP layers)
- User plane E2E latency: user plane E2E latency (IP, TCP and APP layers)
- Radio range: not supported
- UE radio consumption (lowest possible): estimated based on PHY data rate and APP data rate
- Control latency for the creation of a new network slice: to be implemented during the project
- Control latency for the update of a current network slice: to be implemented during the project

5.5 List of PoC components to be implemented

PoC#4 will demonstrate innovations for the “Underserved Areas” scenario, by assuming the agricultural domain as the main vertical section. In this direction, we select to implement, integrate and demonstrate technical components mainly under the topic of "Mobility and load balancing optimizations" which will focus on optimization of the end-to-end limited available network resources and the simplification of the functionalities and sharing of resources in order to lower the network cost. In addition, the support of different services, with an acceptable level of QoE/QoS, is requested. In this direction, we select to implement, integrate and demonstrate technical components which support:

- Flexibility and fast reconfiguration of network elements (under the topic Mobility and load balancing optimizations)
- Mechanisms for transmission path improvements (under the topic Beam management and multi-service enablers)

- End-to-end optimization of the low cost 5G network based on actual critical events, predictions of critical events and mobility predictions (under the topic Mobility and load balancing optimizations)
- Creation, configuration and management of network slices (under the topic Mobility and load balancing optimizations)

The table below characterizes the selected technical components.

Technical Component	Originating task and sub-topic	Technical stream	Targeted testbed
Flexibility and fast reconfiguration of network elements according to the requested service requirements	**T4.2**: Beam management and multi-service enablers	Future proof multi-service access solutions	Flexible and reconfigurable HW/SW testbed
Multi-service transmission	**T4.2**: Beam management and multi-service enablers	Future proof multi-service access solutions	Flexible and reconfigurable HW/SW testbed
Mechanisms for transmission path improvements	**T4.2**: Beam management and multi-service enablers	Future proof multi-service access solutions	Flexible and reconfigurable HW/SW testbed
Use of wireless backhaul for coverage enhancement in low ARPU network	**T4.2**: Beamforming algorithm **T4.2**: CSI acquisition for mMIMO	Massive MIMO enablers	MIMO Multi-RAT /multi-band testbed
Translation of vertical (high level) requirements into network requirements	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Creation of new network slices (including 5G network and cloud resources) in order to support the vertical end-to-end requirements	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness / Future proof multi-service access solutions	Platform for vertical service delivery through 5G technologies
Creation of time-based and area-based network slices	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness / Future proof multi-service access solutions	Platform for vertical service delivery through 5G technologies

Management of already established slices in order to continuously fulfill the vertical requirements	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Allocation of available network resources using end-to-end network slices	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Slice negotiation between the vertical and the operator	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
Data analysis and predictions including complex event processing, data correlation and predictive analytics	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies
End-to-end optimization of the low cost 5G network based on actual critical events, predictions of critical events and mobility predictions	**T3.2**: Mobility and load balancing optimizations	Network and user-experienced E2E performance optimization and context awareness	Platform for vertical service delivery through 5G technologies

Table 12 List of potential PoC components PoC#4

6 PoC#5: Future Automotive – Tele-operated Driving Proof-of-Concept

6.1 Storyline

Mary is travelling with her small baby using her Level-4 [2] autonomous car to visit her best friend in another city. In the recent years, the destination city received a lot of investment, so the construction of new buildings and road infrastructures is happening everywhere. There are many complexes changing roads and areas which Mary’s Level-4 car cannot handle autonomously.

The car was driving on its own smoothly and safely alone the highway, with moderate traffic to the city, while both Mary and her baby were sleeping sweetly. Just when the car is about to go off the highway and enter a limited area of the city, the baby starts to cry and need some care from his mother. Mary wakes up, smiles and tries to calm her baby down by feeding with some milk. She doesn’t even notice that her car is entering a limited zone which may need her to take over the driving. However, the car just continues driving, slowing down according to the speed limitation, following yellow lines (not the white ones) and recognising all the temporary road signs. For example, if there are some workers on the road, the car stops until they have cleaned it up and then continues driving. Both, Mary and her baby, are happily getting along with each other and finally reaching the friend’s home without anyone even touching the driving wheel.

So, what has happened to the car? It was not able to autonomously handle all the limited areas along the route by itself.

The scene turns into a control centre where many screens are displaying a lot of driving and traffic information together with some controlling seats with driving wheels and all the pedals. Sam is sitting in one of these controlling seats, relaxed, monitoring the view and the sensor information from Mary’s car (a bird view of the construction site, a map of the situation ahead as well as some indications of next actions from the artificial intelligent (AI) in the cloud). Most of the time, Sam is just monitoring Mary and some other customer’s vehicles and the cloud side AI service. He only has to intervene and drive manually when a highly complex traffic situation is indicated.

It is the 5G mobile communication, through which Mary’s car is connected to the cloud AI and the controlling centre. When the car is driving off the highway and about to go into the limited zone, the autonomous driving mode is seamlessly switched to the tele-operated driving (ToD) mode in which the cloud AI and Sam take over.

6.2 Description

In the automotive industrial, Tele-operated driving (ToD)[TeleDrv] is a recent application in which a remote operator controls a fully or partially automated vehicle over a wireless telecommunication network. The vehicle’s cameras and sensors send live video streams and sensor data to the operator control desk which are used to control the vehicle’s motion including steering, acceleration and braking. Hence ToD technology combines the human or cloud-based AI capability of fast and accurate scene understanding with the benefits of automated technology inside the car. ToD is a complementary technology to autonomous driving and represents a shift

[2] The “Level-4” is related to the autonomous driving levels defined by SAE, means “High Automation” level (https://en.wikipedia.org/wiki/Autonomous_car#Levels_of_driving_automation)

in driving intelligence from the local vehicle (human or autonomous) to the remote cloud with the goal of enhancing driving safety, comfort and redundancy.

- In near-term, the ToD can help to solve complex traffic situations (temporary construction, traffic sign is unclear or even distorted, jam or conflicting traffic flows) which are not solvable by local human (passenger who is not able to drive) or local AI (considering Level 4/5 autonomous driving in any road condition with local AI is still far from being mature).
- In a more futuristic scenario, if all the vehicles are tele-operated with unified cloud-side AI, the whole road traffic system will become highly coordinated, and as a result, highly efficient and safe.
- The ToD is also applicable to professional areas such as freight hub and mining, in which large number of vehicles move and cooperate with each other; however, the direct field operation of human should be minimized due to safety and economic reasons.

In both ToD and cloud robotics concepts, the URLLC connectivity is crucial to guarantee that the controlling signal from the remote operator or cloud can reach the vehicle or robot reliably within low-latency constraint, considering the highly dynamic natures of the traffic environment and the factory automation process. Meanwhile, the eMBB capability is also desired to share the sensor information to the remote operator or cloud-side AI in real-time, which is the input for fast decision making.

The scope of the PoC #5 is to demonstrate based on the testbed systems of ToD and robotic cloud which are centred on Huawei's 5G PoC prototype.

The 5G prototype is designed to offer low-latency connectivity with high reliability for limited number of terminals, enabled by short and scalable frame structure, on-the-fly reconfigurable numerology, pilot density, bandwidth and MCS, etc., which is implemented with highly optimized software radio architecture.

For the PoC of ToD, the terminal node of the 5G prototype will be installed into a real experimental car and interconnected with the car's driving control onboard unit (OBU) while the BS node of the prototype will be interconnected with the driving station with steering wheel, gas/brake pedals and large display showing the video sent back from the vehicle. We try to integrate the radio and vehicular system in order to achieve the real ToD driving in a closed testing area and expect that the driving experience based on low-latency 5G link will outperform the experience via existing commercial cellular network. It should be noted that the 5G PoC prototype is not capable of real eMBB with data throughput of hundreds Mega of or even Giga bit per second. However, the maximum throughput of 8Mbps is able to handle the TOD video with sufficient quality.

6.3 Related WP2 use cases

- Main use cases:
    - Vertical: Automotive
        - Assisted, cooperative and tele-operated driving (between vehicles, and between them and infrastructure)

6.4 KPIs specification aligned with WP2

6.4.1 5G URLLC V2X testbed

The statistics and KPIs presented in the following can be used for assessing the performance of the Tele-operated driving use case. Such use case holds for “Future Networked Automotive” vertical.

Statistics (and KPIs) that the testbed supports

The HWDU radio testbed supports the TDD connection between one terminal and cloud side services, with different latency, reliability and bandwidth requirements. The following KPIs are supported:

- PHY data throughput ranging from 300kbps ~ 5Mbps
- Latency ranging from 1ms to 5ms
- 99.999% PHY reliability achievable at SNR as low as 1dB
- 1 Tx by 2 Rx with receive diversity for reliability enhancement
- Signal bandwidth: 1MHz to 10MHz
- Frame length: 0.25ms ~ 5ms
- Subcarrier spacing: 30kHz, 60kHz, 120kHz
- Reference signal density: every 2 to 12 OFDM symbols
- Cyclic-prefix ratio: 0.08 ~ 0.5 length of DFT window
- ZF or MMSE channel equalization
- Coding rate 1/9 ~ 0.9
- Live query of SNR, BLER
- Live display of QAM constellation and signal PSD
- PHY parameter reconfiguration on-the-fly
- Defining and simulating frame structures in Matlab reference chain
- PDCP size: 42 ~ 600Bytes
- PCAP & IP tunnel based interface
- Diagnostic with self-transmitted signal

Significant statistics for the demonstration of the PoC and mapping to testbed statistics/KPIs

- IP packet drop rate: PHY reliability, coding rate, subcarrier spacing, CP length, Rx diversity, reference signal density
- Video codec throughput: PHY data throughput, coding rate, CP length, reference signal density
- Controlling latency: frame length, PHY data throughput
- IP packet MTU size: PDCP size

6.5 List of PoC components to be implemented

PoC#5 will demonstrate Automotive applications in a "Megacity" environment. In detail, this PoC will demonstrate tele-operated driving of a real vehicle via the 5G eMBB and URLLC communication links. In automotive sector, URLLC services are of paramount importance in order to allow the automotive safety procedures to be supported (e.g. autonomous car), while eMBB services provide many possibilities for infotainment applications for the car passengers. This PoC will include the following technical components:

- Flexible short frame structure and frequency bandwidth
- Flexible pilot pattern
- Robust synchronization and channel equalization in URLLC
- Multi-antenna enhancement for improving reliability
  Optimization of real-time processing in URLLC

The table below characterizes the selected technical components.

Technical Component	Originating task and sub-topic	Technical stream	Targeted testbed
Flexible short frame structure and frequency bandwidth	T4.1: Solutions for Ultra Reliable and Low Latency Communication	Future proof multi-service access solutions	5G URLLC V2X testbed
Flexible pilot pattern	T4.1: Solutions for Ultra Reliable and Low Latency Communication	Future proof multi-service access solutions	5G URLLC V2X testbed
Robust synchronization and channel equalization	T4.1: Solutions for Ultra Reliable and Low Latency Communication	Future proof multi-service access solutions	5G URLLC V2X testbed
Multi-antenna enhancement of reliability	T4.1: Solutions for Ultra Reliable and Low Latency Communication	Optimized multi-link management for improved E2E performance	5G URLLC V2X testbed
Elastic software defined architecture with optimized real-time processing	T4.1: Solutions for Ultra Reliable and Low Latency Communication	Advanced link management based on multi-cell processing	5G URLLC V2X testbed

Table 13 List of potential PoC components PoC#5

7 Rationale behind the selection of technical components per PoC

The main objective of prototyping activities in WP5 is the definition of a set of PoCs covering:

- the main project scenarios: “Megacities” and “Underserved Areas”
- a set of important verticals: Smart City applications (labeled here “smart-megacity” applications), factory applications (FoF), automotive applications, agricultural applications and media, entertainment and eOffice applications.
- the main 5G service types: eMBB, URLLC and mMTC
- the most relevant topics of the project for implementation into the PoCs

The definition of the 5 PoC scenarios and the selection of the technical components to be implemented, integrated and demonstrated in each PoC, presented in the next sections are agreed following the aforementioned objectives.

In detail, regarding the project scenarios, PoC#1, PoC#2, PoC#3 and PoC#5 will demonstrate “Megacities” use cases, while PoC#4 is dedicated to the “Underserved Areas” scenario. ONE5G develops enablers and optimization techniques in order to adjust a generic Radio Air Interface to the needs and requirements of various verticals. In order to demonstrate the applicability of the techniques to the verticals, one PoC per vertical is dedicated. In detail, PoC#1 focuses on Factory of the Future (FoF) applications, PoC#2 and PoC#3 focus on smart-megacity applications, PoC#4 focuses on agriculture applications, while PoC#5 is dedicated to automotive applications. By making this selection, the vertical requirements and characteristics are set as the main point of the project prototypes and demonstrations. Regarding the main 5G service types, all three types are covered by the proposed PoCs. In detail, PoC#1 will demonstrate mainly URRLC and mMTC services. This is very important for the factory of the future applications to support both time critical machine-to-machine communications, as well as, non-time-critical communications including sensing, component management and factory logistics. PoC#3 will demonstrate eMBB services in a Smart City using the MIMO technologies as the main enabling technologies considering the Media, entertainment and eOffice vertical, while PoC#2 will both demonstrate eMBB services and mMTC service to realize smart-megacity applications. PoC#4 will include mMTC services, since this is the main service type in agricultural applications. In addition, it will demonstrate URLLC services to support critical infrastructures (e.g. agricultural disease, fires, floods, etc.) in Underserved Areas environment. Finally, PoC#5, which focuses on automotive applications, will demonstrate URLLC since in this sector the safety applications are the most promising and profitable (e.g. safety procedures, tele-operating cars etc.).

Regarding the demonstration of the important topics of the project, the intention is to cover as much WP3 and WP4 topics as possible that are meaningful to be implemented and integrated into prototypes and also to select promising technical components that can demonstrate innovations under the prism of the selected verticals. In order to clearly present the relation of the PoCs with the topics/sub-topics of WP3 and WP4, the **¡Error! No se encuentra el origen de la referencia.** is proposed. This table illustrates the mapping between the targeted five PoCs and the tasks and sub-topics of WP3 and WP4. The green cells indicate that promising technical components from this specific task and sub-topic will be implemented and integrated into the targeted testbeds and finally demonstrated. The orange cells indicate that technical components from these topics/sub-topics will not be integrated and demonstrated as prototypes, while the yellow cells indicate that the implementation/integration of the relative components is under examination and at this time it is not clear if the project will finally demonstrate these functionalities.

Originating task and sub-topic	Targeted PoC
T3.1: RRC state and DRX handling	
T3.1: Multi-service and context aware RRM optimizations	PoC#2
T3.1: Signalling and control plane optimizations	
T3.2: Dynamic multi-link/multi-node connectivity	PoC#1, PoC#2
T3.2: Dynamic spectrum aggregation mechanisms	PoC#2?
T3.2: Mobility and load balancing optimizations	PoC#1, PoC#2 , PoC#4
T3.2: Performance optimization for UEs with D2D schemes	
T4.1: Design of non-orthogonal multiple access and code design	PoC#3
T4.1: Solutions for Ultra Reliable and Low Latency Communication	PoC#1, PoC#2
T4.2: Array design	PoC#3
T4.2: Beamforming algorithms	PoC#2?, PoC#4?
T4.2: CSI acquisition for mMIMO	PoC#3, PoC#4
T4.2: Beam management and multi-service enablers	PoC#3, PoC#4
T4.3: Multi-node cooperation, cell-less design	PoC#1
T4.3: Advanced connectivity: D2D, multicasting, network coding	PoC#2
T4.3: Prediction and learning	PoC#1

Table 14 Mapping between the five targeted PoCs and WP3/WP4 tasks and sub-topics

As it has been said before, the orange cells refer to the topics that will not be covered by prototyping activities. Technical components from the topic "RRC state and DRX handling" were not selected to be implemented and integrated into the PoCs because of the lack of UEs with the three new RRC states and the lack of a complete NR radio control and user-plane. The implementation/integration of even a basic functionality of the aforementioned topic will require high effort without proportionate gains for the demonstration of the selected vertical applications. The same applies for the topic "Signalling and control plane optimizations" which would require full network with complete radio control and user-plane such a full CRAN network. In addition, "Performance optimization for UEs with D2D schemes" has not been selected for implementation and integration because of the lack of testbeds in the project that support a complete infrastructure for D2D communications.

Regarding the topics in the yellow cells, they are both under consideration and, at the time of edition of this deliverable, further consolidation is needed before deciding to implement technical components from these topics. In detail, regarding both the topics "Dynamic spectrum aggregation mechanisms" and "Beamforming algorithms", some hardware limitations prevent from deciding at this point in time (e.g. number of antenna elements that are needed in order to demonstrate the innovation of the algorithms). It is needed further examine these limitations and decide at a later stage of the project.

Regarding the topics from which we select to implement and integrate technical components into the PoCs (green cells), we will give more details in a per PoC manner in the following sections.

8 SW integration methodology

Representational State Transfer (REST) is an architectural style for designing and building distributed and loosely coupled applications that mainly use HTTP requests to post data (create / update), read data (making queries), and delete data. Hence, RESTful applications use HTTP for all four CRUD (Create / Read / Update / Delete) operations [INFOSYS]. REST is not linked to any particular platform or technology thus making it an ideal solution for integration of diverse functional components. Formats that can be used for the exchange of information include widely used open-standards such as JSON, XML, CSV, TSV, which also allow for great flexibility in the specification of respective interfaces between different components. It is envisaged that each software component can be represented as a RESTful web and can thus easily communicate with other software components.

9 Hardware integration methodology

When integrating hardware blocks, difficulty comes from the fact that many different interfaces can exist making the integration work very painful.

RFNoC (RF Network on Chip) approach simplifies system design by allowing easy connection between components. This kind of interfacing is appropriate for streaming high-speed data, reading and writing registers, and communicating with software parts. By using these standard interfaces, you enhance the interoperability of your designs and you can make them work either on b<>com platforms or other commercial platforms. This approach was first proposed by Ettus research (https://www.ettus.com/sdr-software/detail/rf-network-on-chip).

9.1 RFNoC architecture overview

The RFNoC architecture is based on a main crossbar on which are connected one or more RFNoC block(s), also called computation engine (CE). See **¡Error! No se encuentra el origen de la referencia.**. RFNoC block integration is simple since the interface with crossbar is made of only two buses (stream IN and stream OUT). Stream IN and stream OUT buses are of AXI-stream type. Streams are formatted as requested by the Vita 49 standard. Data and commands share the same bus.

The crossbar is also connected to software via an HW/SW wrapper.

The HW/SW wrapper will allow software to send/receive data from/to HW and also allow configuration and control of HW blocks. The HW/SW wrapper will communicate with hardware via Giga bit Ethernet, Optical links or PCI express link (Gigabit Ethernet will be the first implementation).

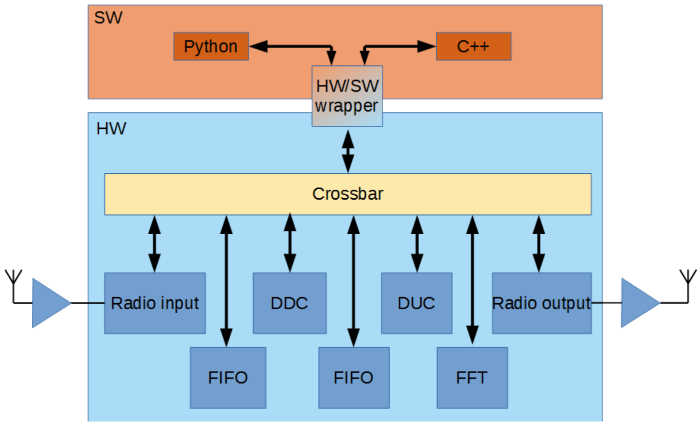


Figure 1 RFNoC architecture overview

9.2 RFNoC block overview

Signal processing algorithms are contained in modules known as "NoC Blocks" or "Computation Engines" (CE). These HW blocks are designed in Verilog or VHDL. Each RFNoC block communicates with the crossbar via a streaming interface based on AXI stream and VITA 49 protocol (http://www.vita.com/VITA-49). Inside each RFNoC block, there is an RFNoC interface whose role is to encapsulate/un-encapsulate data coming from/to the user IP. The RFNoC interface also allows register access to configure the user IP.

The crossbar routing may be dynamic (configured by software) or static (defined at compilation time). See **¡Error! No se encuentra el origen de la referencia.** below.

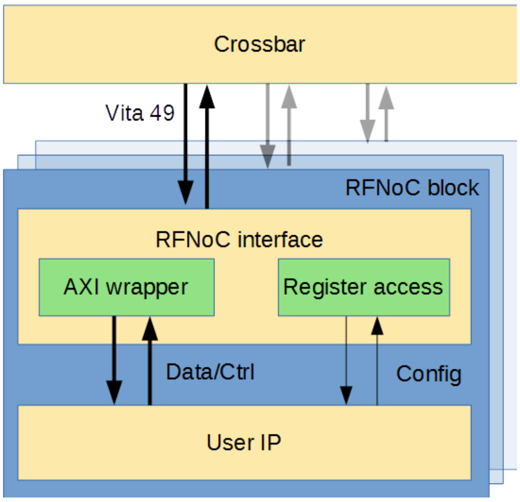


Figure 2 RFNoC block architecture

9.3 Example of interconnection

In the example below, the radio input block gets the signal from RF antenna via external ADCs, converts I&Q demodulated signals into AXI-stream which is then sent to the crossbar. In a second step, the stream is sent to DDC through a FIFO, and then to FFT through a FIFO likewise. Finally, the FFT block sends the stream to the HW/SW wrapper through the crossbar. It is then possible for an application written in Python, to process data or display them into a GUI. This is explained in **¡Error! No se encuentra el origen de la referencia.**.

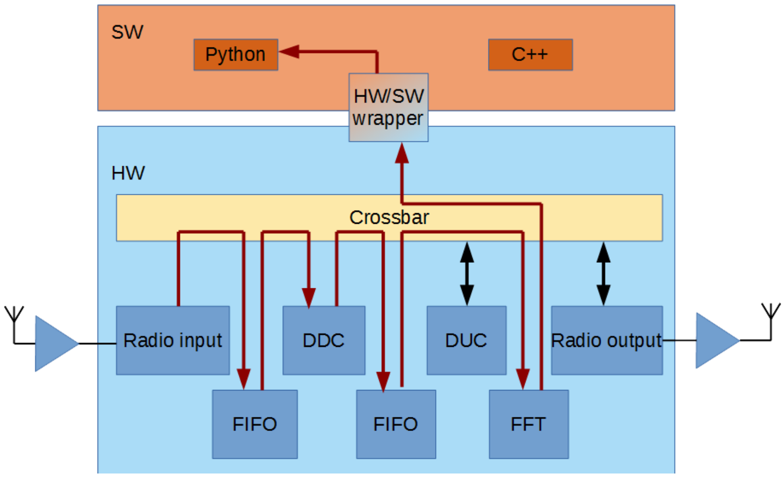


Figure 3 Example of RFNoC interconnection

9.4 AXI stream signals overview

In the table below are listed signals that will be used for communication between RFNoC blocks.

AXI Stream signals	Type	Role
clk	Signal	Clock used by the RFNoC block
tdata	Bus	Data coming from the RFNoC block going to another RFNoC block
tready	Signal	Used to notify an RFNoC block that downstream RFNoC block is ready for data.
tvalid	Signal	Used to indicate that upstream RFNoC block has valid data.
tlast	Signal	Used to delimit packets to downstream RFNoC block.

The **¡Error! No se encuentra el origen de la referencia.** shows a time diagram of data exchange between HW blocks.

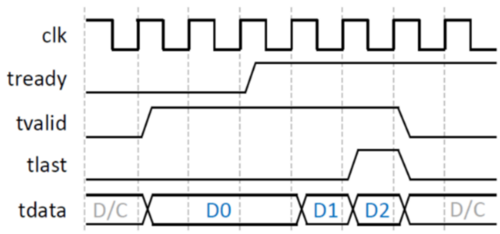


Figure 4 AXI stream transfer example

9.5 b<>com development environment

To simplify development cycle, b<>com will provide to partners:

- HW/SW wrapper as C++ code for SW side and VHDL/Verilog code for HW side,
- The crossbar component with static configuration (dynamic configuration will come later),
- An RFNoC template in verilog with RFNoC interface logic,
- Radio input and output blocks,
- Fifo blocks,
- Some other data processing blocks on demand (Digital Front End, FFT, …),
- One or more examples,
- Top testbench and RFNoC block testbench.
- Simulation scripts.

10 Conclusions

This deliverable has qualitatively introduced the ONE5G PoC scenarios that will demonstrate and evaluate the main innovations of the project. Initially, a brief description of the 8 available testbeds is presented, including a short summary of the equipment, as well as, their capabilities on implementing and integrating functionalities on top of them. In addition, a detailed description of the testbeds is included in the Annexes. Then, in this document, the five PoC scenarios have been presented and the ONE5G features related to each of them have been defined.

The PoCs presentation have been performed considering several aspects: a storyline, a general description of the scenario, the relations of the scenario with the WP2 use cases, the KPIs definition related to them and lastly, the list of related PoC components. This presentation has been performed for each of the five PoCs. The storyline is a brief user story that contextualises the PoC and provides a general idea about the potential applications that it plans to demonstrate. The description details the PoC technical requirements and at the same time relates, these technical requirements, to the testbeds involved. The WP2 use cases relationship section lists the main verticals and use cases that are related to the PoC. In line with the definition of use cases in WP2, a set of preliminar KPIs have been defined to be taken into account in the PoC evaluation. This KPI selection among others, takes into consideration the limitations of the participating testbed. Finally, the last section of PoC presentation, is the list of PoC components to be included in the specific PoC. In this section, the set of WP3/WP4 technical components to be implemented and integrated into the PoC are presented, including the technical components names, the originating task and sub-topics and the testbed where they will be implemented. Furthermore, the rationale behind the selection of the technical components have been included, justifying why of the total of WP3/WP4 technical components, some of them have been selected and others do not.

Lastly, some general guidelines have been proposed, related to hardware / software methodology, in order to set the scene for the implementation, integration and evaluation of the technical components and the participating testbeds. In this line, the following WP5 deliverables will give more details.

A. ANNEX: DETAILED TESTBEDS DESCRIPTION

A.1 Multi-link/multi-node and C-RAN testbed

The AAU testbed is based on 24 USRP RIO 2953 boards with 2x2 MIMO capabilities. Couples of boards can be grouped in a 4x4 MIMO configuration. An example of a 4x4 MIMO setup is shown in Figure 5. The two boards are connected through PCIexpress with an Intel I7 host PC. Both boards share the same local clock with a master-slave configuration (daisy synchronization). The USRP boards are used as RF front ends as well as for digital up-down conversion, while the baseband processing runs on the host PC. The processing functions are implemented with LabVIEW Communication Suite. The overall Tx/Rx node architecture is shown in Figure 6.

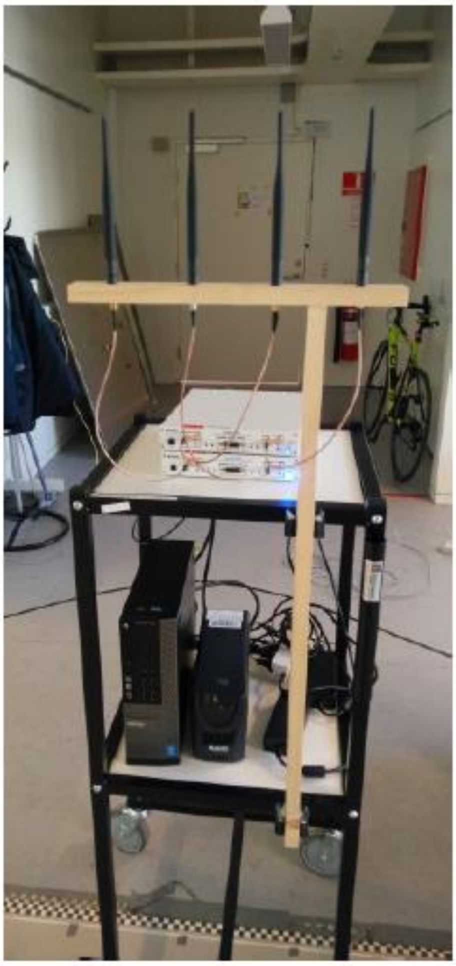


Figure 5. MIMO 4x4 node, composed of 2 USRP RIO 2953R connected to an Intel I7 host PC. Each node has an UPS which may facilitate the re-deployment in a new position without powering down the node.

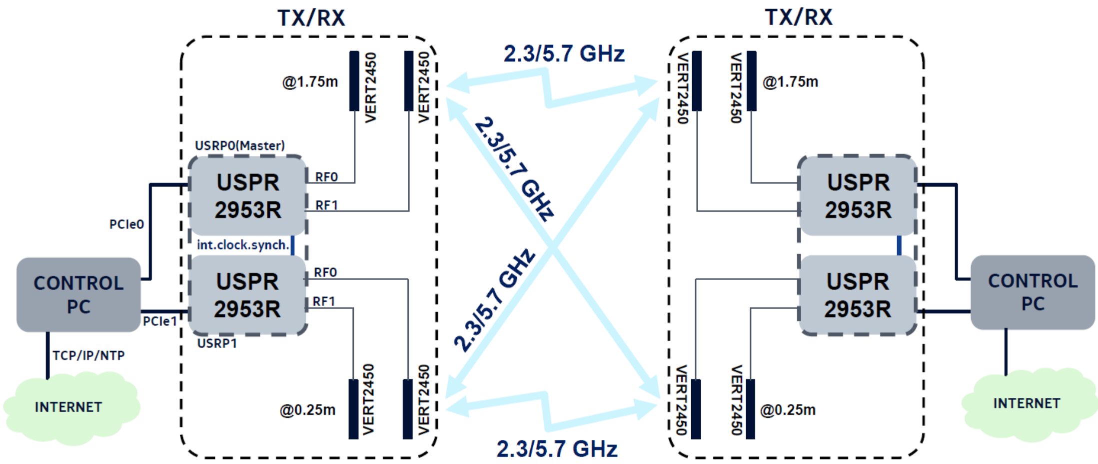


Figure 6. Tx/Rx node architecture

Parameter	Value
Reference configuration	12 nodes, 4x4 MIMO
Operational Bands	2.4 GHz, 5-6 GHz
Reference Sequences	Zadoff-Chu
Effective bandwidth	24 MHz, 601 subcarriers with 39.06 kHz subcarrier spacing, muted DC carrier
Max time resolution	41.66 ns
Sampling Rate	40 MS/s
Symbol size/duration	1024 samples /25.6 us
Measurement dynamic range	Max : -25 dBm Max sensitivity (Dynamic range 86 dB@14 bit resolution): -111 dBm
Transmit power	6 dBm @ 2.4 GHz, 5 dBm @ 5-6 GHz
Synchronization	Internal ref. clock accuracy : 25ppb, Single-link (reference sequence correlation), Multi-node (NTP, accuracy ~10 ms).
Antennas	Dipole VERT2450, ~2dBi @ 2.4 GHz / 5-6 GHz

Table 15 Key Features of the AAU testbed

A number of boards can also be grouped and connected with a PXI-chassis featuring a PXIe-8135 controller, to emulate a base station with a large number of antennas. 3 octoclocks are used in this configuration as timing distribution network. However, so far, such configuration has only been used in reception mode.

The boards are transmitting time or frequency interleaved reference sequences (Zadoff-Chu), which are used at the receiver nodes for estimating the channel responses. The receiver correlates against a copy of the reference sequence used at the transmitter in order to achieve the correct timing and phase reference for the sake of a correct channel estimation. KPIs such as SINR for different receiver types (e.g. Maximum Ratio Combining or Interference Rejection Combining) or throughput are calculated from such estimated channel responses. The key technical features of the testbed are summarized in Table 15. The values in the table refer to a recent measurement campaign run at Aalborg University premises.

The testbed can be operated in the following modes:

- Channel sounder: the testbed estimates the channel responses from multiple transmitters and save them for offline analysis. The algorithms are then studied offline with a system level simulator, using however real channel measurements.
- Live demo: the measurements are collected on-the-fly and used as an input for the processing. The algorithm's performance is then estimated and displayed live.

The testbed is able to estimate up to *NxN* channel matrices in a network of *N* nodes, where each entry of the matrix has a 4x4 dimension in case the MIMO 4x4 node configuration is used. In a generic configuration in which the transmitting nodes are $n<N$, each receiver node is able to estimate the channel responses of the links of all the transmitting nodes.

The estimation of the channel responses from multiple nodes can be obtained by executing a Time Division Duplex (TDD) pattern where only one node at a time is transmitting in a certain time slot, while the others are receiving. Such TDD pattern subsumes time synchronization among the nodes, which can be achieved by relying on the Network Time Protocol (NTP). The accuracy of the NTP is in the order of tens on milliseconds, and poses a constraint on the duration of each time slot. A time slot should be indeed significantly longer than the NTP accuracy in order to avoid overlapped transmissions and corrupted measurements.

The estimated channel matrices at each node, are then sent through a backhaul network (Ethernet or WiFi) to a centralized server.

The server acts as testbed controller. It activates/deactivates the multiple nodes, and collects the instantaneous measurements. In case of live demo mode, the measurements are then used for estimating the performance of a given algorithm, also considering different receiver types; the estimated performance can be then displayed over a GUI.

A.2 MIMO Multi-RAT and multi-band testbed

A.2.1 Overview

The Multi-RAT platform is a small equipment (210mmx160mm) that allows RX/TX on multiple bands and in particular, on the 60GHz band.

Features:

- Two FPGAs Arria 10 GX660
- 2 Dual ADCs with sampling rate > 1.5 GHz
- 2 Dual DACs with sampling rate > 1.5 GHz
- 50MHz – 10,5GHz RF frontend
- 4Gb DDR4
- 24 high speed optical links (For instance: aggregate data coming from other Multi-RAT equipment)
- 2 Giga Ethernet links
- 2 USB links
- 1 expansion port for general purpose daughter board.
- No CPU.

Figure 7 Equipment I

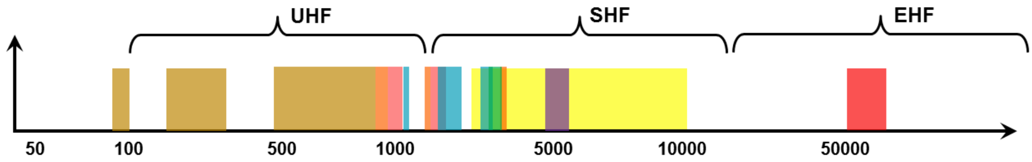
Figure 8 Equipment II

A.2.2 Supported spectrum

The RF frontend has two local oscillators that allow reception and transmission on 2 bands of 900MHz in both UHF and SHF frequency bands.

It has also a 60 GHz frontend that allows transmission/reception in the 60GHz band.

Below is presented the supported spectrum by the RF frontend:



Name		BW	Operating Frequencies
2G	GSM, CDMA, GPRS (2.5G) EDGE (2.75G)	200 kHz	850-900 MHz 1800-1900 MHz
3G, 3G+	UMTS, WCDMA	5 MHz	1885-2025 MHz 2110-2200 MHz 900-2100
3,5G	HSDPA	10 MHz	5 GHz
4G	LTE	Max 20 MHz	800 MHz 1800 MHz 2600 MHz
WiFi	802,11 x	Max 80 MHz	2,4 GHz
Broadcast	FM band TV Band III TV Band IV-V	10 kHz 8 MHz	87-108 MHz 174-230 MHz 470-862 MHz
Bluetooth		Max 1 MHz	2,4 GHz
UWB		Max 500 MHz	3.1 – 10.6 GHz
60 GHz mmW		2.16 GHz (1.8 GHz)	57 – 64 GHz

- Radio frequency operating bands :

  U – SHF : 100 MHz – 10.5 GHz
  EHF : 57 – 64 GHz

- Radio frequency channel bandwidth :

  U – SHF : 500 MHz
  (2 x 250 MHz Base Band)

  EHF : up to 1.8 GHz
  (2 x 900 MHz Base Band)

- **Fully independent Tx and Rx mode**
  (except for the 10 MHz reference frequency)

Figure 9 Supported spectrum

A.2.3 Internal architecture

The multi-RAT platform has a very powerful clock generator. Frequencies can be generated with steps lower than milli Hz.

ADC and DAC are high performance Analog Devices chips. Their sample rate can go up to 2GSPS.

Below is presented the internal architecture of the equipment that shows the capabilities of the platform to aggregate multi-bands for multi-connectivity services transmission for both Tx and Rx sides.

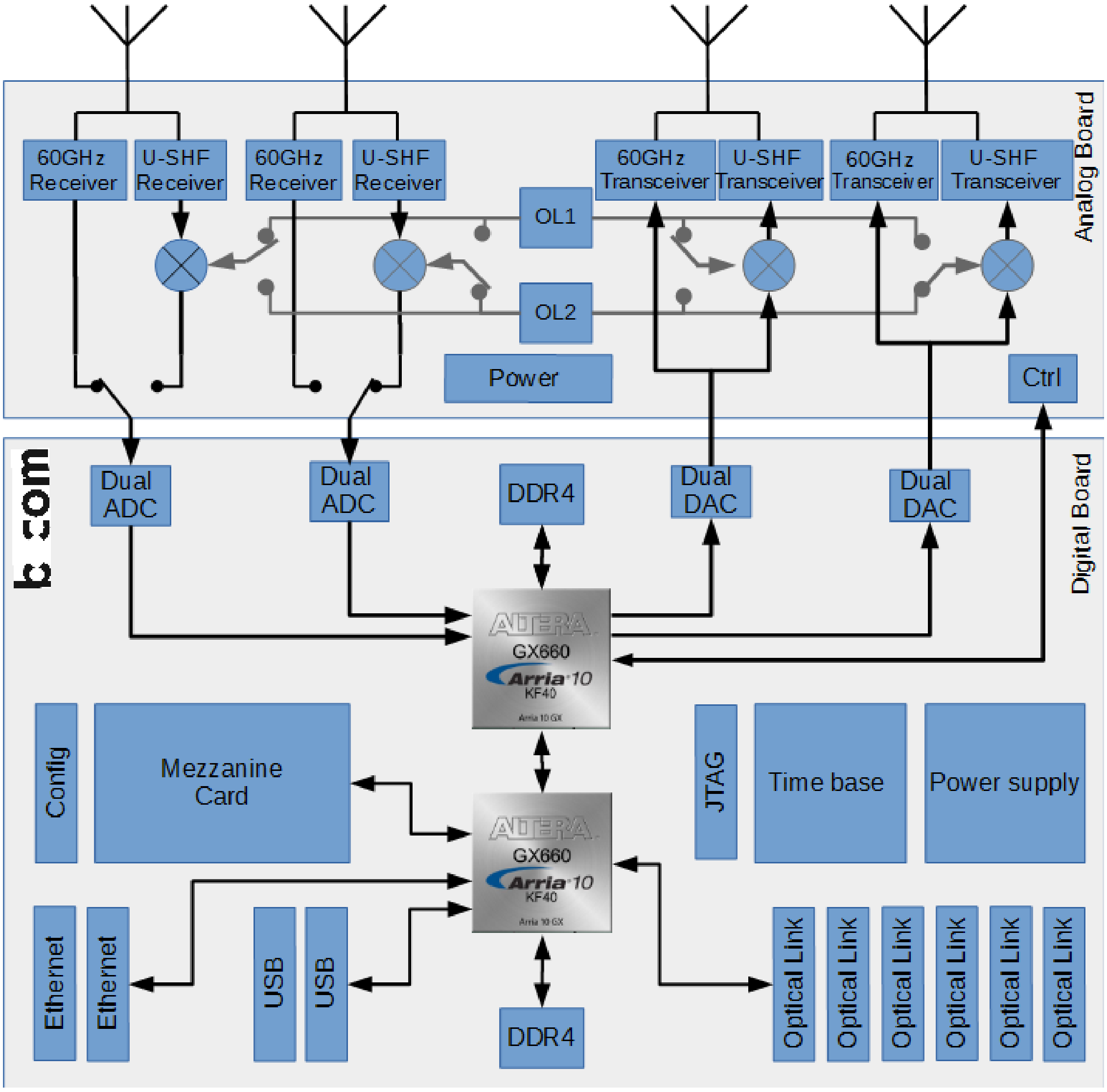


Figure 10 Equipment internal architecture

A.2.4 Interfaces

There are two possibilities to connect with this equipment:

1. Connection can be made by the Giga Byte Ethernet interface by mean of one the following protocols (Not decided yet):
    - VITA-49
    - SNMP
    - REST
    - House-made protocol based upon MAC layer.
2. Connection can also be made via a PCI express bus connected to one of the optical links. This approach needs a specific board on PC side.

A.2.5 Hardware parts available for PoCs

B-COM has developed FPGA processing blocks for telecommunication purposes.

These processing blocks are freely available for partners as pre-compiled code during the time of the ONE5G project (considered as background).

New blocks developed during the ONEG5 project will be available as source code for all partners.

Wireless Library (Channel Coding)

- Rx/Tx Convolutional coder
- Rx/Tx 4G Turbo Coder
- Rx/Tx WiFi LDPC Coder
- Rx/Tx 4G Rate Matcher
- Rx/Tx DeMapper/Mapper
- (BPSK, QPSK, 16QAM, 64QAM)

Signal processing library

- CIC (cascaded integrator–comb)
- FARROW
- FIR (Finite Impulse Reponse)
- Filter Bank
- FFT (Fast Fourier Transform)

The methodology of development (architecture design) allows the system to be very fast reconfigurable enough (few nanoseconds) to switch between different radio interfaces and/or parameters that could be very useful in case of flexible reconfigurable radio design.

A.3 Flexible reconfigurable testbed

This testbed is based on several USRPs X310 with home-made RF frontend to improve performances. USRPs are driven by Open Air Interface.

A.3.1 USRP X310 Overview

- Xilinx Kintex-7 FPGA. No CPU.
- SBX-120 daughter board (up to 4,4GHz with 120MHz bandwidth)
- 200 MSPS sample rate
- B-COM is able to modify USRP firmware and can implement its own hardware blocks.

Figure 11 USRP X310

A.3.2 RF Frontend for USRP

B-COM has also developed a RF-frontend specifically for USRP X310 that improves Rx sensitivity and Tx gain as well as filtering in the 2,6GHz band.

Input and output gain is directly controlled by the USRP frontend GPIO port. It has quite the same form factor as the USRP X310.

Figure 12 RF Frontend

A.4 Flexible Massive MIMO testbed

Fraunhofer Heinrich Hertz Institute (HHI) M-MIMO Lab can be used for initial indoor tests. A selection of calibrated measurement equipment for real-time signal generation and analysis from ROHDE&SCHWARZ is available.

- FSW13 (Signal- and Spectrumanalyzer)
- SMU200A (Vector signal generator)
- TSMW (Universal Radio Network Analyzer)

Figure 13 Fraunhofer Heinrich Hertz Institute (HHI) M-MIMO Lab

A.4.1 Measurement equipment: Synchronomat

The Synchronomat is developed by Fraunhofer HHI. Each of these synchronizations units has a 10 MHz calibration input and output port. Both any 10 MHz reference source, as well as several of these devices can be connected together in an initial calibration step at the beginning of each measurement campaign. Thanks to the internal battery backup system, each calibrated device can then be brought to any required measuring location. Each Synchronomat itself is thermally stabilized and locked by a Rubidium and GPS. In addition to the two 10 MHz ports, two separate programmable timer-controlled arbitrary trigger ports are also available.

Figure 14 Synchronomat

A.4.2 Measurement equipment: M-MIMO NAMC-SDR

The NAMC-SDR platform for the radio side is also developed at Fraunhofer HHI. This flexible software defined radio (SDR) platform is for developing, prototyping and testing 5G massive multiple-input, multiple-output (MIMO and M-MIMO) base station transceiver (BTS) systems as well as for user equipment (UE) side. This device uses four flexible analog two antenna port transceiver SoCs from Analog Devices. All AD9361 transceiver are fully synchronized tuneable from 70 MHz up to 4 GHz (max. 6 GHz not synchronized) with a bandwidth/sample frequency of 30.72 MHz (max. 56 MHz). Several NAMC-SDR can be cascaded to support more antennas for M-MIMO. Signal processing and controlling is done by a powerfull Xilinx Zynq XC7Z045 SoC, consisting of a programmable logic and an integrated processing system (PS) running linux on a dual ARM-A9.

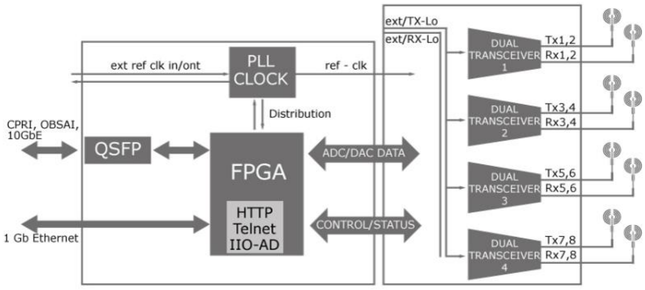


Figure 15 Schematic drawing of software-defined radio module

Four GTX transceivers (12Gbit lanes) are wired to a QSFP+ port on the front panel. This allows to implement high speed interfaces like CPRI and 10 GbE, which makes the SDR ready to use as flexible Remote Radio Head (RRH). CPRI protocol as well as GbE and has been tested with long fibers of more than 1 Km for fronthaul experiments. Another eight GTX transceivers are wired to the MicroTCA backplane. The NAMC-SDR also has an Industrial IO (IIO) interface, which provides transmit and receive buffer to offline processing, e.g. with MATLAB, python or C code. This standardized interface will enable HHI and the rest of partners to test their waveform using either hardware-in-the-loop approach or transmission over the air.

Figure 16 NAMC-SDR module

A.4.3 Measurement equipment: M-MIMO Antennas

M-MIMO antennas are planned to have 4 rows and 8 columns elements per array. Each planar uniform linear array (PULA) can be used for both receive and transmit. Every individual antenna element in this array has a horizontal and a vertical polarization port. The planed center frequencies are WLAN band 7 at 2.442 GHz, LTE band 7 (FDD) and band 38 (TDD) at 2.6 GHz and LTE band 42 (TDD) at 3.5 GHz.

Figure 17 Massive MIMO antenna

A.5 5G URLLC V2X testbed

The 5G URLLC V2X Testbed includes a software defined radio platform with flexible L1/L2 protocol stack as well as the emulated higher layers. The hardware consists of several small form factor UE platform PCs, USRPs and additional power amplifiers, aiming to support carrier frequency from 700MHz up to 3.6 GHz. The UE platform is scalable depending on the required data rate and limitation of the power consumption. On the cellular base station side, multiple antennas will be employed. In addition, high precision positioning system will be included. The software implementation intends to carry out 5G baseband processing supporting different numerologies, multiple antenna processing, retransmission mechanism, as well as basic traffic management/control. A typical setup is depicted in Figure 18.

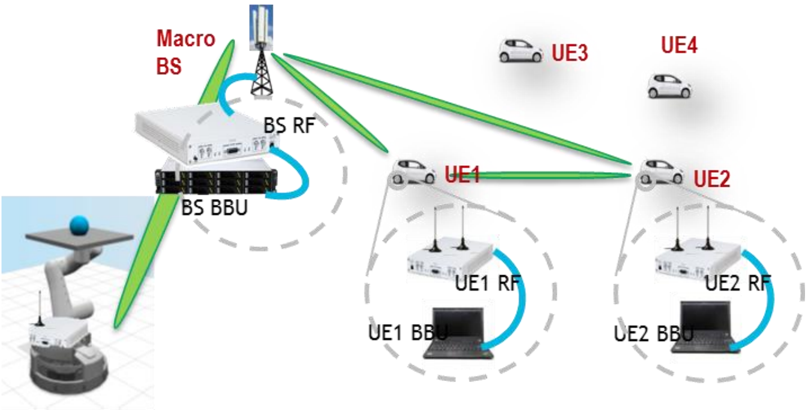


Figure 18 5G URLLC V2X Testbed

In detail, the 5G URLLC V2X Testbed is essentially based on flexible SDR architecture with the key enabler of the highly efficient and highly reconfigurable PHY/MAC processing software core. The side-by-side Matlab reference is available for link performance assessment (Figure 19). The major capabilities are listed below:

- Low-latency (<1ms) machine-type communication
- Reliability through customizable numerology, pilot density/strength, sync preamble length/strength, DFT spreading and optimal Rx diversity
- High flexibility in frame structure/numerology definition (Matlab -> C++ realtime), reconfigurable on the fly
- Versatile data interface to any smart machines (verified with DLR autonomous car)
- Small form factor, low power consumption

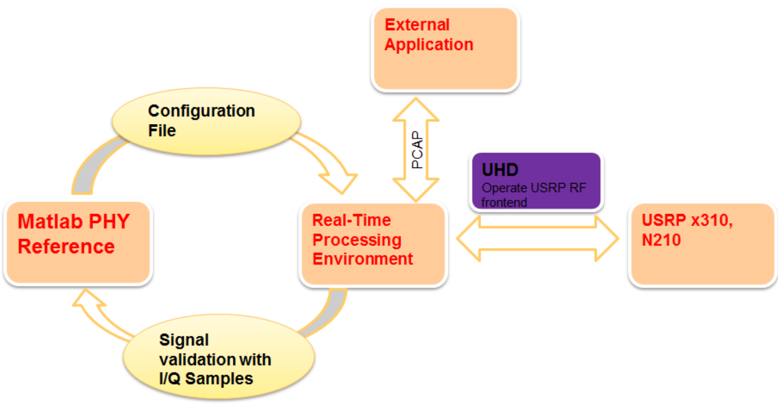


Figure 19 5G URLLC V2X Testbed

A.6 Full indoor commercial LTE network: UMAHETNET

A.6.1 General scheme

The UMAHetNet is a full indoor LTE network with all the elements it is composed of. This network is based on the solution for private networks that Huawei provides, where all the core network elements (HSS, MME, S-GW, P-GW and PCRF) are grouped into a single compact equipment, namely, the eCNS (evolved Core Network Solution), as shown in the figure below.

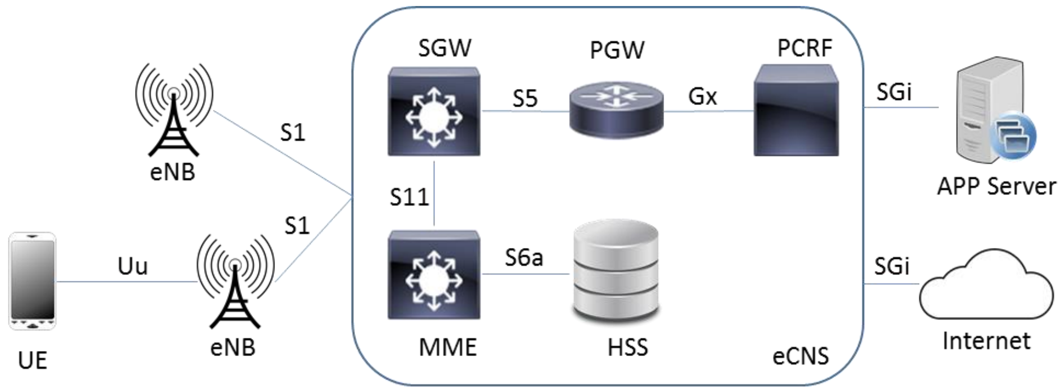


Figure 20 General scheme of the LTE network deployed at the University of Málaga.

Together with the eCNS, a tool for the management of the whole network is provided: the iManager U2000, the same manager used in the public networks deployed by the vendor.

The base stations are 12 picocells BTS3911B, which include a WiFi access point. The infrastructure is completed with the WiFi controller MAG9811, which, together with the iManager U2000 are expected to provide LTE/WiFi mobility.

By the moment, 12 LTE/WiFi-capable cell phones are available. Nevertheless, a higher number of MTC-like devices are expected to be part of this equipment during next year.

Finally, a 24-port GB switch is provided to interconnect all the elements, allowing other servers to be added and providing all the equipment access to the Internet.

Both the picocells and the eCNS are fully configurable. The picocells can be managed either directly through an LMT (Local Management Terminal) client or by means of the U2000 and eCNS clients. The latter allow the user to fully customize all the network parameters, as well as monitor the network status using built-in and user-defined KPIs. Furthermore, this testbed allows the user to integrate his own SON applications and algorithms, from self-configuration techniques to any self-optimizing and self-healing application.

A.6.2 Picocell characteristics

The specifications of the BTSs BTS3911B are shown in the figures and tables below.

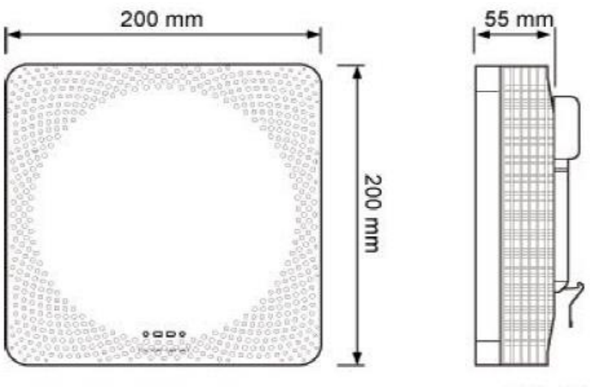


Figure 21 Physical measures.

Scenario	Frequency Band (MHz)	Receive Band (MHz)	Transmit Band (MHz)	Bandwidth (MHz)
PCS + AWS	PCS	1850 to 1910	1930 to 1990	5, 10, 15, 20
	AWS	1710 to 1755	2110 to 2155	5, 10, 15, 20
2.1G +2.6G	2.1G	1920 to 1980	2110 to 2170	5, 10, 15, 20
	2.6G	2500 to 2570	2620 to 2690	5, 10, 15, 20

Frequency band (MHz)	Single-antenna receive sensitivity (dBm)	Internal omnidirectional antenna gains(dBi)
PCS	-94	2
AWS	-94	2
2.1G	-94	2
2.6G	-94	3

Figure 22 LTE air interface specifications.

Item	Specifications
Maximum number of cells	● One band: 1 ● Two bands: 2
Maximum throughput	For a 2T2R cell: ● Downlink: 150 Mbit/s ● Uplink: 50 Mbit/s For the 2T2R BTS3911B: ● Downlink: 300 Mbit/s ● Uplink: 100 Mbit/s
Maximum number of UEs in RRC_CONNECTED mode	192 per cell 384 per eNodeB
Maximum number of concurrent data radio bearers (DRBs) per UE	8
Maximum number of concurrent DRBs	576 per cell 1152 per eNodeB

Figure 23 Capacity specifications.

Frequency Band (MHz)	Configuration	Maximum Output Power (mW)
PCS	2T2R	2 x 125
AWS	2T2R	2 x 125
2.1G	2T2R	2 x 125
2.6G	2T2R	2 x 125
Wi-Fi 2.4G	3T3R	3 x 40
Wi-Fi 5G	3T3R	● 3 x 40 (11n) ● 3 x 25 (11ac)

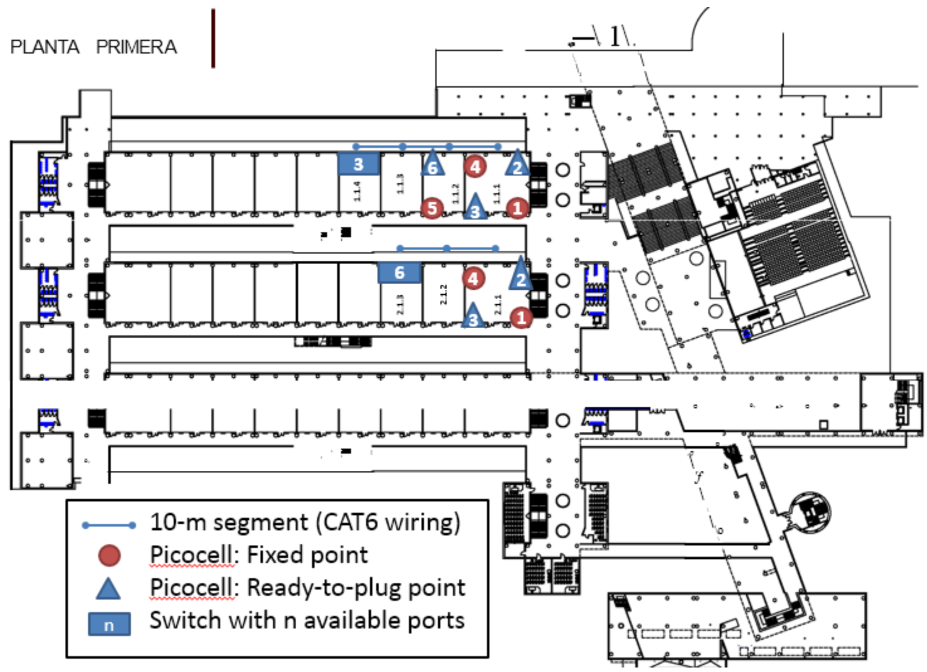
Figure 24 Output power.

Item	Specification
Supported Frequency Band	● 2.4 GHz frequency band: 2.4000 GHz to 2.4835GHz ● 5 GHz frequency band: 5.15 GHz to 5.850GHz
Gain (dBi)	● 2.4 GHz frequency band: 3 ● 5 GHz frequency band: 7
Transmit Power (dbm)	● 11n: 16 ● 11ac: 14
Maximum rate of physical layer (Mbit/s)	● 2.4 GHz frequency band: 450 ● 5 GHz frequency band: 1300
Single/Dual Band Mode	● 2.4 GHz frequency band: 802.11b/g/n ● 5 GHz frequency band: 802.11a/n/ac
MIMO	3T3R
Maximum number of associated users	256
Polarization Mode	Linear
Directionality	Omnidirectional

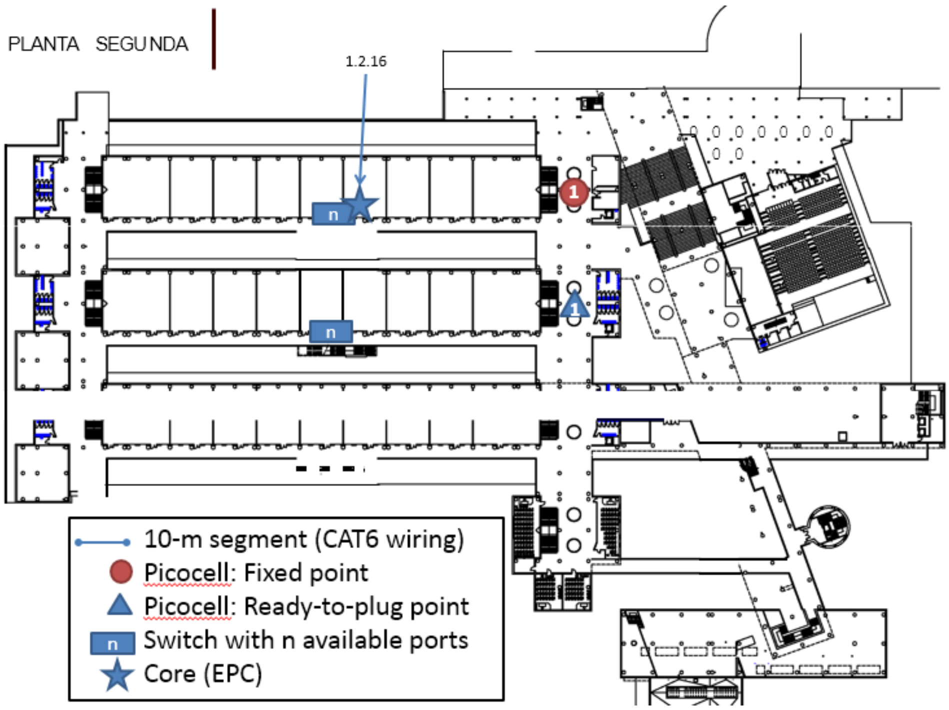
Figure 25 WiFi specifications.

A.6.3 Distribution

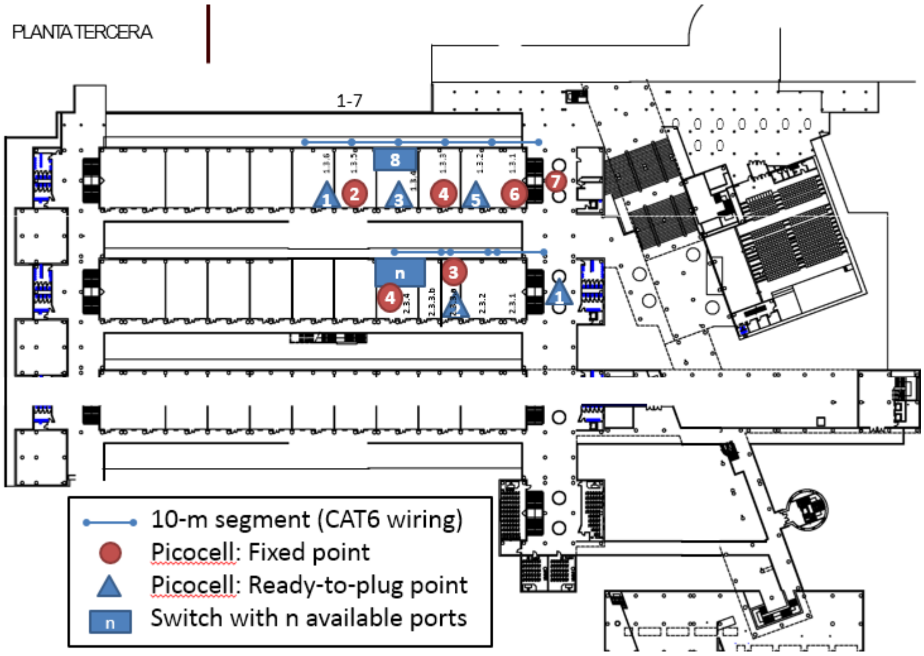
The UMEHetNet is deployed in the ETSI de Telecomunicación (Telecommunication Engineering School) of the University of Málaga. The distribution of the different HW elements of the network is provided in the drawings below.



a) First floor.



b) Second floor.



c) Third floor.

Figure 26 HW elements distribution.

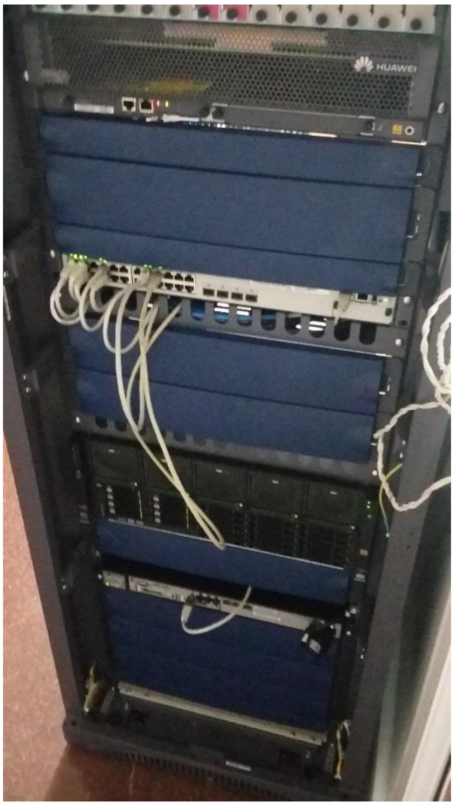
A.6.4 Captures of the HW elements

Some captures of the different elements of the network are provided for context on the system.

Figure 27 Example of deployed picocells.

a) Core in server room.

b) Front view.



c) *Rear view.*

Figure 28 Network core.

A.6.5 Internal network management tool (U2000)

The original management platform for the UMAHetNet is the U2000 Huawei software. The U2000 is capable of uniformly managing transport, access, and IP equipment.

This tool would be not accessible outside UMA staff but it would provide the functionalities of monitoring and configuration to be used by external users, as described in the next section.

A.6.6 Rest API

A REST API has been defined to gather measurements and perform changes in the UMAHetNet. Although this API will be detailed in further deliverables, here their main parameters and characteristics are described, considering its level of development by the time when this deliverable is generated.

The RESTful interface gives access to internal functions of the UMAHetNet:

- Performance Management: query PM (performance management)/CM (configuration management)/FM (fault management) variables for the e-NodeBs and core, filtering by network element and date/time.
- Configuration Management: modify the configuration of the e-nodeBs and core, using MML (Man-Machine Language) commands. MML is a language used typically in the configuration interface of mobile telecommunications equipment. More information can be found in the ITU-T Z300 recommendation series.

This interface is accessible as a REST API that can be used with standard HTTP libraries easily integrable in any algorithm for SON functions, monitoring, etc.

To use the REST API, a set of URLs will be provided for authentication and access, as well as documentation for the request formats and JSON output.

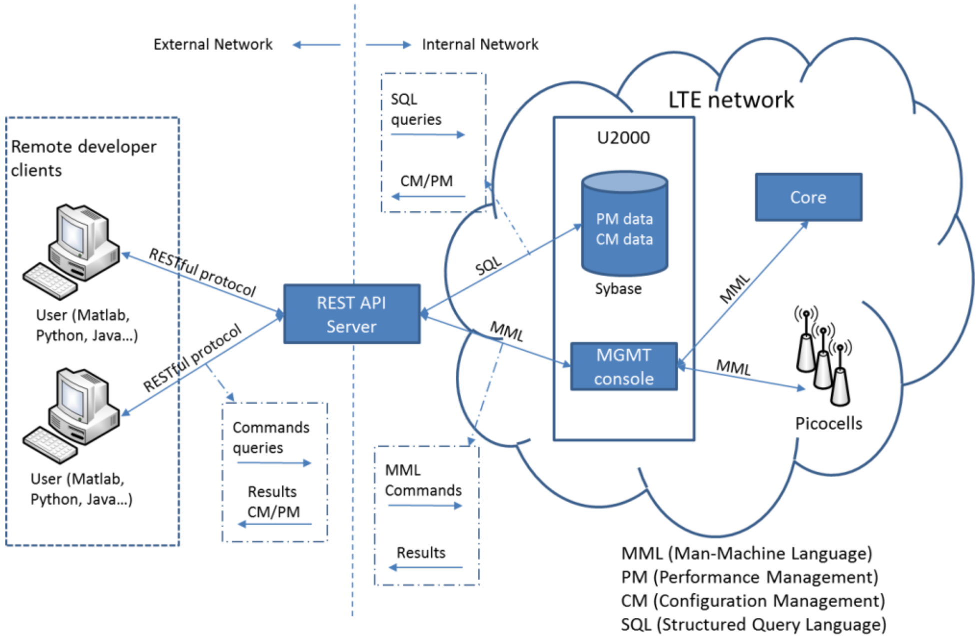


Figure 29 API current status.

A.7 Platform for vertical service delivery through 5G - IoT and big data- technologies

The platform for vertical service delivery through 5G - IoT and big data- technologies enables experimentation on 5G small cell network deployments by using USRPs.

The testbed comprises:

- 2 USRPs X310 [UX310]
- 4 USRPs B210 [UB210]
- 4 CBX-120 Daughterboards
- 2 VERT2450 and 2 VERT900 Antennas
- 2 Wi-Fi APs (COTS)
- 6 PCs connected with the USRPs
- 3 UEs (COTS)
- 2 Servers
- Arduino Uno with DHT11 Temperature and Humidity sensors, LDR Analogue Luminosity sensors, Motion detection sensors, LED actuators and buzzer
- Libelium WaspMote with Libelium Temperature Sensors and LDR Analogue Luminosity sensors
- SparkFun FIO board with DHT22 Temperature and Humidity sensors, LDR Analogue Luminosity sensors, LED actuators and buzzer.

In all the aforementioned USRPs, the OpenAirInterface (OAI) framework [OAI] is deployed. The main elements of the testbed are illustrated in Figure 30.

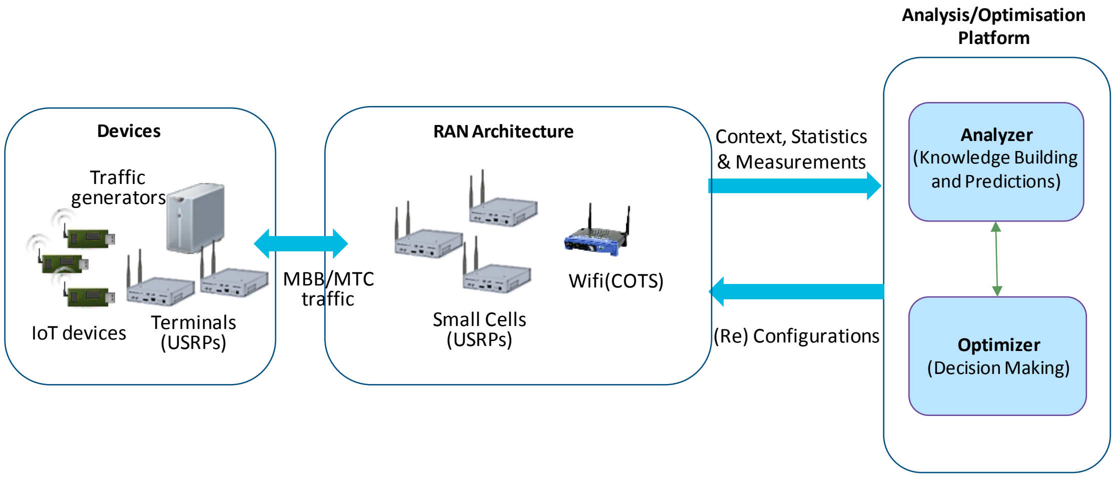


Figure 30 Network optimisation and predictive analytics testbed

In addition, the testbed includes an in-house software platform which supports network measurement collection, analysis, knowledge building, predictions generation and network optimisation. The testbed can support licensed (LTE), unlicensed (Wi-Fi) and lightly-licensed (3.5GHz) bands. The software platform and its basic functionalities are depicted in Figure 31.

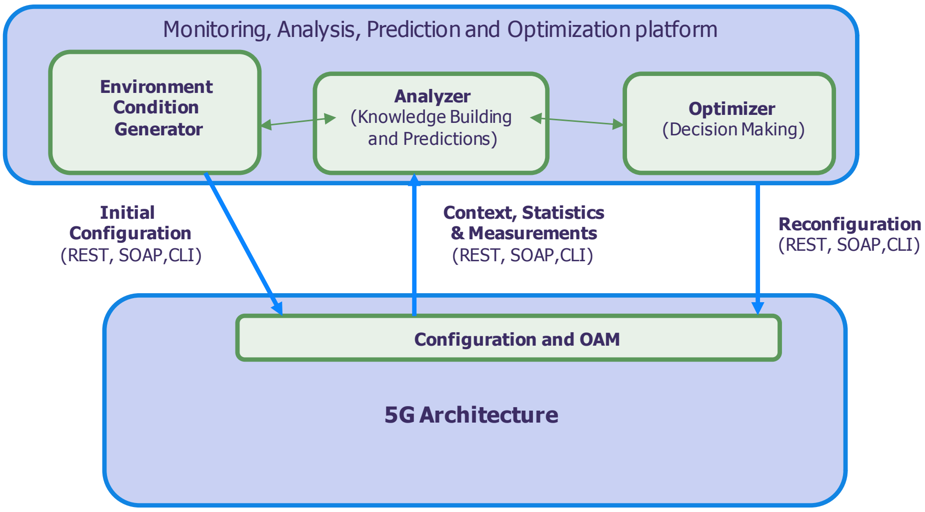
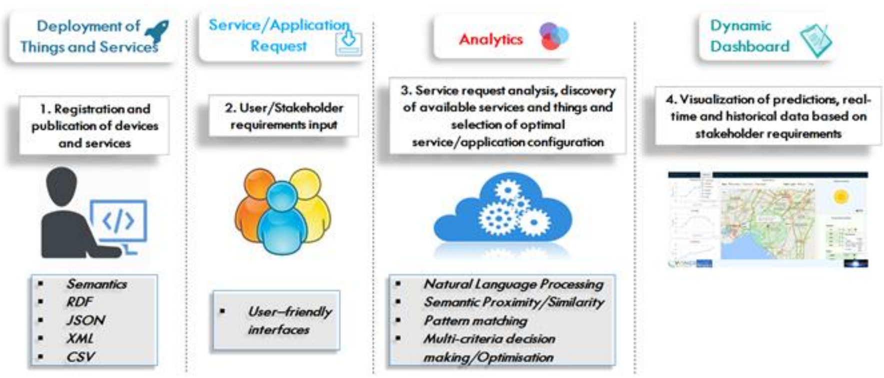
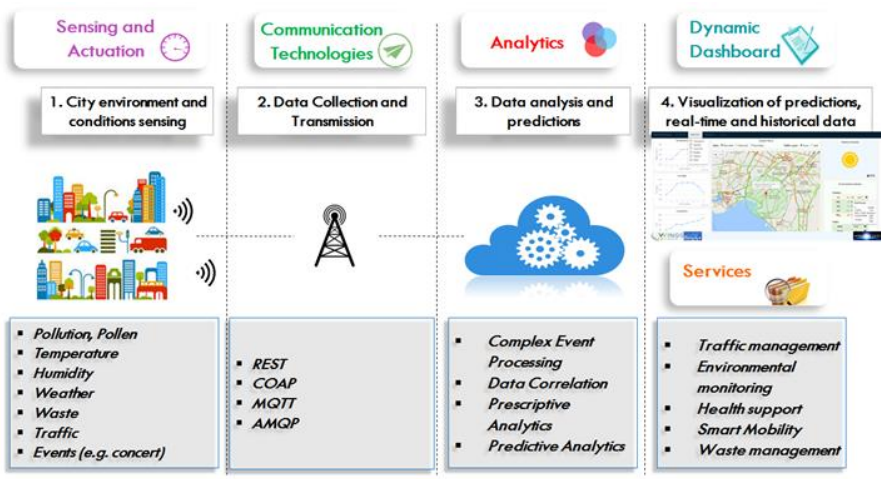


Figure 31 Analysis, optimisation and control platform

The testbed also includes a Cloud based IoT platform that aims to address two key issues in the context of future internet applications, namely: (i) the abstraction of the heterogeneity that derives from the vast amounts of diverse objects/devices and data sources while enhancing intelligence and reliability of relevant service and applications. (ii) the consideration of the views of different users/stakeholders for ensuring proper application provision, business integrity and, therefore, maximize exploitation opportunities. In this direction, the platform realizes the principle that any resource, real world object, digital object, data source which is available, accessible, observable or controllable, can have a virtual representation. This means that the functionality or features offered by any kind of object can become part of more composite functionality/features, which will be reusable in the context of sophisticated application/service provision e.g. in Smart Cities. Moreover, the testbed comprises features for dynamically selecting its behaviour (managed system's configuration), through self-management/awareness functionality, taking into account information and knowledge (obtained through machine learning) on the context of operation (e.g., internal status and status of environment), as well as policies (designating objectives, constraints, rules, etc.).



(a)



(b)

Figure 32: Concept overview (a) Focus on deployment of Things and Services and Dynamic Service creation; (b) Focus on process for visualisation of real-time and historical data as well as predictions in a Smart city scenario

The platform leverages on: (i) Standardized open communication technologies and protocols, (ii) Cloud technologies such as OpenStack, FIWARE, Docker, Kubernetes, (iii) Analytics and Artificial Intelligence and (iv) Visualization and customizable dashboards through Web and mobile applications.

Figure 33 depicts a high-level view of the system architecture and the technologies used.

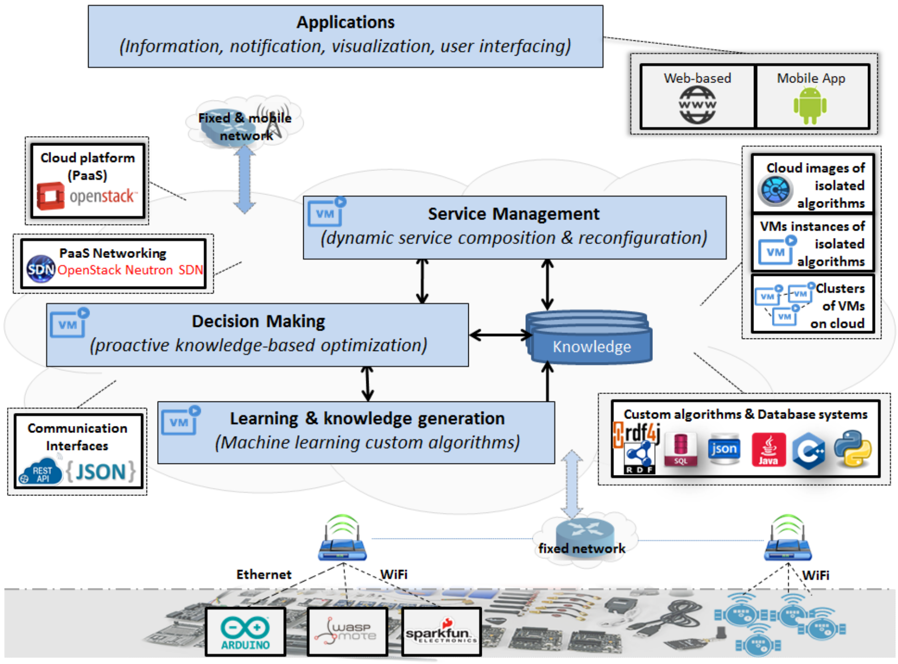


Figure 33: System architecture overview

The platform comprises: (i) Capabilities for self-management of services/application so as to facilitate greater flexibility, reliability and robustness. (ii) Machine learning functionality (e.g. Bayesian statistics, timeseries forecasting, Self-organising maps) for building knowledge and predicting contextual factors in various scenarios (e.g., network traffic, environmental pollution, user’s vital signs evolution, etc.). The derived knowledge can be exploited for reliable raising of alarms, efficient recommendations and application and system configuration. (iii) Decision making capabilities for the autonomous selection of the optimal application configuration actions taking into account current context, user profiles and knowledge. Application actions include for example the dynamic adjustment of indoor temperature based on user profile and behaviour knowledge in a smart home scenario.

All software components of the platform have been developed as Java RESTful Web services. For the implementation of storage and management of data on devices, services, user profiles the RDF4j API and the SPARQL query language are exploited. The data are stored in the form of RDF, while other supported data formats include JSON, XML, CSV, TSV. Moreover, in order to gather and transmit data that corresponds to heterogeneous data-sources (e.g. various types of sensors, datasets, APIs, etc.) an API combining REST and MQTT is provided that allows for real-time synchronous and asynchronous data streaming. For the visualisation of available data JavaScript visualization frameworks (like D3.js) combined with CSS3.0 and HTML5.0 representations are exploited.

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