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D6.1: Testbed Architecture and Setup

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Abstract

The proof-of-concepts (PoC) in SPEED-5G aim to implement and validate key technical components developed within the project. The demonstrations aim at showcasing feasibility and the superiority of the different components of the propose MAC/RRM designs. The document reports on the envisioned demonstrators, evaluation Key Performance Indicators (KPI) and the selected use-cases. Detailed information on the five intermediate demonstrators plus the integrated PoC, serving as the main SPEED-5G integrated testbed, for final demonstrations and trials, is provided. In addition to extensive set of planned test cases, document contains descriptions of the available and yet to be developed software components and hardware.

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Executive Summary

The demonstrators in SPEED-5G aim to implement key technical components developed within the project, and to validate different MAC designs and RRM techniques developed in SPEED-5G. This document provides a complete overview of the planned demonstrations, their configurations and associated test cases. The planned intermediate demonstrators, so called 'individual proof-of-concepts' (PoCs 1-5), serve to validate a number *specific solutions* and project innovations as proposed by each partner – these are:

- PoC 1: to validate and test the FBMC-MAC design and the hierarchical RRM solution,
- PoC 2: to validate and test the DCS-MAC solution,
- PoC 3: to validate the backhaul PtMP solution,
- PoC 4: to validate remote cRRM functionality/algorithms and communication with demonstrator platforms 1 and 2,
- PoC 5: to validate interworking of HD/UHD video traffic generation, monitoring and quality measurements.

In chapters 2 to 6, we describe each individual demonstrator, used to showcase individual solutions. As well as providing demonstrator setups, we describe available and to be developed software components and hardware platforms together with applicable test-cases, that are described and detailed in Appendix 1.

The intermediate demonstrators are then combined and integrated into a single demonstrator platform (PoC 6), described in section 7, which is the main SPEED-5G integrated testbed, for final demonstrations and trials, used to showcase only the main project innovations relating to capacity improvement, aggregation and offload.

The test cases encompass both functional tests (including tests for evaluation signalling, aggregation and offload procedures) and performance tests covering aspects pertaining to metrics of interest, including, e.g., throughput, delay, data channel performance, coexistence, and video quality. Test case based evaluations are used on the one hand to validate basic expected functionality (as designed and reported in deliverables D5.1 and D4.2) and on the other hand to enable qualitative comparisons of the proposed innovations against state-of-the-art and legacy technologies, so to clearly highlight achievable gains. The evaluation results will be reported and analysed in deliverable D6.3.

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Abbreviations

ACK	Acknowledgement
ACL	Adjacent Channel Leakage
ACIR	Adjacent Channel Interference Ratio
ACL	Adjacent Channel Leakage
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ADC	Analogue to Digital Converter
AIV	Air Interface Variant
AMC	Adaptive Modulation & Coding
A-MPDU	Aggregated-MAC PDU
A-MSDU	Aggregated-MAC SDU
AP	Access Point
AWGN	Additive White Gaussian Noise
BDP	bandwidth-delay product
BH	Backhaul
BLER	Block Error Rate
BP	Beacon Period
BPSK	Binary Phase Shift Keying
BS	Base Station
ASA	Authorized Shared Access
CA	Carrier Aggregation
CAP	Contention Access Period
CAPEX	Capital Expenditure
CCA	Clear Channel Assessment
CCA-ED	Clear Channel Assessment – Energy Detection
C-IoT	Cellular IoT
CoMP	Coordinated Multipoint
COTS	Commercial Out-of-The-Shelf
CP-OFDM	Cyclic Prefix based Orthogonal Frequency Division Multiplexing
CQI	Channel Quality Indicator
cRRM	Centralized RRM
CSAT	Carrier Sensing Adaptive Transmission
CSI	Channel State Information
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
cSON	centralized Self-Organizing Network (SON)
CTS	Clear To Send
D2D	Device-to-Device
DAC	Digital to Analogue Converter
DASH	Dynamic Adaptive Streaming over HTTP
dBm	Decibel relative to 1 milliwatt

DCI	Data Control Indicator
DFS	Dynamic Frequency Selection
DL	Downlink
DL/UL	Down Link / Up Link
dRRM	Distributed RRM
DTX	Discontinuous Transmission
DUT	Device under Test
Eb/No	Energy per bit to noise power spectral density ratio
EDCA	Enhanced DCA
EPC	Evolved Packet Core
eMBB	Extreme Mobile Broadband
FEC	Forward Error Correction
FER	Frame Erasure Rate
FFS	For further Study
FPGA	Field Programmable Gate Array
FTP	File Transfer Protocol
GbE	Gigabit-Ethernet
GHz	Gigahertz
GTP	GPRS Tunneling Protocol
HARQ	Hybrid ARQ
HD	High Definition (1920 pixel x 1080 lines)
HEVC	High efficiency video encoding
HMAC	Higher-MAC
HSMC	High Speed Mezzanine Card
HTTP	Hypertext Transfer Protocol
HW	Hardware
I/Q	Input/output
ID	Identification number
IE	Information Element
IPTV	Internet Protocol Television
LAA	Licensed Assisted Access
LAN	Local Area Network
LBT	Listen-Before-Talk
LMAC	Lower-MAC
LSA	License Shared Access
MCS	Modulation & coding Scheme
mIoT	Massive IoT
MMBS	Multimedia Broadcast Service
MO / MT	Mobile-originated / mobile-terminated
MOS-V	Mean opinion score video
MP4	Motion Picture Experts Group standard number 4
MSC	Message Sequence Chart

MTU	Maximum Transmission Unit
OAI	Open Air Interface
OS	Operation System
OSA	Open Software Alliance
OTA	Over The Air
OTG	Open Air Traffic Generator
OTT	Over The Top video service
PAR	Packet Error Rate
PDU	Packet Data Unit
PMF	Prob. Mass Function
PSNR	Peak Signal to Noise Ratio
PtMP	Point to Multi-point
Q-HD	Quarter High Definition (960x540)
QoS /QoE	Quality of Service / Quality of Experience
R&S	Company Rohde & Schwarz GmbH & Co. KG
RAT	Radio Access Technology
RF	Radio Frequency
RLC	Radio Link Control
RLF	Radio Link Failure
RPC	Remote Procedure Call
RRM	Radio Resource Management
RSSI	Received Signal Strength Indicator
RTT	Round Trip Time
RX	Receiver
SAP	Service Access Point
SAS	Spectrum Access System
SC & UE	Small cell & user equipment
SCell	Secondary cell
SDI	Serial Data Interface
SDN	Software-defined networking
SFTP	Secure File Transfer Protocol
SNR	Signal to Noise Ratio
SPI	Synchronous Parallel Interface
SSIM	Structural Similarity
SW	Software
TAU	Tracking Area Update
TBD	To Be Determined
TCP	Transmission Control Protocol
TDD	Time division duplex
TDMA	Time division Multiple Access
TFTP	Trivial File Transfer Protocol
Tput	Throughput

TX	Transmit
UC	Use Case
UDP	User Datagram Protocol
UHD	Ultra-High Definition (3840 pixel x 2160 lines)
UM/AM	Unacknowledged-mode / Acknowledged-mode
UnL	Unlicensed
USB	Universal Serial Bus
USRP	Universal Software Radio Peripheral
VLAN	Virtual LAN
VoIP	Voice over IP
XML	Extensible Mark-up Language
Y, Cb, Cr	Luminance and Colour differential signals

1 Introduction

An integral part of the validation of the SPEED-5G concepts and innovations is the realization of Proof of Concept (PoC) demonstrators. PoC demonstrators show that a certain concept or approach is technically feasible and can be implemented with reasonable effort. This deliverable outlines the design, physical setup, demonstrations plans, applicable use cases (UCs) and test-cases (TCs) of the demonstrators devised by the SPEED-5G consortium. The intermediate, so called 'individual demonstrators' (PoCs 1-5) have been designed to validate partner-specific solutions and project innovations, and are:

- PoC 1: to validate and test the FBMC-MAC design and hierarchical Radio Resource Management (RRM) solution. The demonstrator will showcase basic FBMC MAC supported procedures as well as select UCs,
- PoC 2: to validate and test the DCS-MAC solution. The demonstrator will showcase essential DCS MAC functions, procedures and selected UCs,
- PoC 3: to validate the backhaul Point-to-Multipoint (BH PtMP) solution. This demonstrator will showcase the capabilities of the proposed solution (applicable to both PoC 1 and 2) in terms of throughput and delay (with focus on the BH segment),
- PoC 4: to validate remote centralized RRM (cRRM) functionality/algorithms and communication with PoC 1 and 2,
- PoC 5: to validate interworking of HD/UHD video traffic generation, monitoring and quality measurements, in conjunction with PoC 1 and 2.

The intermediate demonstrators are then combined and integrated into a single demonstrator platform (PoC 6), which is used as the main SPEED-5G integrated testbed, for final demonstrations and trials. PoC 6 is therefore the project main testbed and trial platform and is used to showcase only the main project innovations relating to capacity improvement, aggregation and offload.

The choice of adopting a bottom-up approach for PoCs stems from the need to reduce integration risks in the final demonstrator platform (PoC6) and from the willingness to clearly evaluate partner-specific innovations, so to best showcase individual solutions from relevant project partners, via individual PoCs, covering only selected aspects, e.g. MAC design, RRM, BH etc., of the SPEED-5G palette of innovation.

With a focus on the broadband (capacity improvement) scenario and based on the related use cases identified in deliverable D3.2 [1], each intermediate PoC attempts to showcase individual features and use cases, e.g. PoC 1 and 2, both comprising the new MAC design, showcase aggregation, offload and channel switching. In addition the same set of features is also demonstrated within the scope of the integrated PoC, which brings together components validated by the intermediate demonstrators.

This deliverable is organized as follows: Section 1 describes a generic testbed architecture and its main components. The FBMC-MAC PoC 1 (from CEA) setup, use cases and applicable configurations are detailed in section 2. Section 3 covers DCS-MAC PoC 2 (from UNIS) configurations and use cases. In section 4, the PoC 3 setup for advanced PtMP BH solution (from ICOM) is discussed. The cRRM PoC 4 (from BT) focusing on validation of remote/local connectivity is described in section 5. PoC 5 (from R&S), described in section 6, aims to validate the communication and interfacing with other PoCs. Section 7 presents the integrated PoC 6 setup, used for final demonstrations of the project's main innovations. Finally, the conclusions and future steps are outlined in section 8. Details of test cases can be found in Appendix 1.

1.1 SPEED-5G Architecture and Alignment with Demonstrators

Speed-5G identified a number of use-cases (UC), as detailed in [1] namely:

- UC #1: Dynamic channel selection,
- UC #2: Interference management within a group of cells via load balancing,
- UC #3: Capacity boosting in a small cell using resource aggregation,
- UC #4: co-existence on shared channels.

The propose PoC designs and configurations not only serve to showcase the identified UCs and project innovations relating to MAC/RRM design, BH solutions and traffic monitoring, but also are closely aligned with the proposed system architecture, and used to validate it. Each PoC configuration is carefully tailored to validate basic functionalities based on the test-cases identified in Appendix 1.

1.2 Generic PoC Demonstrator Setup

Figure 1 illustrates the most generic setup for PoC demonstrations, consisting of an LTE system composed of an EPC and small cells connected to the evolved packet core (EPC). Apart from legacy LTE modules, the small cells also contain Higher-MAC (HMAC), Lower-MAC (LMAC) and RRM functional blocks for WiFi, FBMC-MAC and DCS-MAC, developed within the project. The UE can connect to the mobile network and access services offered or access any service on the Internet. As shown Figure 1, the UE that connects to the small cell can be a laptop with LTE/WiFi/FBMC/DCS interfaces or a commercial of-the-shelf (COTS) mobile phone with LTE/WiFi connectivity. For simulating the services, a content server is setup and connected to the EPC, running a web application accessible to the user(s). The cRRM server hosts RRM algorithms that manage resources on longer time-scales and communicates RRM decisions to the HMAC.

Due to the large number of different demo configurations, detailed demonstrator setups corresponding to different PoC configurations are depicted in sections 2 -6.

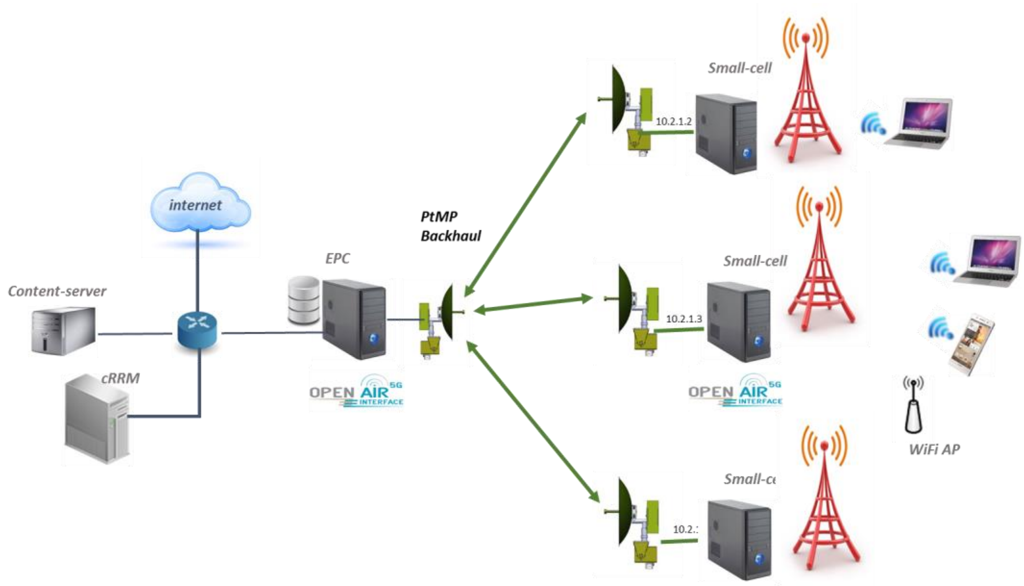

Figure 1: PoC demonstrator generic architectural setup

1.2.1 Physical Architecture

Figure 2 illustrates the physical architecture and topology corresponding to the generic setup shown in Figure 1. The LTE testbed comprises two servers: one for the EPC, and a second one for the eNB. The eNB server (hosting HMAC functions) is connected to radio components, e.g. Universal Software Radio Peripheral (USRP) 2954 [2] and X310 [3], or FBMC FLEX boards (hosting LMAC modules), via external RF interface, allowing the connection of UE. The EPC server is connected to a router that provides access to the Internet and to the content server. The remote cRRM entity, whose functionality and constituent blocks are described in [9] is hosted on a stand-alone server that is able to communicate with small cells. State-of-art video measurement and monitoring equipment is also integrated for use during demos and trials. COTS LTE and WiFi terminals are also included to evaluate impact of new techniques on legacy services (ongoing simultaneously) in terms of achievable capacity, fairness and interference, in co-existence scenarios.

Due to the large number of different demo configurations, detailed physical setups corresponding to different PoC configurations are depicted in sections 2 -6.

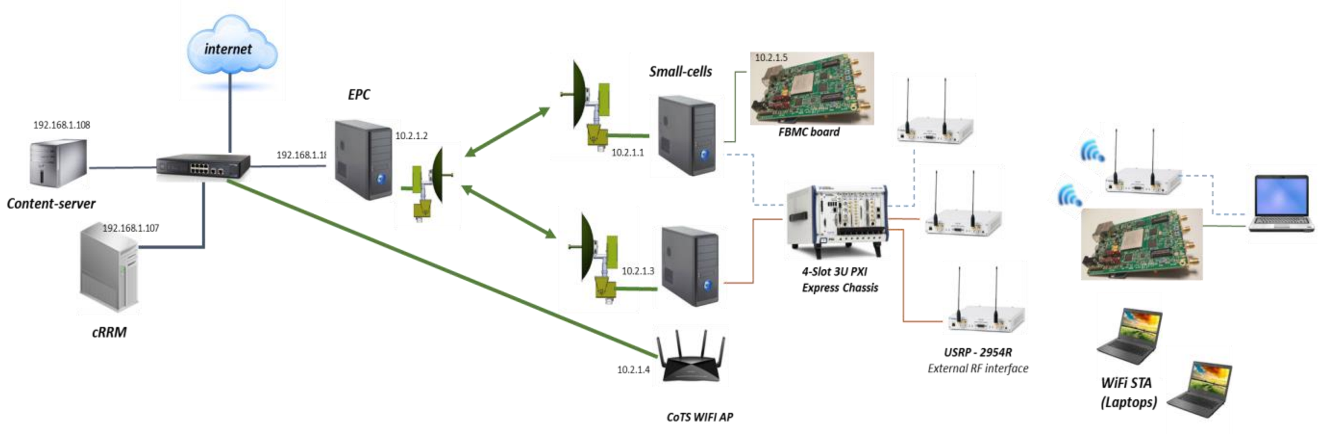

Figure 2: PoC demonstrator generic implementation (physical view) – example setup

1.2.2 Software Components

Figure 3 depicts the used software components of a typical demonstrator setup. The general architecture comprises of:

- The LTE EPC and small cell servers running Open Air Interface (OAI) software [4],
- The same multi-RAT/mode small cell servers also host HMAC functions required by FBMC-MAC, DCS-MAC as well as legacy WiFi systems,
- Multi-mode UE (laptops), which can connect to the network,
- The application server with Ubuntu 14.04, running Lighttpd web server [5]. A web application is created to test accessibility (used for stand-alone tests in PoCs 1, 2, 4 – The integrated PoC 6 will make use of video monitoring setup, as outlined in section 6).

The following provides a high-level description of the software components that are installed and deployed for the purposes of the demonstrations.

Open Air Interface software

The OAI from the Open Software Alliance (OSA) [6], provides an open-source ecosystem for the core (EPC) and access-network (E-UTRAN) protocols of 3GPP cellular systems with the possibility of interoperating with closed-source equipment in either portion of the network. OAI provides a standard-compliant implementation of a subset of 3GPP Release 10 LTE for UE, eNB, MME, HSS, SGw and PGw on standard Linux-based computing equipment (Intel x86 PC/ARM architectures), distributed under an Apache v2.0 license. Through this platform, it is possible to emulate a LTE base station (OAI eNB) and a backbone network (OAI CN), all on a computer or distributed over multiple PCs. In addition, it allows connecting commercial mobile devices in order to test distinct configurations and network settings, while monitoring them in real time.

Traffic generation and monitoring

A R&S video monitoring setup is used, as well as the OTG (OpenairTrafficGenerator) software [7] for generating traffic, and iPerf 3.3 [8] as the monitoring tool. The OTG network traffic generator allows for different traffic types to be used. The attributes of the created packets and connections can be controlled by several parameters, such as send rate or payload size, or can be determined randomly.

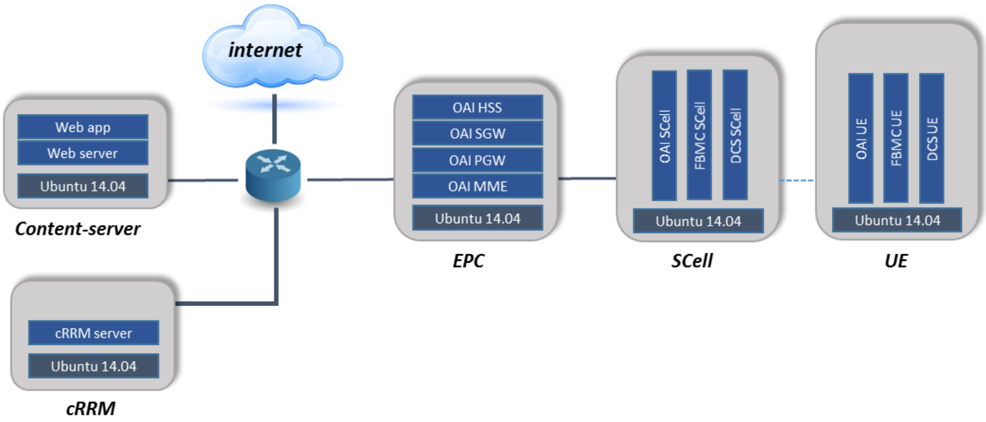

Figure 3: Software components of the PoC demonstrator

2 PoC 1: “FBMC MAC and Hierarchical RRM”

This demonstrator is used to showcase the feasibility of the proposed 5G FBMC-MAC on a real-time hardware platform to demonstrate the advantages that it can provide, as well as the gains from the implementation of hierarchical RRM. The PoC (and related variants) are based on a particular hardware platform and are used to demonstrate a number of functionalities. The following sections will describe the PoC variants in more detail, specifying the used hardware platforms, their hardware and software architecture and all relevant interfaces.

2.1 Motivation and Scope

The objective of PoC 1 is to highlight project innovations related to resource aggregation, offload/traffic steering, and dynamic channel selection, based on different eDSA configurations, using FBMC MAC. In light of this demonstration plan, 3 distinct demo configurations are identified (A to C below), each one providing ability to test and validate certain identified SPEED-5G features and algorithms. More specifically, this PoC addresses one of the key expected drivers of 5G, the capacity improvement that follows the provision of increased user data rates compared to the LTE system, considered as the baseline. The improvement of data rate is expected thanks to the extension of the carrier aggregation concept, relying on new spectrum chunks, and more efficient waveforms. Specific validation and tests are listed below:

- **Config. A (FBMC-MAC):**
    - “Basic call setup (incl. random access) and tear-down” for single UE on LL carriers,
    - “Multiple Access” - Basic call setup for multiple UEs on LL carriers,
    - "Dynamic channel switching" in LL regime
- **Config. B (FBMC-MAC and LTE) – co-located scenario:**
    - “Resource Aggregation” of licensed and LL carriers,
    - “Offload/steering” to UnL/LL bands,
    - "Hierarchical RRM"
- **Config. C (FBMC-MAC coexistence with WiFi) – co-located scenario:**
    - “Coexistence w/ WiFi” - on 5 GHz band,
    - "Hierarchical RRM - Coexistence"

This PoC focuses on the FBMC-MAC and RRM designs and on investigating their added benefits. In particular, this PoC targets the aggregation of FBMC-based secondary carrier working in conjunction with LTE, based on an OAI implementation. Show-casing traffic steering on UnL and LL spectrum, this PoC plans to validate the SPEED-5G eDSA framework by implementing key features of the split between H-MAC and L-MAC functions. This allows to highlight major outcomes of the eDSA concept, which are:

- Configuration and management of MAC components by the hierarchical RRM entity,
- Inter-RAT scheduling at H-MAC: logical channel management and mapping on L-MAC components,
- Utilisation of FBMC modulation in shared spectrum to exploit the excellent coexistence capability of this modulation, coming from the sharp spectral confinement of the signal.

The test cases associated with this PoC are outlined in section 2.5.

2.1.1 Use Case and Features Descriptions

This PoC focuses on the use cases identified in [1] involving dense deployment of small cells where home, office and shopping malls environments can coexist in a close vicinity. This leads to the deployment of dense heterogeneous networks where small cells are used to improve the capacity of the cellular access network at the expense of a high interference levels due to frequency reuse.

In addition to heterogeneous networks, resource aggregation is considered to boost the user data rates, employing license exempt (UnL, 5 GHz band for instance) and LL spectrum resources like 2.3 GHz or 3.5 GHz bands. For LL bands, spectrum sharing options like LSA (License Shared Access) or SAS (Spectrum Access System) are envisaged as spectrum access enablers. Whether it is because of license spectrum resource reuse in heterogeneous networks or because shared spectrum is used in carrier aggregation schemes, this PoC requires management of high levels of interference in both cases, relying on efficient channel selection algorithms for instance.

The demonstrator intends to address basic functionalities associated with the FBMC-MAC design as well as to showcase the identified UCs of Speed-5G, outlined in section 1.1, based on the FBMC MAC design.

2.1.2 KPIs for PoC 1

Table 1 and Table 2 below depict list of data plane (D-plane) and control plane (C-plane) KPIs considered in PoC 1 evaluations.

Table 1: D-plane KPIs

KPI	Description
Throughput	Average throughput (MAC and IP/APP layers)
Latency	End-to-end latency from source to destination
Reliability	Reliability in terms of Block Error Rate (BLER) and Packet Error Rate (PAR) under given data rate demands
Out-of-band leakage	Out-of-band leakage (PHY layer)
Power consumption	Power consumption in case of HW components
Hardware complexity	Hardware complexity in case of HW components

Table 2: C-plane KPIs

KPI	Description
eDSA latency	Total latency to accomplish a full eDSA cycle (measurements collection, algorithm execution, decisions enforcement)
dRRM latency	Total latency to accomplish a full distributed RRM (dRRM) cycle (measurements collection, algorithm execution, decisions enforcement)
cRRM latency	Total latency to accomplish a full cRRM cycle (measurements collection, algorithm execution, decisions enforcement)
eDSA bandwidth overhead	Bandwidth overhead in terms of percentage of additional control traffic (due to eDSA) to offered traffic
cRRM bandwidth overhead	Bandwidth overhead in terms of percentage of additional control traffic (due to cRRM) to offered traffic

2.2 PoC 1 Configurations

This PoC can be set-up in 3 different configurations, which are meant to implement the UCs in co-located and non-co-located scenarios, respectively. The PoC IDs corresponding to different configurations, are:

- **PoC 1A** – corresponding to Config. A: **FBMC-MAC**
    - Related to UC: #1
- **PoC 1B** – corresponding to Config. B: **FBMC-MAC & LTE, in co-located scenario**
    - Related to UC: #2 and #3
- **PoC 1C** – corresponding to Config. C: **FBMC-MAC + WiFi, in co-located scenario**
    - Related to UC: #4

2.2.1 Configuration A: FBMC-MAC (PoC ID: 1A)

The configuration shown in Figure 4 is used to validate basic signalling functionality e.g. random access, call setup/tear-down and handover. Moreover, dynamic channel switching can also be performed (i.e., sub-bands) within the LL band (FBMC-MAC) (intra-band channel switching) to ensure the best utilization of each channel, for example by mitigating interference. In addition to intra-band channel switching, the FBMC-MAC can support dynamic channel switching between licensed, UnL and LL spectrum (i.e. inter-band channel switching). This configuration allows for validation and testing of:

- Basic call setup (incl. random access) & tear-down" for single UE on LL carriers,
- "Multiple Access" - Basic call setup for multiple UEs on LL carriers,
- "Dynamic channel switching" in LL, to demonstrate HMAC configuration by cRRM.

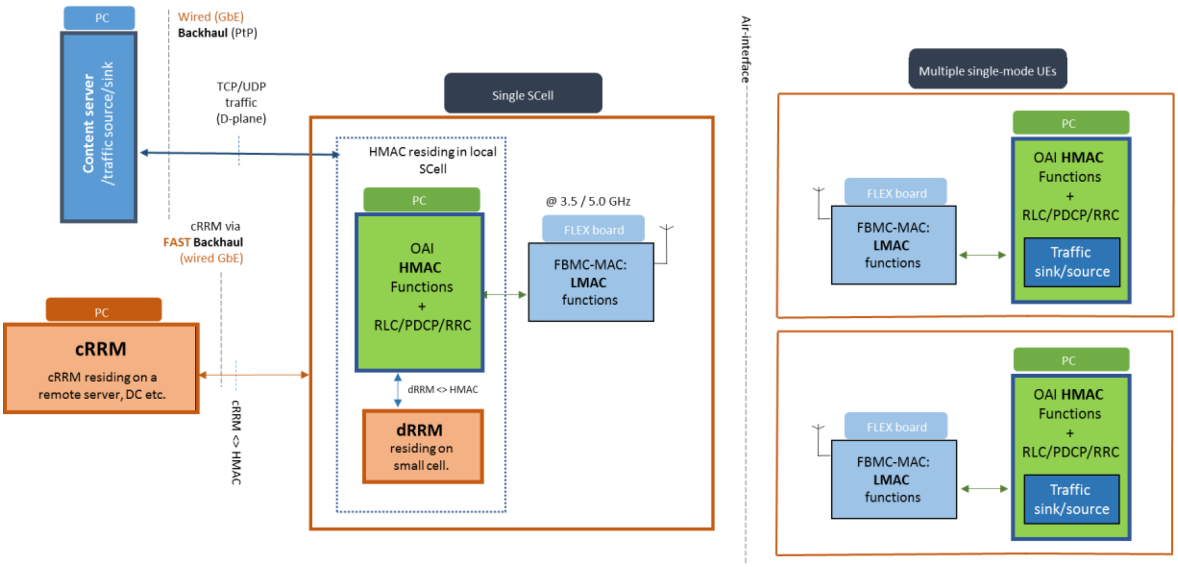

Figure 4: PoC 1A setup

The tests on this configurations will be run by setting up a SC and two UEs. The FBMC-MAC will be started at the SC which will begin transmitting beacons on the selected channel. The two UEs will be started and they will search for the SC's beacon and synchronise on it, so that they get associated, complying with the association procedure described in D5.2 (figures 65 and 66). Traffic establishment procedures will be executed with uplink and downlink traffic flows. The SC will be connected to the RRM entity through a graphical interface able to send configuration requests to the SC HMAC to change the frame structure, the LBT threshold or the channel selection. During the test, the RRM entity will send a request for a channel reselection procedure, as reported in D5.2, figures 62 and 63.

2.2.2 Configuration B: FBMC-MAC and LTE, in co-located scenario (PoC ID: 1B)

This configuration depicted in Figure 5 considers a small cell capable of using multiple RATs simultaneously with the ability to steer logical channels from one RAT to another. More precisely, the small cell embeds a HMAC and 2 co-located LMACs entities supporting respectively LTE and FBMC MAC. This multi-RAT MAC can be configured by a hierarchical RRM framework in order to satisfy objectives like capacity boosting or interference management via load balancing. The hierarchical RRM framework is comprised of two blocks, the dRRM entity and the cRRM entity, which are localized near the small cell and centralized in the infrastructure respectively; the latter case implying an interface to convey the measurement configuration and reports between RRM and the cell. In this collocated scenario, the PoC aims at showing the aggregation of LTE and FBMC-MAC relying on UnL or LL spectrum. The goal is to highlight traffic steering algorithms and dynamic channel selection to make the best use of shared spectrum resource, boosting the user data rate.

This configuration allows validation and testing of:

- Resource Aggregation of licensed spectrum and UnL or LL spectrum carriers
- Offload/Traffic steering to UnL and LL
- Hierarchical RRM

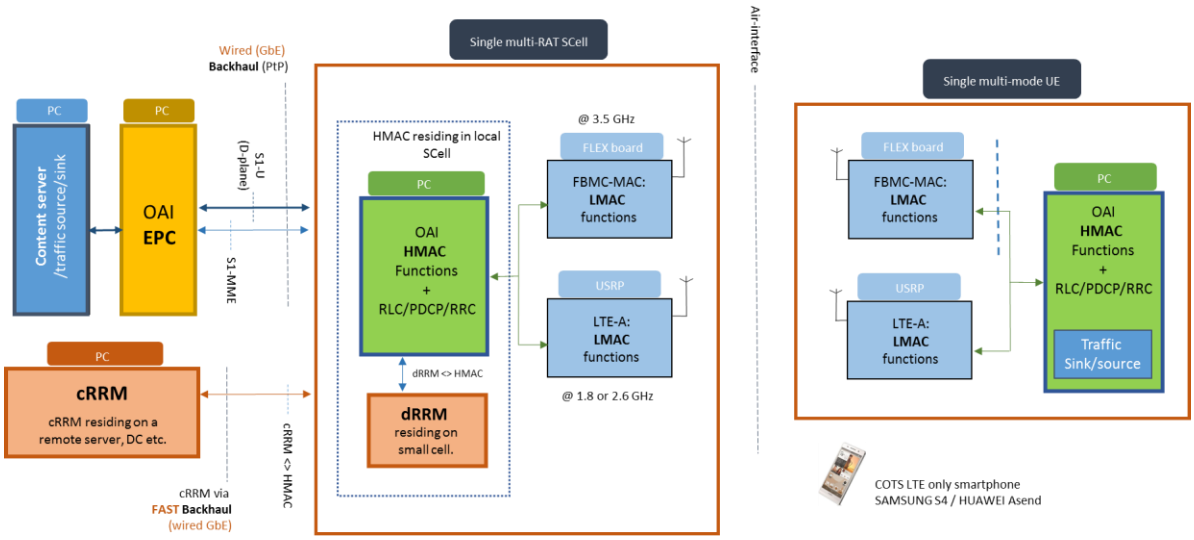

Figure 5: PoC 1B setup (co-located scenario)

In this configuration, the test will start with having a LTE small cell operating in a licensed spectrum band, having an on-going active radio bearer with a UE. Both SC and UE are able to activate a FBMC air interface (AI) which implements the FBMC MAC. The test will implement the procedure of traffic steering configuration and capacity boosting (aggregation) with traffic steering depicted in D5.2 (figures 8 to 11), consisting of

- Receiving a steering request from RRM at HMAC level
- Switching on the FBMC AI on the SC, selecting an appropriate channel in the non-licensed spectrum
- Sending a RRC reconfiguration request to the UE via LTE, to make it switch on the FBMC AI
- Waiting for the UE association confirmation on the FBMC component carrier
- Upon reception of the association complete primitive, traffic is steered by HMAC on to both LTE and FBMC LMAC entities, following the RRM request

2.2.3 Configuration C: FBMC-MAC coexistence with WiFi, in co-located scenario (PoC ID: 1C)

This configuration depicted in Figure 6 is similar to config. B, with the addition of WiFi COTS AP and terminals acting as sources of interference. This configuration demonstrates the capability of FBMC to coexist with WiFi due to its inherent characteristics, the LMAC/HMAC innovations and the capabilities of the proposed RRM approaches (e.g. hierarchical RRM) to effectively allocate the available resources on both licensed and UnL bands. This configuration in Figure 6 allows for validation and testing of:

- Coexistence with WiFi, both RATs at 5GHz band
- Hierarchical RRM - Coexistence

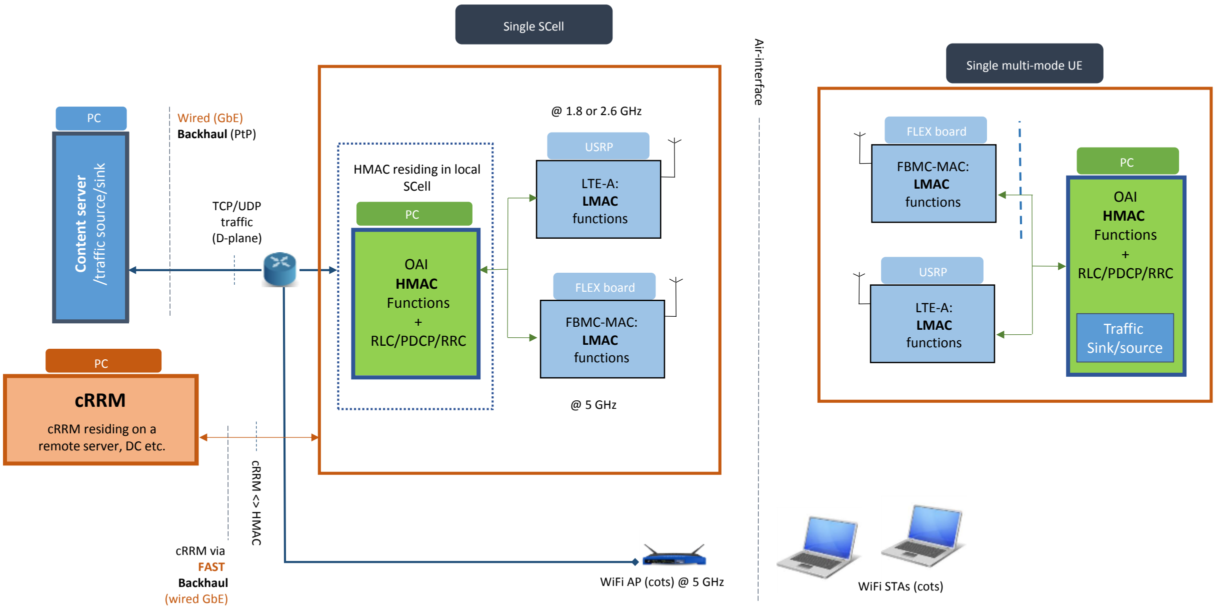

Figure 6: PoC 1C setup (co-located scenario)

In this configuration, we will setup the coexistence between a SC and a Wi-Fi AP, having the SC able to steer some traffic on FBMC AI as a secondary downlink carrier, FBMC PHY being configured to transmit on 5GHz band. In parallel, the WiFi AP is connected with devices, implementing downlink traffic. The test will consist of the following: WiFi and FBMC PHY sharing the same channel, one can see that the SC downlink data rate is reduced when WiFi AP is activated and transmitting to the associated WiFi devices, due to the contention process. At some point, the RRM entity invokes secondary carrier channel reselection procedure, to avoid interference with Wi-Fi. Once the channel is reselected, the SC downlink data rate reaches back the same level as before the WiFi activation.

2.2.4 Physical Architecture

The physical architecture of the POC is presented in the following two figures. Figure 7 demonstrates the architecture where only the FBMC is present, while Figure 8 the case in which the LTE-A and FBMC coexist.

In the first case, the testbed is composed of three FBMC boards, one step attenuator, one Ethernet switch and several PCs. The first FBMC board is directly connected to a PC acting as the small cell. This PC is then connected via the switch to two other PCs, in which the Content-server and cRRM functionalities are deployed respectively. The first FBMC board is wirelessly connected to two other FMBC boards, while a step attenuator is connected to the first FBMC board in order to control the quality of the wireless connection. The second and third FBMC boards are directly connected to two

PCs acting as UE. In this scenario, video traffic is generated in the Content-server (on the left side) and delivered to the wireless terminals (on the right side).

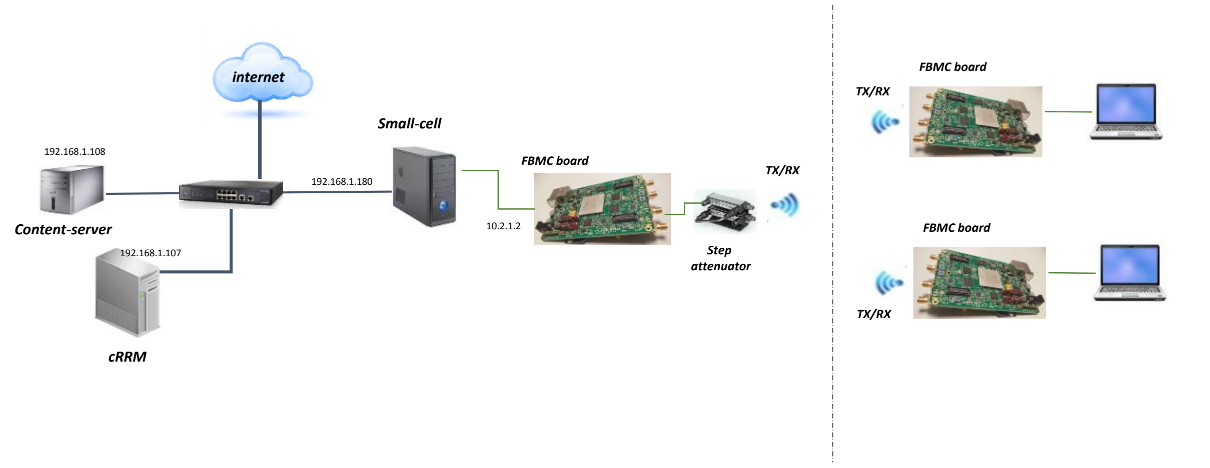

Figure 7: Physical view of the PoC#1A demonstrator

In the second case, in which the LTE-A and FBMC coexists, the testbed is comprised of two FBMC boards, three USRPs, one (or two) Ethernet switches and several PCs. In the collocated scenario, one PC serving as the small cell is directly connected with the FBMC board and the USRP, therefore providing both FBMC and LTE connectivity. This PC is then connected via an Ethernet switch with three other PCs in which the EPC (OAI EPC), the Content-server and the cRRM are deployed. In some cases a second USRP is present connected directly to a PC serving as a second small cell. On the other side, a PC acting as the wireless client is connected with the FBMC board and USRP supporting both FBMC and LTE-A connectivity. In this case, video traffic flows are generated on the Content-server and delivered through the EPC toward the wireless client. The video flows are forwarded either to LTE-A or to FBMC or to both connections creating a set of interesting scenarios. The physical setup of PoC#1C is very similar to PoC#1B with only the addition of WiFi COTS AP and terminals.

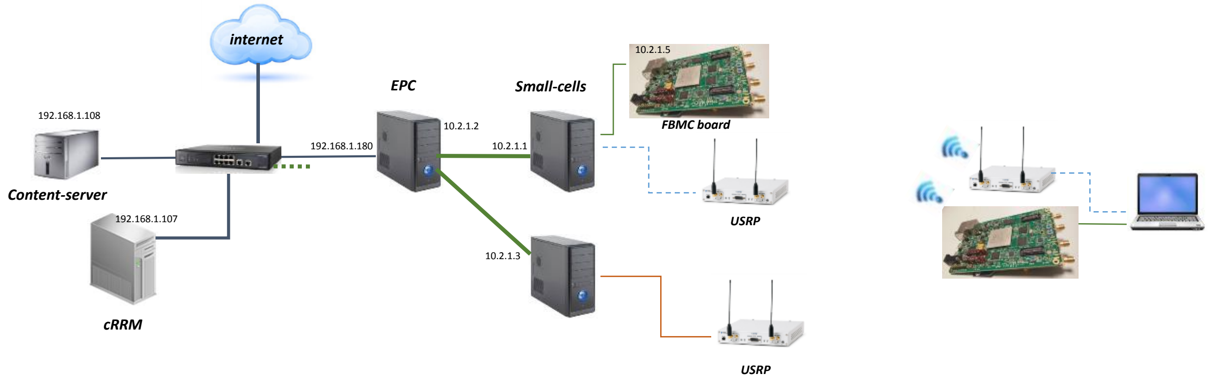

Figure 8: Physical view of the PoC#1B demonstrator

Demonstrator 1 makes use of USRP X310/300 nodes, with the following features [3]:

- Two wide-bandwidth RF daughterboard slots
- Up to 120MHz bandwidth each
- Daughterboard selection covers DC to 6 GHz
- Multiple high-speed interfaces
- Dual 10 GbE interface- 200 MS/s Full Duplex
- PCIe Express (Desktop) - 200 MS/s Full Duplex

- Express Card (Laptop) - 50 MS/s Full Duplex
- Dual 1 GbE interface- 25 MS/s Full Duplex

Table 3: USRP X310/300 performance and clocks

ADC sampling rate (max)	200	MS/s
ADC resolution	14	bits
DAC sampling rate	800	MS/s
DAC resolution	16	bits
Host sampling rate (16b)	200	MS/s
Internal Reference accuracy	2.5	ppm
Accuracy w/GPSDO option (not locked to GPS)	20	ppb

Figure 9: Physical Front and backend views of USRP X310/300

2.3 SW/HW development plans

The SW/HW development plans can be summarised as:

- The extension of the OAI framework in order to support eDSA and the 5G RRM functionalities designed and implemented in the project,
- The implementation of new modules (HMAC functional blocks) realising a set of eDSA algorithms and cRRM and dRRM functionalities (e.g. hierarchical RRM),
- The implementation of the appropriate interfaces between already available and extended modules of OAI, and newly implemented modules.

In detail, the implementation process will include the:

- Development of the Dynamic RAT Selection module, responsible for the selection between the legacy and FBMC technologies,
- Development of the Channel-selection module,
- Development of the KPI Collection module, responsible for the collection of the measurements. This module communicates with the OAI framework for the collection of the LTE-A related information and the FBMC-MAC (Flex board and FBMC HMAC module) for the collection of the FBMC related measurements,
- Development of a selected set of eDSA algorithms implemented as different modules. Each module communicates with the Measurement Collection module and based on the current measurements and past measurements decides on the dynamic RAT/ channel selection,
- Development of the Traffic Aggregation/Separation module, responsible for the split of downlink traffic between the OAI and FBMC platforms, and the aggregation of uplink traffic coming from both OAI and FBMC,
- Extension of the MAC controller of the OAI in order to realise the decisions of dRRM and cRRM modules regarding scheduling. In addition, several extensions will be realised in order to support the communication of the OAI modules with the newly created modules,

- Extension of any other OAI modules (to be identified during the implementation phase), in order to support the aforementioned functionalities of the testbed. The extension will be realised in terms of modifying the current OAI implementation or implementing extra functionalities on top of the available OAI implementation,
- Implementation of the interface between the HMAC and the cRRM functional blocks,
- Implementation of the interface between the FBMC-MAC module and the Traffic Aggregation/Separation module,
- Implementation of the interface between the OAI and the Traffic Aggregation/Separation module,
- Implementation of the interface between the eDSA modules and i) the Dynamic RAT Selection module; ii) the Channel Selection module and; iii) the Measurement Collection module.

In order to implement this PoC, an implementation of the FBMC MAC is required. This is currently done within task T5.3, using a custom HW/SW prototyping board developed by CEA. This prototyping board (shown in Figure 10) relies on a mother board built on a Xilinx Zynq XC7Z045 chip, which is composed of an FPGA and an embedded dual-core ARM cortex A9 processor. From signal perspective, the mother board hosts a RF daughter board, developed by Terasic and based on an AD9361 chip from Analog Device. This daughter board supports a 2x2 transceiver able to transmit from 70 MHz up to 6 GHz and integrating 12-bits ADCs and DACs for the receive and transmit modes respectively. This daughter board is connected to the mother board via a HSMC (High Speed Mezzanine Card) connector, which allows to interface the baseband processing chain (implemented on the FPGA) to the RF chain at the digital I/Q samples level for both TX and RX sides. The RF board is controlled with the ARM processor via a SPI interface, using a library developed by Analog Device, which gives a direct access to the configuration registers.

Also, the mother board has a wide set of high speed interfaces like Gigabit-Ethernet (GbE) or high speed USB in order to be connected to a PC for both data and control/debug paths.

Figure 10: FLEX board developed by CEA

From the FBMC MAC perspective, the following developments are required:

- FBMC LMAC: the whole LMAC is developed within task T5.3. This requires the adaptation of an existing FBMC PHY hosted in the FPGA of the FLEX board and includes the development of the data path interface with higher layers (AXI bus) and with the RF chip through high speed digital IOs; it also requires the development of a control interface in order to configure the PHY layer, implemented via an appropriate register barrier. From the MAC standpoint, the development plan covers the TDD and TDMA engine implementations as well as the synchronisation management thanks to the beaconed structure of the superframe, both on the small cell and UE sides. The implementation of the scheduler algorithm is also required although state of the art scheduling techniques will be used, like round-robin or proportional fair algorithms. Coexistence functions like listen-before-talk (LBT) will also be implemented as they represent a central feature of the MAC design.

- Development of the HMAC functions required to configure the LMAC in terms of MAC superframe structure (superframe and slot lengths, number of uplink and downlink slots, inactive period duration), communication channel (central frequency, bandwidth, transmit power) and coexistence management (sensing method, sensing duration, detection thresholds). Another important part to be developed relates to the monitoring plane, needed in order to implement the configuration and the reporting of measurements and KPIs coming from the LMAC and PHY layers. The monitoring management functions are located in the HMAC and communicate with RRM messages through a dedicated interface for both measurement configuration requests and measurement reports. The examples given in this section are not exhaustive as the list of configuration parameters will be finalised during the PoC development.

Figure 11 shows the FBMC MAC split and the HW/SW implementation of the MAC on the FLEX board. It also illustrates the interface for the data and control planes, the latter being notably dedicated to the interaction with RRM for configuration and monitoring purpose. RRM can be hosted on a PC where a debug and visualisation tool coexists. This tool is a graphical interface where the time variation of PHY and MAC KPIs can be displayed at run time. The physical interface for both control and data planes is implemented via the GbE interface using an IP-bridge where the planes are (de) multiplexed. The whole communications between the MAC and the upper layers, for both control and data planes, relies on sockets, where control and data streams are routed. The reception and transmission of data on the two paths will be managed at the HMAC thanks to a set of threads.

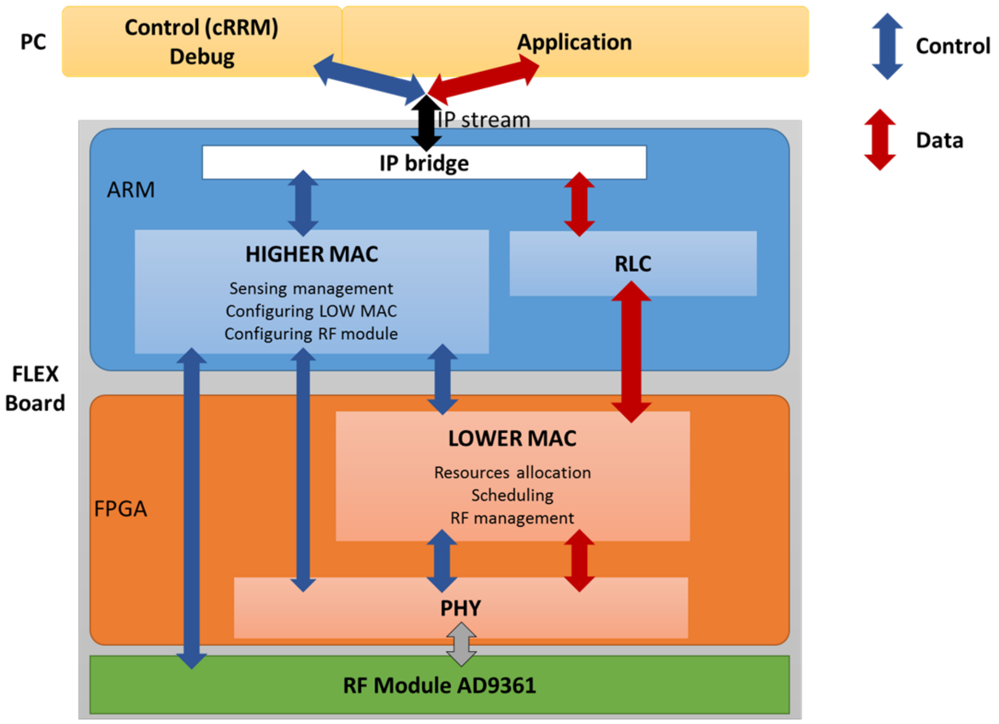

Figure 11: MAC split implementation and interface with upper layers

2.4 List of equipment and interfaces

Table 4 below lists the required equipment for the PoC 1.

Table 4: Summary list of Equipment

ID	Equipment type	Quantity	Vendor and model	Source
1	FLEX Board	Up to 4	Custom HW/SW board	CEA
2	Variable RF attenuator	2	Keysight 8494B/8496B	CEA
3	USRP	2	USRP X310	WINGS
4	USRP	2	USRP B210	WINGS
5	Daughterboard	2	SBX-120 Daughterboard	WINGS
6	Card	2	10 GbE Card	WINGS

2.5 Test case mapping to PoC 1

The Table 5 below lists the applicable TCs and corresponding PoC 1 configurations. The full description of TCs in the table can be found in Appendix 1.

Table 5: List of TCs applicable to PoC 1

Test case ID	Test case title	Relevant PoC ID	notes
S1	Resource (Random) Access	1A	FBMC-MAC operating on LL or UnL bands
S2	Call setup/tear-down signalling procedure	1A	FBMC-MAC operating on LL or UnL bands
S3	Dynamic channel switching	1A	FBMC-MAC operating on LL or UnL bands
S4	Multiple Access	1A	FBMC-MAC operating on LL or UnL bands
A1	Aggregation of licensed LTE and LL (co-located SC scenario)	1B	FBMC-MAC operating on LL and LTE on licensed bands
A3	Aggregation of UnL WiFi and LL (co-located SC scenario)	1C	FBMC-MAC operating on LL and WiFi on UnL bands
A5	Aggregation of UnL WiFi and licensed (co-located SC scenario)	1C	FBMC-MAC operating on UnL and LTE on licensed bands
O1	Offload/steering to UnL band (co-located SC scenario)	1B	FBMC-MAC operating on UnL and LTE on licensed bands
O3	Offload/steering to LL band (co-located SC scenario)	1B	FBMC-MAC operating on LL and LTE on licensed bands
R2	Hierarchical RRM	1B	FBMC-MAC operating on LL and LTE on licensed bands

R3	Hierarchical RRM - Coexistence	1C	FBMC-MAC & WiFi operating on UnL and LTE on licensed bands
P1	Physical DATA channel tests	1A	FBMC-MAC operating on LL
P2	Throughput, Delay, Packet Loss tests	1A	FBMC-MAC operating on LL
C1	Clean channel selection	1C	FBMC-MAC & WiFi operating on UnL and LTE on licensed bands
C2	Co-channel coexistence - Channel sharing with one DL full buffer WiFi link	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands
C5	Co-channel coexistence - Channel sharing with a DL full buffer + DL VoIP WiFi links	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands
C7	Co-channel coexistence - Channel sharing between intra-operator SCells	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands
C8	DL-only LAA Channel sharing with one (DL) full buffer WiFi link (co-located SC scenario - intra-operator)	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands
C9	DL-only LAA Channel sharing with two (DL + UL) full buffer WiFi links (co-located SC scenario - intra-operator)	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands
C11	Adjacent channel interference in WiFi-LAA scenario	1C	FBMC-MAC/WiFi operating on UnL and LTE on licensed bands

3 PoC 2: "DCS MAC"

This demonstrator is used to showcase the feasibility of the proposed 5G DCS-MAC on a real-time hardware platform and the advantages that it can provide. The PoC (and related variants) are based on particular hardware platform and used to demonstrate a number of functionalities. The following sections will describe the PoC variants in more detail, specifying the used hardware platforms, their hardware and software architecture and all relevant interfaces.

3.1 Motivation and Scope

The objective of various demos under PoC 2 is to highlight project innovations related to resource aggregation, offload/traffic steering, dynamic channel selection, co-existence aspects and interference mitigation, based on different eDSA configurations and using the DCS MAC. In light of this demonstration plan, 4 demo configurations have been identified (A to D below) with each setup providing ability to test/validate certain identified SPEED-5G features (and algorithms). Specific validation and tests (directly mapped to UCs) are listed below:

- **Config. A (DCS-MAC):**
    - "Basic call setup (incl. random access) and tear-down" for single UE on LL carriers,
    - "Multiple Access" - Basic call setup for multiple UEs on LL carriers,
    - "inter-SC handover" (between DCS cells),
    - "Dynamic channel switching" in LL band,
    - "Control channel switching" to licensed band.
- **Config. B (DCS-MAC & LTE) – co-located scenario:**
    - "Resource Aggregation" of licensed and UnL/LL carriers,
    - "Offload/steering" to UnL/LL carriers.
- **Config. C (DCS-MAC & WiFi) – co-located scenario:**
    - "Resource Aggregation" of UnL and L/LL carriers,
    - "Offload/steering" to UnL/LL carriers.
- **Config. D (DCS-MAC coexistence with WiFi/LTE) – co-located scenario:**
    - "Coexistence w/ WLAN" on 5 GHz band,
    - "Coexistence w/ LTE" on 5 GHz band.

The scope of the demonstrations is limited to the DCS-MAC related innovations. The test cases associated with this PoC are outlined in section 3.5.

3.1.1 Use Case and Feature Descriptions

Based on the broadband wireless scenario, the PoC intends to validate basic functionalities of the proposed design as well as to showcase the identified UCs of Speed-5G based on the DCS-MAC design, highlighted in section 1.1.

In all cases, multiple RATs co-exist and can be either co-located or non-co-located: in co-located cases, which are in focus in these demonstrators, there is a common HMAC for all multiple RATs and separate LMACs for each RAT. In the non-co-located cases there are separate HMAC and LMAC for each RAT.

There are three common features that will be demonstrated as follows:

- **Resource Aggregation:**

  The purpose of the resource aggregation is to aggregate carriers for supporting wider transmission bandwidths, resulting in higher throughputs. In this demonstration, both inter-carrier (carriers aggregated in different operating bands) and intra-carrier (carriers aggregated in the same operating band) are investigated.

- **Traffic Offloading/Steering:**

  The purpose of traffic offloading is to balance traffic loads by offloading certain traffic from one RAT to another so that the overall throughput performance is improved.

- **Dynamic Channel Switching/Selection:**

  One of the main features of this demonstration is to allow channel switching dynamically in order to mitigate interference as well as to improve the overall throughput.

3.1.2 KPIs for PoC 2

Table 6 and Table 7 below list D-plane and C-plane KPIs considered in PoC 2 evaluations.

Table 6: D-plane related KPIs

KPI	Description
Throughput	Average throughput (MAC and IP/APP layers)
Latency	End-to-end latency from source to destination
Reliability	Reliability in terms of Block Error Rate (BLER) and Packet Error Rate (PAR) under given data rate demands

Table 7: C-plane related KPIs

KPI	Description
eDSA latency	Total latency to accomplish a full eDSA cycle (measurements collection, algorithm execution, decisions enforcement)
dRRM latency	Total latency to accomplish a full dRRM cycle (measurements collection, algorithm execution, decisions enforcement)
cRRM latency	Total latency to accomplish a full cRRM cycle (measurements collection, algorithm execution, decisions enforcement)
eDSA bandwidth overhead	Bandwidth overhead in terms of percentage of additional control traffic (due to eDSA) to offered traffic
cRRM bandwidth overhead	Bandwidth overhead in terms of percentage of additional control traffic (due to cRRM) to offered traffic

3.2 PoC Configurations

The PoC 2 can be set-up in 4 different configurations. The PoC IDs corresponding to different configurations, are:

- **PoC 2A** – corresponding to Config. A: **DCS-MAC**
  - Related to UC#1.
- **PoC 2B** – corresponding to Config. B: **DCS-MAC and LTE, in co-located scenario**
  - Related to UC#2 and UC#3.
- **PoC 2C** – corresponding to Config. C: **DCS-MAC and WIFI, in co-located scenario**
  - Related to UC#2 and UC#3.
- **PoC 2D** – corresponding to Config. D: **DCS-MAC and WiFi/LTE COTS, in co-located scenario**
  - Related to UC#4.

As the main focus of this PoC is on the proposed DCS-MAC related functionalities, a number of RRM algorithms are being developed to enable to enhance resource utilization upon traffic fluctuations and to respond to changing inter-cell interference conditions. In this PoC, the cRRM directly interacts with the HMAC. The cRRM functionalities including the centralized coordinated scheduling for interference mitigation via, for example, multi-RAT MAC configuration, RAT selection, inter-RAT CA, and load balancing, are usually placed on the cloud and assume a fast BH connection between cRRM and the cell, e.g. wired GbE. In this demonstration, the cRRM functionalities are executed on a separate PC, which is connected to SCs via GbE.

The cRRM functionality in this PoC considers 3 algorithms (one for each feature):

(i) Algorithm for traffic off-loading, which takes account of interference conditions experienced at each UE, to make the traffic offload decision among multiple RATs;
(ii) Algorithm for dynamic channel switching, which considers a number of factors in making the channel switching decisions such as interference, UE capabilities, etc.;
(iii) Algorithm for resource aggregation, in which the resource aggregation decisions are made based on aggregation criterion such as QoS requirements, overall traffic level, traffic load per carrier, the channel quality information from UE, and aggregation priorities.

During demonstrations, the real-time performance of these algorithms will be evaluated.

3.2.1 Configuration A: DCS-MAC (PoC ID: 2A)

The configuration of Figure 12 is used to validate basic signalling functionality e.g. random access, call setup/tear-down and handover. Moreover, dynamic channel switching can also be performed (i.e., over sub-bands) within the LL band (intra-band channel switching) to ensure the best utilization of each channel, for example by mitigating interference. In addition to intra-band channel switching, the DCS-MAC can support dynamic channel switching between licensed, UnL and LL bands (i.e. inter-band channel switching). This configuration allows for validation and testing of basic procedures:

- “Basic call setup (incl. random access) and tear-down” for single UE on LL carriers,
- “Multiple Access” - Basic call setup for multiple UEs on LL carriers,
- “inter-SC handover” (between DCS cells),
- "Dynamic channel switching" in LL,
- “Control-channel switching” to licensed band

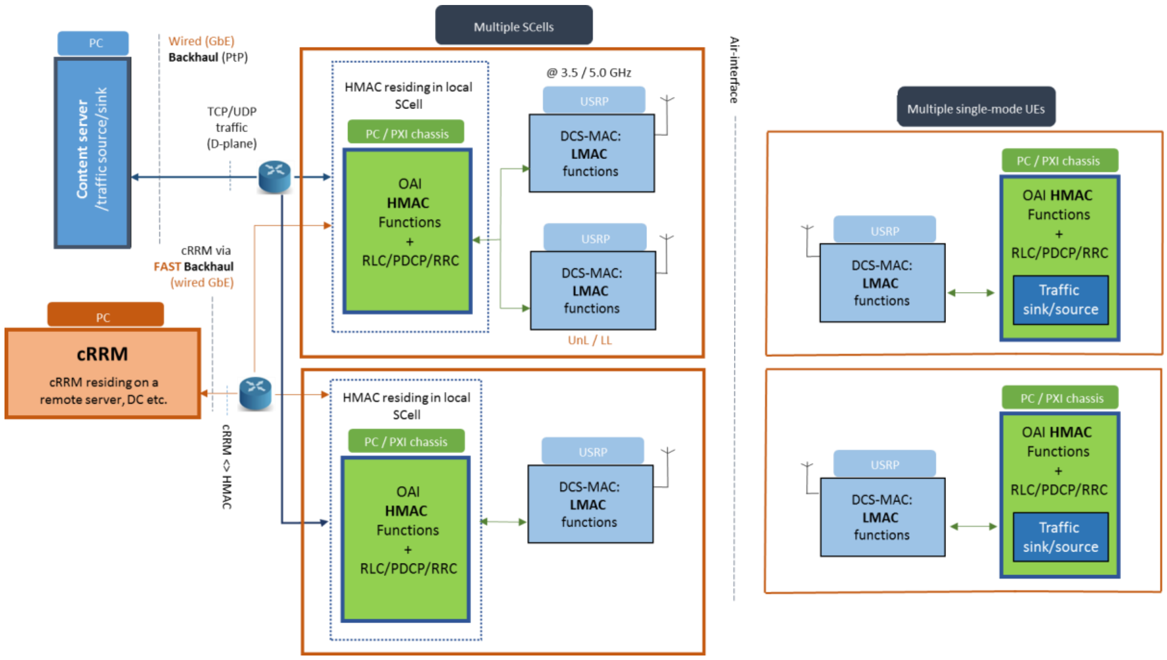

Figure 12: PoC 2A setup

For testing the aforementioned procedures, two SCs (one SC with two DCS-MAC_RATs and other one with one DCS-MAC) and two UEs are deployed. To test the basic call setup and multiple access procedures the DCS-MAC is first activated at the SC which will broadcast synchronization signals and System Information over the broadcast channel. Initially, one UE is (and for the multiple access procedure testing, both UEs are) powered on and will then search for the SC synchronization signals and synchronize on it. Upon retrieval of the system information, the UE(s) will start Random Access procedure, followed by RRC Connection Establishement, Attach and Authentication, and Default Radio Bearer Setup procedures. Traffic establishement procedure will be executed with UL and/or DL traffic flows. The SC HMAC is connected to the cRRM, which will trigger the SC HMAC to initiate KPI measurement configuration of HMAC (Figure 2 in D5.2). The SC HMAC will then collect and store in the HMAC's KPI collector (Figure 3 in D5.2). During the test, the cRRM entity will send a request for a channel reselection procedure (for the channel selection procedure), which will dynamically select an interference free channel. For testing the handover procedure, the UE switches reception and start monitoring the newly detected SC with a stronger signal. Upon obtaining the synchronization signal, it then initiates the HO procedure to the new cell.

Note that this configuration is also used to conduct performance tests, as outlined in section 8.

3.2.2 Configuration B: DCS-MAC and LTE, in co-located scenario (PoC ID: 2B)

In the configuration shown in Figure 13, two co-located RATs (the new 5G DCS-MAC and LTE) are considered where traffic from each RAT can be offloaded to the other RAT and traffic aggregation (at MAC-level) is possible. In this case, the HMAC and layers above HMAC of both RATs are common. This demo configuration also aims to aggregate LTE licensed with DCS-MAC LL or UnL transmissions. This configuration allows validation and testing of:

- "Resource Aggregation" of licensed and UnL/LL carriers,
- "Offload/steering" to UnL/LL bands

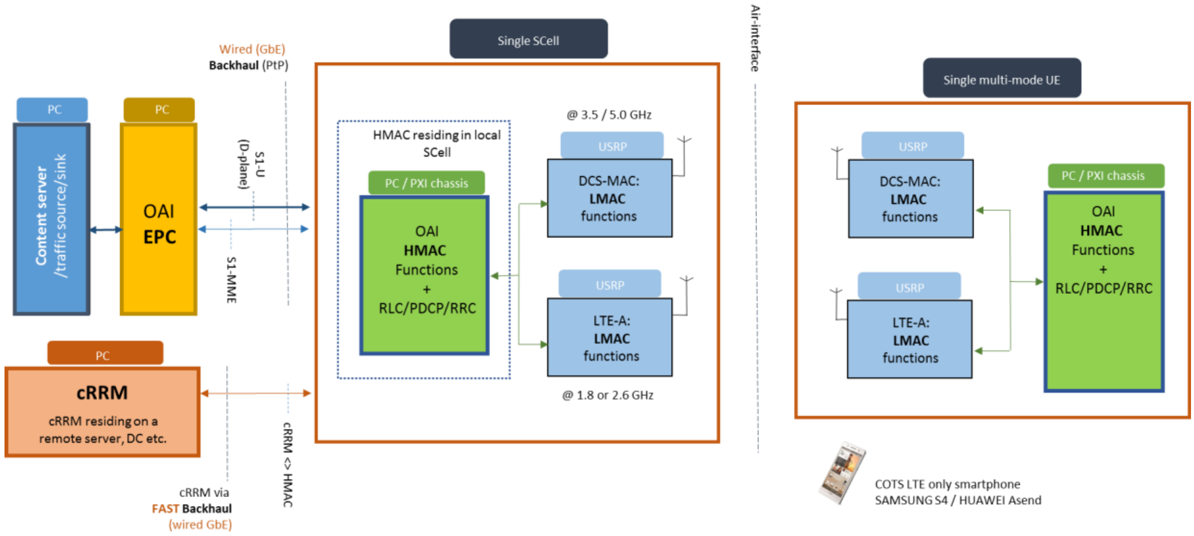

Figure 13: PoC 2B setup (co-located scenario)

In this co-located configuration (DCS-MAC and LTE), the test will start with a LTE SC operating in a licensed spectrum band with having an on-going active radio bearer with a UE on the LTE air interface. Both SC and UE are able to activate the DCS-MAC based air interface, which will allow to the SC to steer traffic and/or aggregate resource (LL or UnL) upon reception of the traffic steering and aggregation commands from the cRRM entity depicted in D5.2 (figure 8 to 11). The procedure consists of

- The cRRM entity triggers the HMAC with a traffic steering/aggregation request.
- The HMAC then activates the DCS-MAC air interface with selecting an appropriate channel in the UnL/LL spectrum (component carrier).
- The SC sends a RRC reconfiguration request to the UE via LTE for activating its DCS-MAC air interface and waits for the UE association confirmation on the DCS-MAC component carrier
- Upon reception of the association complete primitive, traffic is steered by the HMAC on both the LTE and DCS-MAC LMAC.

3.2.3 Configuration C: WiFi and DCS-MAC, in co-located scenario (PoC ID: 2C)

In the configuration of Figure 14, co-located DCS-MAC and WiFi (w/ aggregation at MAC-level) RATs are considered. In the case of aggregation, both DCS-MAC and WiFi are served by a common HMAC and layers above HMAC. This configuration allows for validation and testing of:

- “Resource Aggregation” of UnL and L/LL carriers,
- “Offload/steering” to UnL band

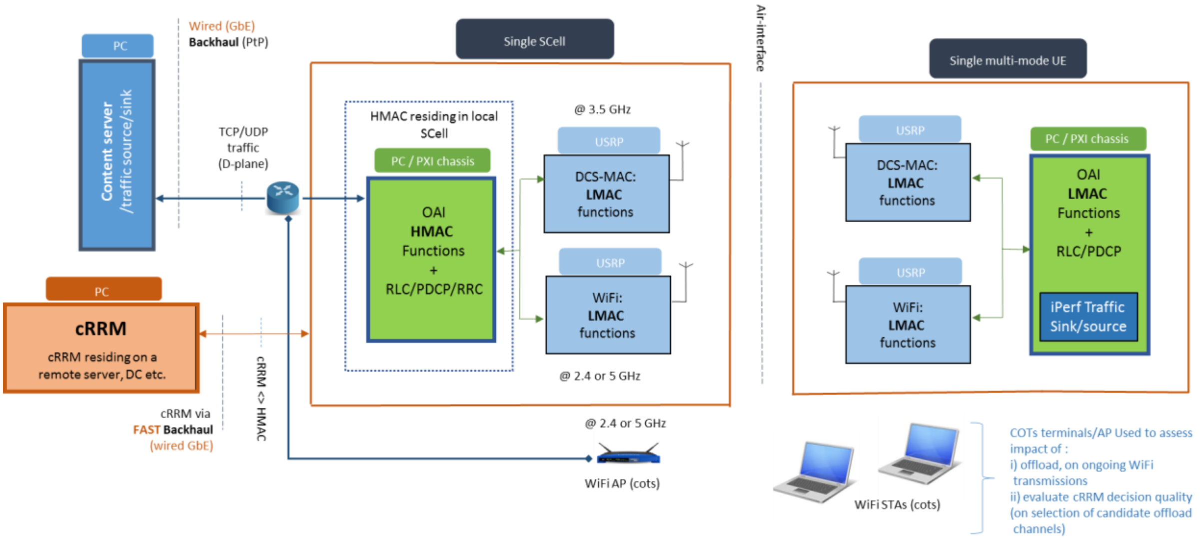

Figure 14: PoC 2C setup (co-located scenario)

In this co-located configuration (DCS-MAC and WiFi), the test procedure will be the same as in the PoC 2C. However, in this case, the DCS-MAC SC acts as the primary cell and will activate the WiFi interface via the DCS-MAC air interface upon receiving the traffic steering/aggregation request from the cRRM entity. When the WiFi air interfaces on both SC and UE are activated, the SC will offload some traffic via the WiFi air interface for boosting the capacity and/or mitigating interference depending on the decisions made by the cRRM entity.

3.2.4 Configuration D: DCS-MAC coexistence with WiFi/LTE, in co-located Scenario (PoC ID: 2D)

The configuration of Figure 15 allows for validation and testing of:

- “Coexistence with WiFi” - both RATs at 5GHz band
- “Coexistence with LTE” - both RATs at 5GHz band

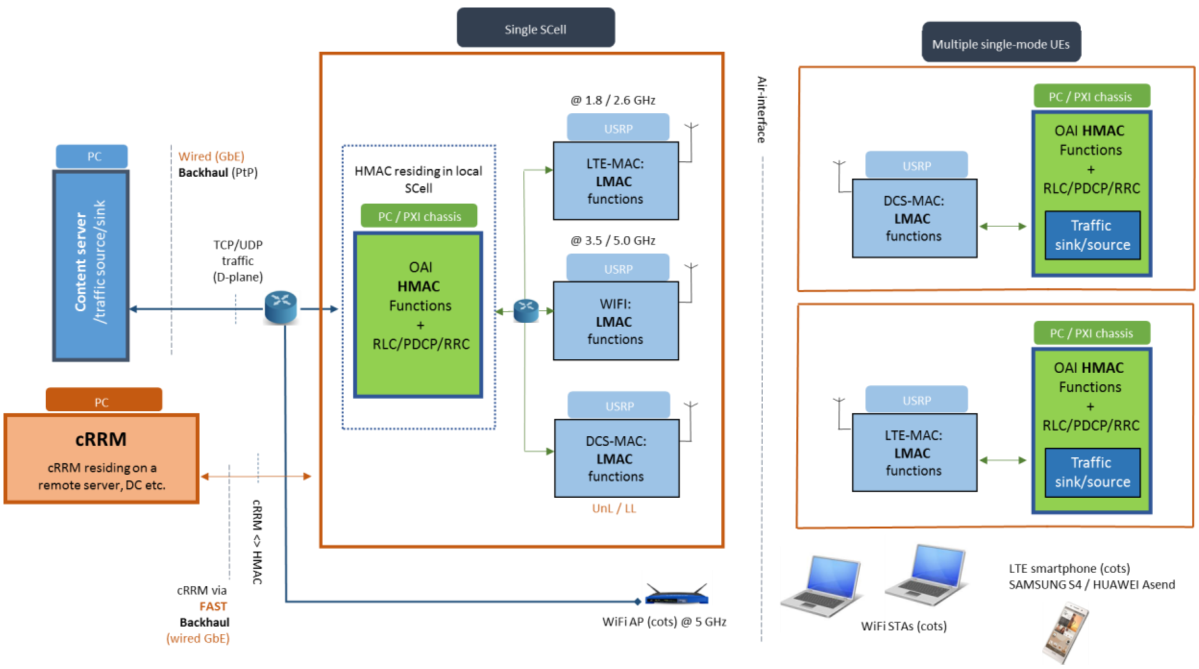

Figure 15: PoC 2D setup (co-located scenario)

The tests in this configuration will be run by first activating a SC with LTE, DCS-MAC and WiFi RATs, and two UEs, with each having a single DCS-MAC air interface. The coexistence of DCS-MAC with WiFi and LTE will be tested on the same channel (5GHz spectrum band), which may lead to the degradation of performance (throughput/latency). The channel reselection procedure will then be triggered by either the HMAC entity (or the cRRM entity) and procedures depicted in D5.2 (Figure 62 and 63) in order to maintain the required performance level, are then executed.

3.2.5 Physical Architecture

Figure 16 illustrates the physical architecture of the test set ups using OAI and USRPs.

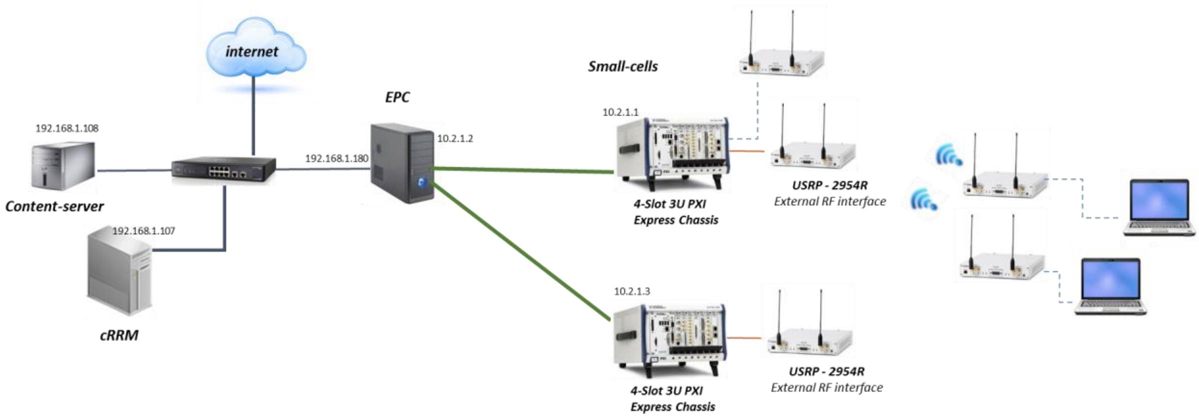

Figure 16: Physical view of the PoC#2A demonstrator

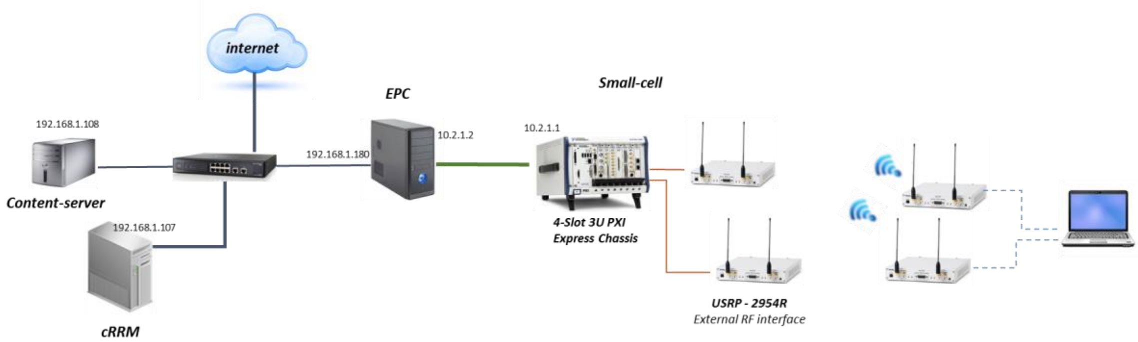

Figure 17: Physical view of the PoC#2B demonstrator

Demonstrator 2 makes use of USRP 2954R nodes, with the following specifications on transmit and the receive sides [2]:

Transmitter

- Number of channels 2
- Frequency range 10 MHz to 6 GHz
- Frequency step <1 kHz
- Maximum output power (Pout) 50 mW to 100 mW (17 dBm to 20 dBm)
- Gain range 1 0 dB to 31.5 dB
- Gain step 0.5 dB
- Maximum instantaneous real-time bandwidth 160 MHz
- Maximum I/Q sample rate 200 MS/s
- Digital-to-analog converter (DAC) Resolution 16 bit
- Spurious-free dynamic range (sFDR) 80 dB

Receiver

-	Number of channels	2
-	Frequency range	10 MHz to 6 GHz
-	Frequency step	<1 kHz
-	Gain range	30 dB to 37.5 dB
-	Gain step	0.5 dB
-	Maximum input power (Pin)	-15 dBm
-	Noise figure	5 dB to 7 dB

Figure 18: Physical Front and backend views of USRP 2954R

3.3 SW/HW development plans

The setup is based on the OAI [4], which supports 3GPP LTE standard (Release 10) allowing emulation of LTE eNB, UE and EPC. The entire protocol stack in OAI is executed in SW. Specific HW and SW constraints are required for real-time operation using various hardware targets. Table 8 shows the specific HW and SW requirements for running the OAI eNB, OAI UE and OAI EPC.

Table 8: HW and SW requirements for the testbed

Software Requirements		Hardware Requirements	
OS	Ubuntu 14.04 (64-bit)	Processor	Intel® Core™ i7-6700 CPU @ 3.40GHz × 8
Kernel	Low-latency kernel with version 3.19 (pre-emptive scheduling)	Memory	7.7 GiB
OAI RAN + EPC	Eurescom’s Gitlab Server (Branch Master)	SDR platform	USRP 2954

The following SW modules will be implemented as extensions of OAI modules, for this PoC:

1. Extension of OAI to support basic eDSA – i.e., integration of multiple RATs with common HMAC and layers above HMAC.
    - Splitting MAC layer into two sub-layer: LMAC and HMAC
    - HMAC: Development of (i) inter-RAT coordination module that coordinates inter-RAT coexistence and scheduling functionalities, (ii) sensing and measurements management module that is responsible for collecting sensing results from PHY and link control KPIs (measurement reports) from LMAC and forward them to cRRM using monitoring plane (monitoring interfaces), and (iii) a configuration module that is responsible for handling the common configuration parameters related to cells, UE, and MAC.
    - LMAC: Development of RAT-specific scheduling modules responsible for the real-time scheduling of user traffic in the specific RAT.

2. Implementation of basic RAT selection module (residing in cRRM/dRRM)
   - It will allow to select different RATs such as DCS-MAC, LTE-A, or WiFi.
   - Development of various advanced RAT selection algorithms.
3. Implementation of the following interfaces:
   - Monitoring Plane: M_HMAC_cRRM_SAP, M_cRRM_Config_SAP, M_LMAC_HMAC_SAP and M_PHY_HMAC_SAP.
   - Control Plane: C_HMAC_LMAC_SAP, C_5GRLC_HMAC_SAP, C_5GRRC_HMAC_SAP, C_LMAC_PHY_SAP.
   - Data Plane: D_5GRLC_LMAC_SAP, D_LMAC_PHY_SAP.

3.4 List of equipment and interfaces

Table 9 below lists the required equipment for PoC 2.

Table 9: list of Equipment

ID	Equipment type	Quantity	Vendor and model	Source
e1	TV monitor	1	TBC	UNIS
e2	USRPs	4	USRP 2954 from NI	UNIS
e3	PC (Linux)	4	Dell	UNIS
e4	4-slot Express Chassis	2	National Instruments (NI)	UNIS

3.5 Test case mapping to PoC 2

This section presents list of applicable TCs and corresponding PoC 2 configurations, as depicted in Table 10 below. The full description of TCs in the table can be found in Appendix 1.

Table 10: List of TCs applicable to PoC 2

Test case ID	Test case title	Relevant PoC ID	notes
S1	Resource (Random) Access	2A	DCS-MAC operating on licensed or UnL bands
S2	Call setup/tear-down signalling procedure	2A	DCS-MAC operating on licensed or UnL bands
S4	Dynamic channel switching	2A	DCS-MAC operating on licensed or UnL bands
S4	Multiple Access	2A	DCS-MAC operating on licensed or UnL bands
A1	Aggregation of licensed LTE and DCS operating	2B	DCS-MAC operating on LL and

	on LL band (co- located SC scenario)		LTE on licensed band
A3	Aggregation of UnL WiFi and DCS operating on LL band (co -located SC scenario)	2C	DCS-MAC operating on LL and WiFi on UnL band
A5	Aggregation of UnL WiFi and DCS operating on licensed band (co -located SC scenario)	2C	DCS-MAC operating on licensed and WiFi on unlicensed band
O1	Offload/steering to UnL band (co -located SC scenario)	2B	DCS-MAC operating on UnL and LTE on licensed band
O3	Offload/steering to LL band (co- located SC scenario)	2B	As above
P1	Physical DATA channel tests	2A	DCS-MAC operating on licensed/UnL or UnL bands
P2	Throughput, Delay, Packet Loss tests	2A	DCS-MAC operating on licensed/UnL or UnL bands
C1	Clean channel selection	2D	DCS-MAC operating on UnL and WiFi on UnL band
C2	Co-channel coexistence - Channel sharing with one DL full buffer WiFi link	2D	DCS-MAC operating on UnL and WiFi on UnL band
C5	Co-channel coexistence - Channel sharing with a DL full buffer + DL VoIP WiFi links	2D	DCS-MAC operating on UnL and WiFi on UnL band
C7	Co-channel coexistence - Channel sharing between intra-operator SCells	2D	DCS-MAC operating on UnL and WiFi on unlicensed band
C8	DL-only LAA Channel sharing with one (DL) full buffer WiFi link (co-located SC scenario - intra-operator)	2D	DCS-MAC operating on licensed/UnL bands and LTE on UnL band
C9	DL-only LAA Channel sharing with two (DL + UL) full buffer WiFi links (co- located SC scenario - intra-operator)	2D	DCS-MAC operating on licensed/UnL bands and LTE on UnL band
C11	Adjacent channel interference in WiFi-LAA scenario	2D	DCS-MAC operating on licensed bands and WiFi on UnL band

4 PoC 3: “PtMP BH advancements”

4.1 Motivation and Scope

In SPEED-5G, the work concerning BH focuses on solutions for PtMP wireless BH at 28GHz. More specifically, the solutions studied in Task 4.3 are focused on the BH segment and aim at:

- Increasing the available throughput per link and capacity per area,
- Reducing the hop latency,
- Increasing network availability,
- Balancing resources.

This demonstrator is designed to facilitate the testing of the solutions that were selected for realising the achievements above. Applicable test cases are outlined in section 4.7.

4.1.1 Use Case and Feature Descriptions

The purpose of this PoC is to test the backhaul infrastructure. The scenarios it can satisfy have already been described in appendix B, of [1]. The evaluations considered as part of this demonstrator and solutions provided, address requirements of selected UCs listed below, at the backhaul segment:

- dynamic channel selection,
- load balancing, and
- throughput improvement with carrier aggregation

4.1.2 KPIs for PoC 3

Table 11 below lists the KPIs considered in PoC 3 evaluations.

Table 11: PoC 3 – Evaluation criteria and performance metrics

KPI	Description
Link data rate DS	The downstream data rate, i.e. for traffic sent from a CS to a TS
Link data rate US	The upstream data rate, i.e. for traffic sent from a TS to a CS
Aggregate area capacity	The downstream and upstream data rate between two CSs and their TSs
One way latency	Latency between any CS and TS pair
Network availability	In case of a CS failure, the ability of the BH system to still provide service over the working CS
Resource balancing	During provisioning, the ability of the BH system to automatically assign a TS to the best CS according to

KPI	Description
	predefined criteria

4.2 PoC configuration

The diagram in Figure 19 shows the PoC configuration. The equipment under test is shown as black boxes, consisting of two Central Stations (CS1 and CS2) and a number of Terminal Stations (TS1, TS2 and TS3 in this case).

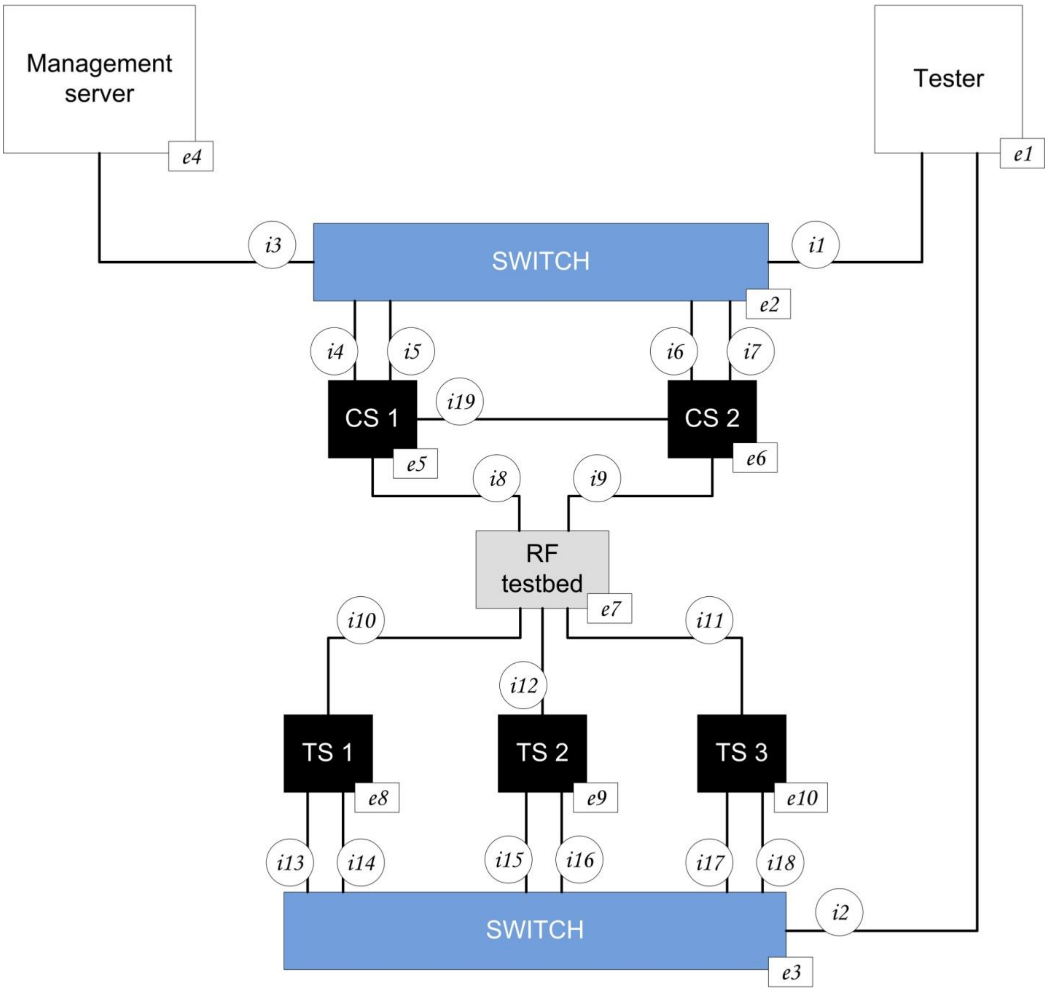

Figure 19. PoC 3 - configuration

The CSs and TSs are connected through a 28GHz RF Testbed (e7). Downstream traffic is generated from a Tester (e1) and injected to the CSs through a Switch (e2). At the other end, the traffic is received from the TSs and forwarded back to the Tester (e1) through another Switch (e3). Upstream traffic can be injected from the Tester (e1) following the opposite path. A Management Server (e4) is also deployed to control and monitor the BH system.

4.3 SW/HW development plans

Both HW and SW development for the BH system are carried out within task T4.3 and focus on implementing and supporting the following solutions:

- Multiply channel capacity per sector. With this solution, the system will be able of handling 112MHz channels at the 28 GHz band,
- Multiply area capacity through aligned sector collocation. With this solution, more than one CSs can be collocated and aligned, increasing the capacity per sector,
- Failsafe attributes in CS (1:1 mode) and TS (automatic frequency scanning). With this solution, both CS and TS are enhanced with the above attributes in order to increase network availability,
- Automatic TS entry at provisioning. With this solution, the BH system automatically decides TS assignment to the best CS according to predefined criteria,
- Modem overclocking. Latency is decreased by overclocking the modem using state-of-the-art hardware,
- Frame-based technique for further latency reduction. Latency is further decreased with innovative technique regarding the air frame.

To support the above solutions, a new platform has been developed in-house, specifically for the project, which is shown in Figure 20.

Figure 20. ICOM's SPEED-5G PtMP BH development board

On this platform the following internal software modules are currently under development:

- FPGA design level; state-of-the-art FPGA is used to support the new modem design,
- Low level software (kernel, drivers) for CS and TS,
- Networking software for CS and TS (upper layers),
- Software for the managing entity.

The platform mates with a 28GHz RF module, which is shown in Figure 21.

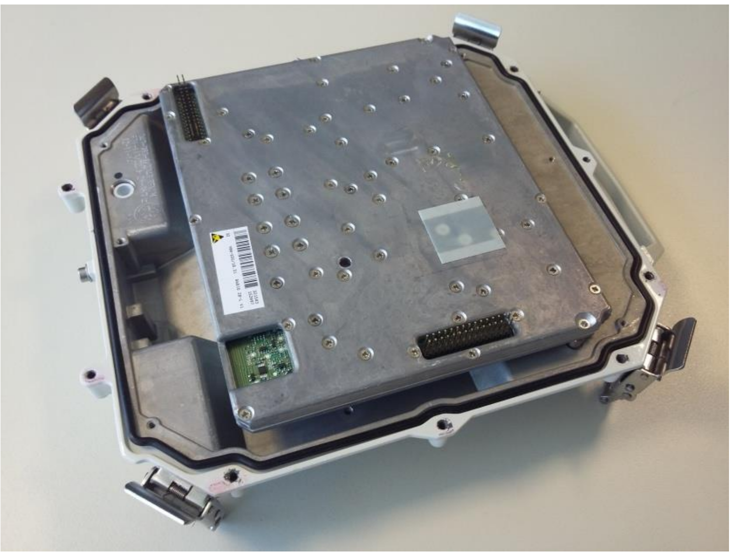

Figure 21. BH 28GHz RF module

4.4 List of equipment and interfaces

Table 12: PoC 3 - List of equipment

ID	Equipment type	Quantity	Vendor and model	Source
e1	Tester	1	Spirent SPT-9000A or JDSU MTS-5800 (depends on lab availability)	ICOM
e2	Ethernet switch	1	Cisco SG500x-24	ICOM
e3	Ethernet switch	1	Cisco SG500x-24	ICOM
e4	Management server	1	Common PC with management server installed	ICOM
e5, e6	Central Stations	2	Intracom Telecom's developed PtMP hardware configured as a Central Station	ICOM
e7	RF testbed	1	28GHz splitters and attenuators between CSs and TSs	ICOM
e8, e9, e10	Terminal Stations	3	Intracom Telecom's developed PtMP hardware configured as -Terminal Stations	ICOM

Table 13: PoC 3 - List of interfaces

ID	Type	Source

ID	Type	Source
i1, i2	10 GbE cable	ICOM
i3, i4, i5, i6, i7, i13, i14 i15, i16, i17, i18, i19	1 GbE cable	ICOM
i8, i9, i10, i11, i12	28GHz RF waveguides	ICOM

4.5 Test case mapping to PoC 3

This section lists applicable TCs and corresponding configurations for the PoC 3, as depicted in Table 14 below. The full description of TCs in the table can be found in Appendix 1.

Table 14: List of TCs applicable to PoC 3

Test case ID	Test case title	Relevant PoC ID	notes
B1	Throughput test	3	-
B2	Latency test	3	-
B3	Network availability test	3	-
B4	Resource balancing test	3	-

5 PoC 4: "communication Protocols for RRM"

5.1 Motivation and Scope

The RRM is a crucial component of the SPEED-5G project, as it is responsible for carrying out the eDSA functions. A *demulator* currently under development is a piece of SW which represents the combined functionality of a *de*monstrator and an e*mulator*. Its intended function is to (1) demonstrate the working of the RRM algorithms in several scenarios closely connected to the SPEED-5G UCs, and (2) incorporate emulation code for RRM functions which can eventually be used in the real system. The demulator is effectively a *reference model* for the RRM.

The cRRM is a high-level component of SPEED-5G, which operates at slow time scales, typically seconds or longer. One of its principal functions is to choose an appropriate RAT for a specified service, upon request from a cell which has UE requiring to be serviced. Because of the slow time-scale of operation, the RRM exists as a self-contained entity quite high in the network hierarchy and communicates with cells over TCP. Thus, the demulator runs as one or more processes on a single CPU with an allocated IP address. This design allows a distributed SPEED-5G architecture; in fact, the demulator may be sufficiently fully functional to act as a real RRM.

5.1.1 Use Case and Feature Descriptions

The SPEED-5G consortium partner BT will run a cRRM entity at its site near Ipswich, and provide a remote procedure call (RPC) interface allowing the HW PoC at Surrey and CEA to communicate with it. The intention is to test the feasibility and practically of the RPC approach, and to obtain some data on performance, such as on latency and overheads of the RPC protocol. The HW will send KPI data concerning radio links to the cRRM, which will run an algorithm and send a response, which might be, for example, a recommendation to change band or channel. This PoC intends to showcase UC #3: Capacity boosting in a small cell using resource aggregation, integrating demonstration platforms (PoCs) 1 and/or 2.

5.1.2 KPIs for PoC 4

The PoC will be considered successful if reliable communication between hardware and the remote cRMM entity. The result will be logged at the client (hardware) side.

5.2 PoC Configurations

The XML-RPC[2] (), will be used to provide an appropriate RPC server, with a small subset of cRRM-RLC and cRRM-hMAC messages implemented (as defind in WP5). An example RPC client for the hardware side will be provided. Note that the RPC will be language-agnostic.

The PoC can be set-up in 2 different configurations, represented in figures below. The PoC IDs corresponding to different configurations, are:

- PoC 4A: DCS-MAC and LTE, in co-located scenario
- PoC 4B: FBMC-MAC and LTE, in co-located scenario

5.2.1 Configuration A: DCS-MAC and LTE, in co-located scenario (PoC ID: 4A)

The configuration of Figure 22 allows validation and testing of:

[2] http://xmlrpc.scripting.com/

- “Resource Aggregation” of licensed and UnL/LL carriers

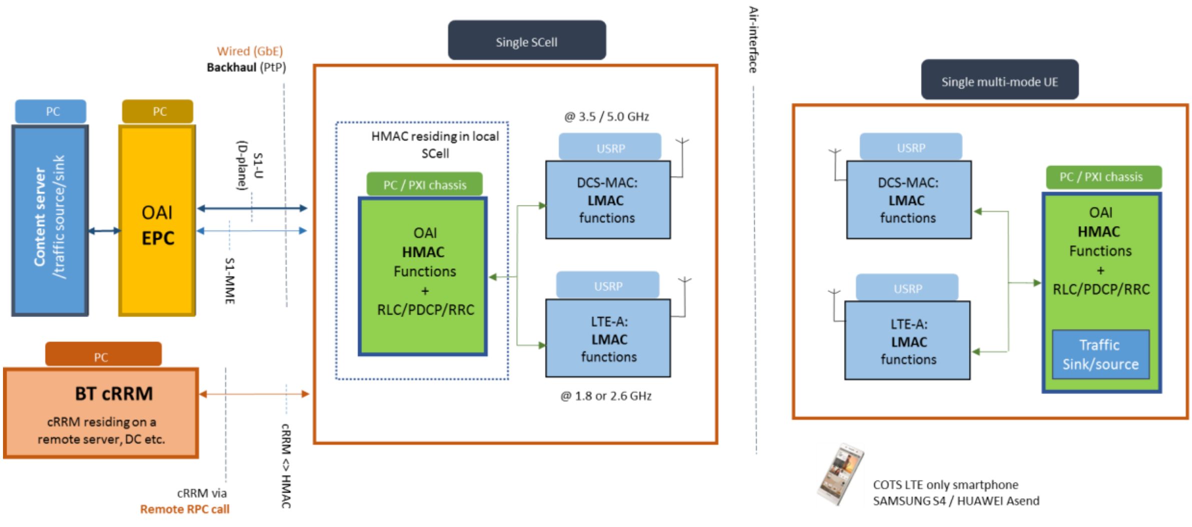

Figure 22: PoC 4A setup (co-located scenario)

5.2.2 Configuration B: FBMC-MAC and LTE, in co-located scenario (PoC ID: 4B)

The configuration of Figure 23 allows for validation and testing of:

- “Resource Aggregation” of L/LL carriers

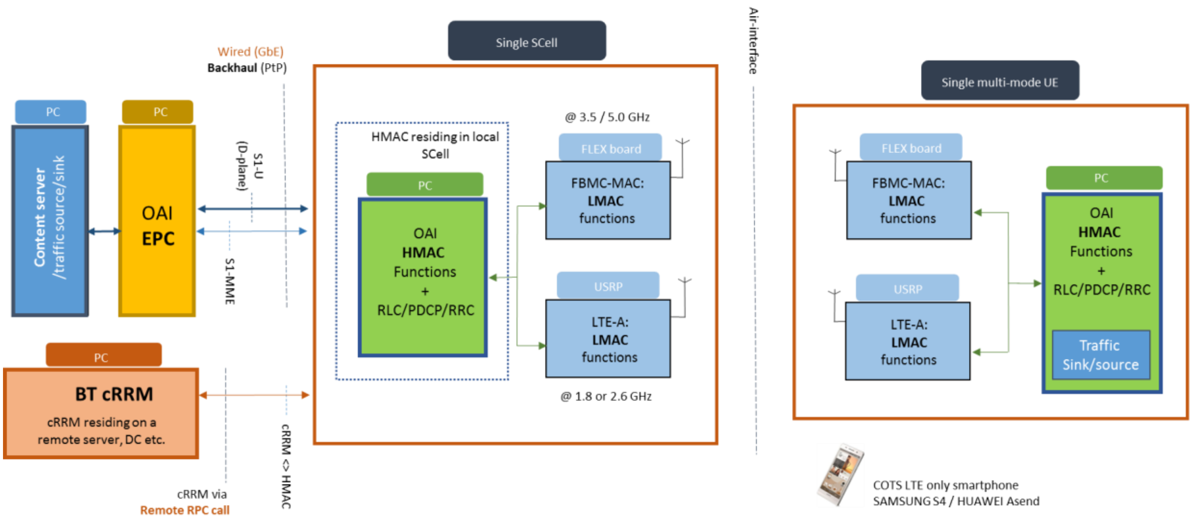

Figure 23: PoC 4B setup (co-located scenario)

5.3 SW/HW development plans

All SW is currently under development. In parallel, the set of supported interfaces is being expanded.

5.4 Test case mapping to PoC 4

This section lists applicable TCs and corresponding PoC 4 configurations, as depicted in Table 19 below. The full description of TCs in the table can be found in Appendix 1.

Table 15: List of TCs applicable to PoC 4

Test case ID	Test case title	Relevant PoC ID	notes
R1	Communication test	4A 4B	DCS on LL and LTE FBMC on LL and LTE

6 PoC 5: "Video quality measurements in 5G networks"

Besides the evaluation of the performance parameters of the SPEED-5G system, the concept of testing mobile networks by using video streaming standards in combination with ultra-high definition video (UHD), shall be performed by PoC 5.

6.1 Motivation and Scope

Actual and future usage of mobile networks is identified by an increasing number of video applications and by the expectation to see very high picture and audio quality. These video applications with their increasing demand of data rates (bandwidth) shall be consumable everywhere although frequency bands are limited. Thus the claim of the SPEED-5G project is to improve the usability of the next generation of mobile communication networks (5G) by providing smaller cells but with enhanced data rate and low latency. The video quality measurement setup shall verify the enhancements and demonstrate the quality of service (QoS) and the quality of experience (QoE) that can be reached with this approach. To fulfil the claim to be future proof and provide solutions that are beyond the state-of-the-art, ultra-high definition television video (UHDTV) and the newest compression standard HEVC (High efficiency video coding) are used to demonstrate future video consumption on mobile devices.

6.1.1 Use Case and Feature Descriptions

The considered use cases are the ones identified in [1]. The advantage of a video quality measurement system vs. a subjective quality evaluation (observation) lies first in that a reliable constant source guaranties a stable setup, and second in that results are reproducible, although they may not always be aligned with objective quality observation. Such a system has to take care about the following 3 aspects:

- Suitable video content,
- Different transmission protocols,
- Objective quality measurement.

Not every video content is suitable to evaluate the video quality. For reliable and repeatable results the video sequences should not be too long and should not contain effects which look like a transmission error. Practical experience showed that the usage of short sequences in an endless repetition fits best to detect picture errors. This is not only the case for tests with human observers, but also for a test system that is thereby able to compare the transmitted sequence with a learned and stored error free version.

Video services may be of different types, although all are based on the internet protocol (IP). Whereas on-demand content require unicast connection to the video server, linear services may be using multicast transmission. In this test setup the suitability of the mobile communication technologies shall be proofed as well as the applicability to qualify the performance by measuring the video quality. Video consumption over IP networks can be performed with four different protocols:

- User Datagram protocol (UDP) Multicast,
- UDP Unicast,
- transmission control protocol (TCP) Unicast fixed data rate,
- TCP Unicast adaptive data rate.

UDP Multicast is usally limited to managed networks, where the routing of multicast adressed packets to registered clients can be performed and garanteed. In general these packets are not broadcasted to every node in the network, so that a management of multicast groups is necessary. This technique, called Multimedia Broadcast Service (MMBS) is implemented although today not commercially employed by network providers.

UDP Unicast overcomes the UDP limitation by adressing every client separately, but with the disadvantage that identical content has to be transmitted through the network, thus causing a high demand of bandwith (bitrate). The UDP also needs extra forward error correction (FEC) techniques to improve the transmission quality, although error free transmission can never be garanteed.

A more reliable transmission protocol is the TCP, which works with handshake protocols where the receiver checks received packets and reports the reception. Not received packets will be re-sent. TCP unicast with a fixed datarate is actually the common video transmission protocol where the user selects the data rate by choosing a picture size. If the choosen data rate is too high for the given channel, the video stops. This makes TCP not suitable for live video. There's therefore the need for an adaptive system, where the client video player (decoder) is able to change the data rate on the fly. This TCP Unicast adaptive data rate protocol is part of the so-called Dynamic Adaptive Streaming over HTTP (DASH) system.As the future common technique for video streaming, the DASH protocol is used for PoC 5. The usage of the DASH protocol implies a change in the video packaging also. Instead of the transport stream protocol, which is used for standard video broadcast via satellite, cable or air as well as for IPTV, DASH is based on an MP4 container format. Of course a full commercial implementation of a video streaming platform would need the development of more components, such as subscribing, billing, advertising etc., but this is not in the scope of this demonstration.

6.1.2 KPIs for PoC 5

The intention of this demonstrator is to enable analyse and evaluation of video quality in the selected UCs. The set of KPI's can be grouped in 3 categories.

- IP Performance,
- QoS,
- QoE,

Because the transmission of video is IP based, the IP performance parameters play a key role, e.g. the origin limiting factor and source of quality decrease. As a result of insufficient IP performance the user experiences a degradation in the quality of the video service (QoS). Finally, also the objective measurable parameters do have an impact to the overall QoE of the video service.

Parameters of IP performance are:

KPI	Description
Bit rate	Data plain content measured in bits per second
Latency	Delay of transmission between sender and receiver
Packet loss	Errored IP packets per transmitted IP packets (UDP)
Packet retransmission ratio	IP packets to be retransmitted compared to original IP packets

An initial and critical service parameter is the guaranteed minimum bit rate, because it influences heavily the QoS / QoE parameters. Insufficient bit rate results in several degradations, dependent on the video playout implementation. Latency is usually not a very critical parameter for video services, because digital video systems include several compression and buffering mechanisms that allow to cope with several seconds of delay. But packet loss in the UDP case generates at least deviations from the original pictures, if not picture freeze. In case of TCP transmission there is additional delay, which may also cause picture freeze, if not avoided by longer buffering (which increases start-up delay). The packet retransmission ratio is the result of an erroneous transmissions in case of a TCP protocol.

Parameters of QoS are:

KPI	Description
Picture freeze (stall)	Repetition of one picture over 4 or more picture periods
Peak Signal to Noise Ratio (PSNR)	For the three components of a video picture Y, Cb and Cr, the PSNR separately indicates the logarithmic ratio of the maximum possible total deviation of all pixels from the nominal value of the reference (MAX)
Mean opinion score video (MOS-V)	Based on ITU-T BT.500 quality in 5 steps (Bad, Poor, Fair, Good, Excellent)

A stall occurs when the video/picture freezes. This is typically due to buffer underruns and playback is resumed after enough segments have been re-buffered. In addition this influences the synchronization to audio. In practice, users experiencing stalls usually report a very low quality and, thus, stalls should be completely avoided (even if it means to increase the start-up delay). As described above, degradation of PSNR is expected with UDP transmission only, because this parameter describes the logarithmic ratio of the maximum possible total deviation of all pixels from the nominal value of the reference for the three components Y, Cb and Cr. For TCP transmission an error free video data reception can be assumed. The same assumption may be made for the MOS-V. This parameter is evaluated with a structural similarity (SSIM) measurement.

Parameters of QoE are:

KPI	Description
Initial/start-up delay	Time between service/content request and start of the actual playout
Quality switches	Number of changed bit rates during defined transmission time
Media throughput	Bit rate, measured in media bits per second
QoS	Summary of parameters described above

Initial/Start-up delay: The initial or start-up delay comprises the time between service/content request and start of the actual playout, which typically involves processing time both at the server and client, network handling and transmission time for sending the media request and receiving first segments and initial buffer time, before the playout starts. In general, the start-up delay should be low but it also depends on the UC. For example, the QoE of live streams or short movie clips is more sensitive to start-up delay than full-length video on demand content.

Quality switches: Under changing network conditions, quality switches - provided by the DASH system - occur to avoid buffer underruns (and stalls) in order to guarantee a smooth video playback. However, if it happens too often (e.g., every second) or with a high amplitude (e.g., switching from a very high quality to a very low quality representation) it negatively impacts the QoE.

Media throughput: The overall media throughput at the client usually determines the picture quality. High media throughput allows pictures with high quantisation and more details.

6.2 PoC Demonstrator Setup

Figure 24 illustrates the usage of the video quality measurement test setup to evaluate the qualification of a mobile IP network for video transmissions.

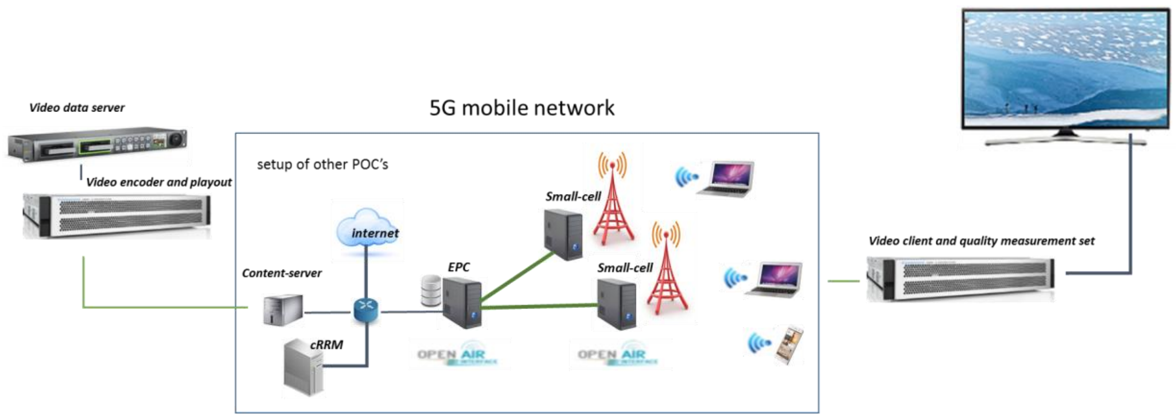

Figure 24: Physical view of the PoC 5 demonstrator

To get reliable measurement results, it is essential to provide a reliable video source with known and not changing parameters. Therefore a video data server produces uncompressed video sequences, the content of which can be used to evaluate the video quality. Scenes like music video clips with lots of switching, flashing, noise and other art effects are not useful. Picture interference would not harm the QoE, even in the case of a poor QoS. Future quality expectation are expected to be very high, so ultra-high definition video content (UHD) is provided. The uncompressed video is transmitted via 12Gbit/s SDI (serial data interface) transmission to the R&S video encoder and playout system.

Usually used as a television broadcast system the unit has been modified to support live playout for over the top (OTT) services. The compressed and packetized video is prepared and is available on a content server, ready to be delivered to requesting clients. The content server can be on the playout server itself or be located on another (separate) machine. The interface is defined as 1GbE. The video client and quality measurement set take the role of a video service consumer. It requests the video packets from the content server and analyses the deviation of the picture quality from the expected quality. The received picture is shown as well as the altered picture areas which are marked for subjective observation.

6.2.1 Physical Architecture

Figure 25 illustrates the usage of the R&S PoC setup. The setup is suitable to be connected to the other PoCs described in this document. The video server system works as sender to produce data traffic to the other PoC setups and the video monitoring system works as receiver.

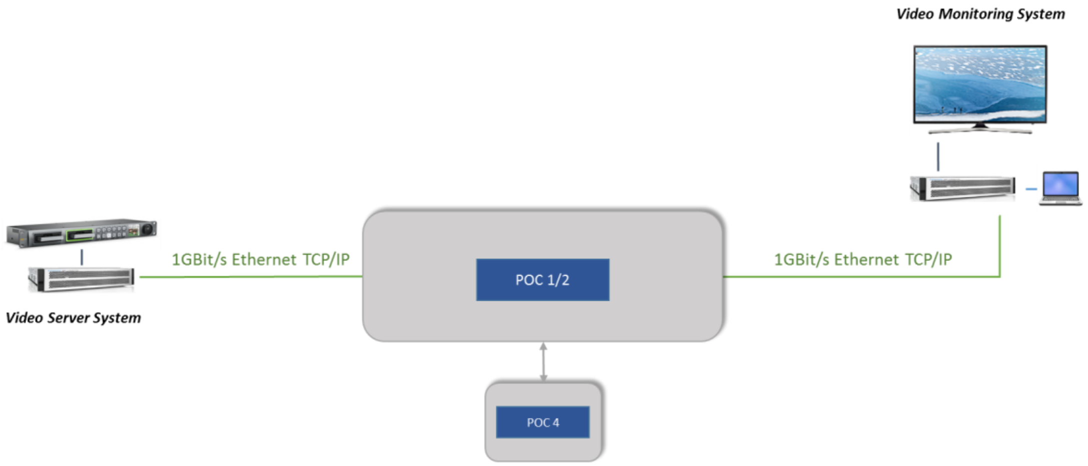

Figure 25: Physical Architecture of PoC 5

6.2.2 SW Components

Figure 26 depicts the SW components of the video server system and the video monitoring system.

The looped, but endless played uncompressed UHD video content has to be interfaced from the 12Gbit/s cable connection to the internal data handling. Because the UHD format may be not suitable for all clients or network conditions, a scaling to smaller picture sizes like HDTV and Quad HDTV is performed in the next step (Scaling). The scaled video pictures with 8, 4 and 2 Gbit/s need to be compressed to video streams at suitable bitrates as 20, 10 and 5 Mbit/s by synchronized HEVC encoders in the compression step, the following OTT service unit prepares the packets for the content delivery server. According to the DASH standard a manifest file describing the service qualities is prepared. The content server provides a WebDAV service for clients request with TCP/IP unicast transmission over Ethernet.

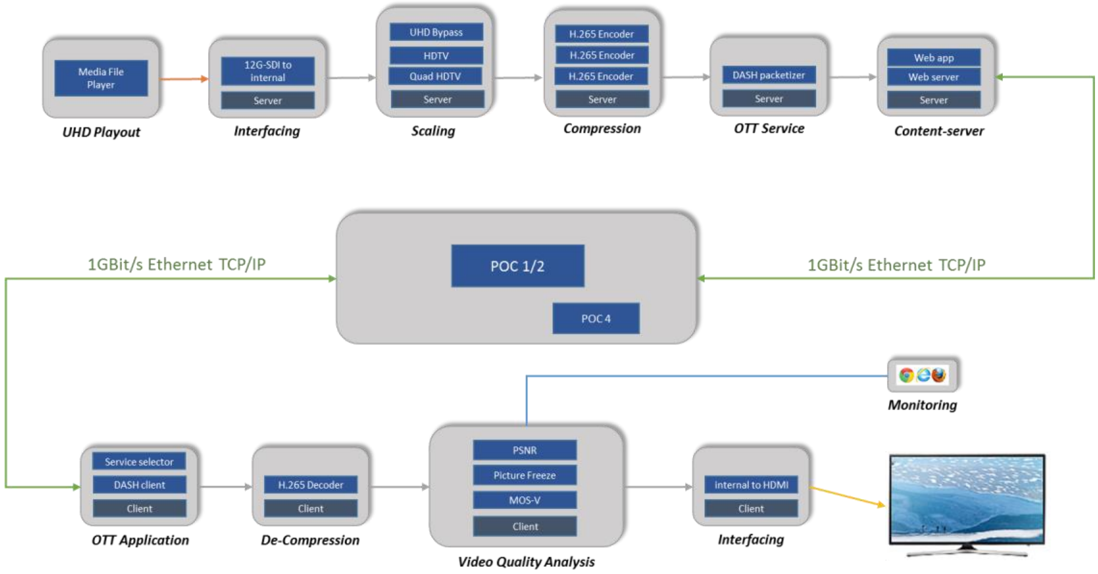

Figure 26: Logical Architecture

6.3 SW/HW development plans

The following SW modules and improvements are currently under development:

- Encoder synchronization,
- DASH packetizer,
- DASH service selector,
- DASH client,
- Adaptation of the quality measurement,
- Monitoring and logging software,

With reference to the logical architecture, the video compression module has to be extended to allow a synchronized encoding of different picture formats of the video signal. This is an essential feature to create exchangeable segments with different quality (representation) to be packetized.

The DASH packetizer provides the coded video and audio samples and stores them on an on-board webserver for consumption through the developed DASH client module placed on the measurement system (receiver side). The DASH service selector enables an adaptive streaming addicted to the achievable transmission performance. The quality measurement requires adaption to HEVC encoding with UHD content and an interface for a long term monitoring and logging software.

6.4 Interfaces and Integration with the test setup of other PoC's

The video test system will interface to PoC 1 (FBMC-MAC) and or PoC 2 (DCS-MAC) via GbE. The system will then be used to measure the achieved video data rates and video quality. The Video QoS/QoE parameters will be used to assess the advantages of the SPEED-5G solution. A video server system for the Broadband scenario with Ultra High Definition (UHD/4k) content on MPEG-DASH protocol will be used. A video client including a video quality measurement will be set up. In detail the following procedures shall be monitored in their behaviour and influence:

- Resistivity to erroneous IP packets, delayed IP packets and reception jitter
- Error free video transmission during dynamic channel selection.
- Error free video transmission during load balancing
- Error free video transmission during carrier aggregation

6.5 Interaction with other PoC configurations

This PoC will connect to POC 1 and/or 2 configurations via standardized Ethernet connection.

6.6 List of equipment and interfaces

Table 16 and Table 17 list the required equipment and interfaces for PoC 5.

Table 16: List of required equipment

ID	Equipment type	Quantity	Vendor and model	Source
e1	Video Storage and Playout Device	1	Blackmagic Hyperdeck Studio	Rohde & Schwarz
e2	Video Headend Compression and streaming device	1	Rohde & Schwarz AVHE 200	Rohde & Schwarz
e3	Streaming Client and Video Quality Measurement System	1	Rohde & Schwarz Prismon	Rohde & Schwarz
e4	Monitoring Device	1	Linux Notebook	Rohde & Schwarz
e5	TV set	1	Samsung	Rohde & Schwarz

Table 17: List of Interfaces

ID	Type	Parameter's / comments	Source
i1	12G SDI or 4 * 3G SDI	12 Gigabit/s	Rohde & Schwarz
i2 i3	1G Ethernet	UDP /TCP	Rohde & Schwarz CEA / UNIS
i4	HDMI	2.0	Rohde & Schwarz

6.7 Test case mapping to PoC 5

This section lists applicable TCs and corresponding PoC 5 configurations, as depicted in Table 18 below. The full description of TCs in the table can be found in Appendix 1.

Table 18: List of TCs applicable to PoC 5

Test case ID	Test case title	Relevant PoC ID	notes
S1	Quality test	5	DCS and FBMC setup as per PoC 1 or 2
S2	Offload video impact test	5	DCS and FBMC setup as per PoC 1 or 2

7 PoC 6: "Integrated PoC"

This PoC demonstrates the feasibility of the proposed SPEED-5G eDSA architecture and the gains from its realisation. This PoC includes all the basic elements of the SPEED-5G eDSA architecture including the LMAC, the HMAC and the cRRM modules, and therefore demonstrates the innovation of the solution as a whole. In this PoC, solutions developed and validated in intermediate PoCs from different partners, are brought together and integrated. The PoC is comprised of selected HW and SW elements and SW platforms in order to demonstrate a number of innovative functionalities. The following sections describe the PoC setup in more detail. The "integrated PoC" includes contributions from several partners:

- Traffic injection and monitoring from R&S,
- cRRM solution from BT,
- DCS-MAC from UNIS,
- FBMC-MAC from CEA
- cRRM and dRRM solutions from WINGS, UNIS, CEA, IT, INTEL,
- PtMP BH and FH solutions from iCOM.

7.1 Motivation and Scope

In contrast to the intermediate PoCs, which focus on select features of the SPEED-5G eDSA architecture (e.g. LMAC, HMAC, dRRM, cRRM), this PoC demonstrates the architecture as a whole. In this direction, this PoC demonstrates only a selected set of functionalities (mapping to specific test cases) which are representative of the main project innovations. **Therefore the PoC demonstrates resource aggregation, offload/traffic steering, using hierarchical RRM (for dynamic channel/RAT selection and interference management).** In addition to this, the objective of the PoC is to demonstrate seamless integration of various solutions provided by different partners. In light of this demonstration plan, 4 demo configurations have been identified (A to D below) with each setup providing ability to test/validate certain identified SPEED-5G features (and algorithms).

- **Config. A (DCS-MAC & LTE) – co-located scenario:**
  - "Resource Aggregation" of licensed and UnL/LL carriers,
  - "Offload/steering" to UnL/LL bands.
- **Config. B (DCS-MAC & LTE) – non-co-located scenario w/ RAN split:**
  - "Resource Aggregation" of licensed and UnL/LL carriers,
  - "Offload/steering" to UnL/LL bands.
- **Config. C (FBMC-MAC & LTE) – co-located scenario:**
  - "Resource Aggregation" of licensed and LL carriers,
  - "Offload/steering" to LL band.
- **Config. D (FBMC-MAC & LTE) – non-co-located scenario w/ RAN split:**
  - "Resource Aggregation" of licensed and LL carriers,
  - "Offload/steering2 to LL band.

7.1.1 Use Case and Feature Descriptions

Based on the broadband wireless scenario, PoC 6 intends to address the identified UCs of resource aggregation and load-balancing. In all configurations, multiple RATs co-exist in a co-located manner. In this PoC, a PtMP BH/ Fronthaul (FH) solutions is also present. Based on the harmonization point of the PtMP, two variants of this PoC are possible: a) Backhauling for traditional D-RAN; b) Fronthauling for C-RAN, with RAN-split at MAC layer.

7.1.2 KPIs for PoC 6

The main KPIs to be evaluated in the PoC are presented in the following tables. The first table illustrates KPIs related to the user end-to-end statistics and the provided QoS. The second table presents KPIs which are related to the performance of the proposed SPEED-5G architecture, mainly latency of eDSA and cRRM functionalities.

Table 19: D- plane related KPIs

KPI	Description
Throughput	Average throughput (MAC and IP/APP layers)
Latency	End-to-end latency from source to destination
Reliability	Reliability in terms of Block Error Rate (BLER) and Packet Error Rate (PAR) under given data rate demands

Table 20: C- plane related KPIs

KPI	Description
eDSA latency	Total latency to accomplish a full eDSA cycle (measurements collection, algorithm execution, decisions enforcement)
dRRM latency	Total latency to accomplish a full dRRM cycle (measurements collection, algorithm execution, decisions enforcement)
cRRM latency	Total latency to accomplish a full cRRM cycle (measurements collection, algorithm execution, decisions enforcement)

7.2 PoC Configurations

The PoC can be set-up initially in 4 different configurations, intended to implement the UCs of aggregation and offload, in BH and FH scenarios respectively. The PoC IDs corresponding to different initial configurations, are:

- **PoC 6A** – corresponding to Config. A: **DCS-MAC & LTE, in co-located scenario**
    - Related to UC2 and UC3,
- **PoC 6B** – corresponding to Config. B: **DCS-MAC & LTE, in non-co-located scenario w/ RAN split @ MAC**
    - Related to UC2 and UC3,
- **PoC 6C** – corresponding to Config. C: **FBMC-MAC & LTE, in co-located scenario**
    - Related to UC2 and UC3,
- **PoC 6D** – corresponding to Config. D: **FBMC-MAC & LTE, in non-co-located scenario w/ RAN split @ MAC**
    - Related to UC2 and UC3.

7.2.1 Configuration A: DCS-MAC and LTE, in co-located scenario (PoC ID: 6A)

The configuration of Figure 27 allows validation and testing of:

- “Resource Aggregation” of licensed and UnL/LL carriers,
- “Offload/steering2 to UnL/LL bands,
- "Hierarchical RRM".

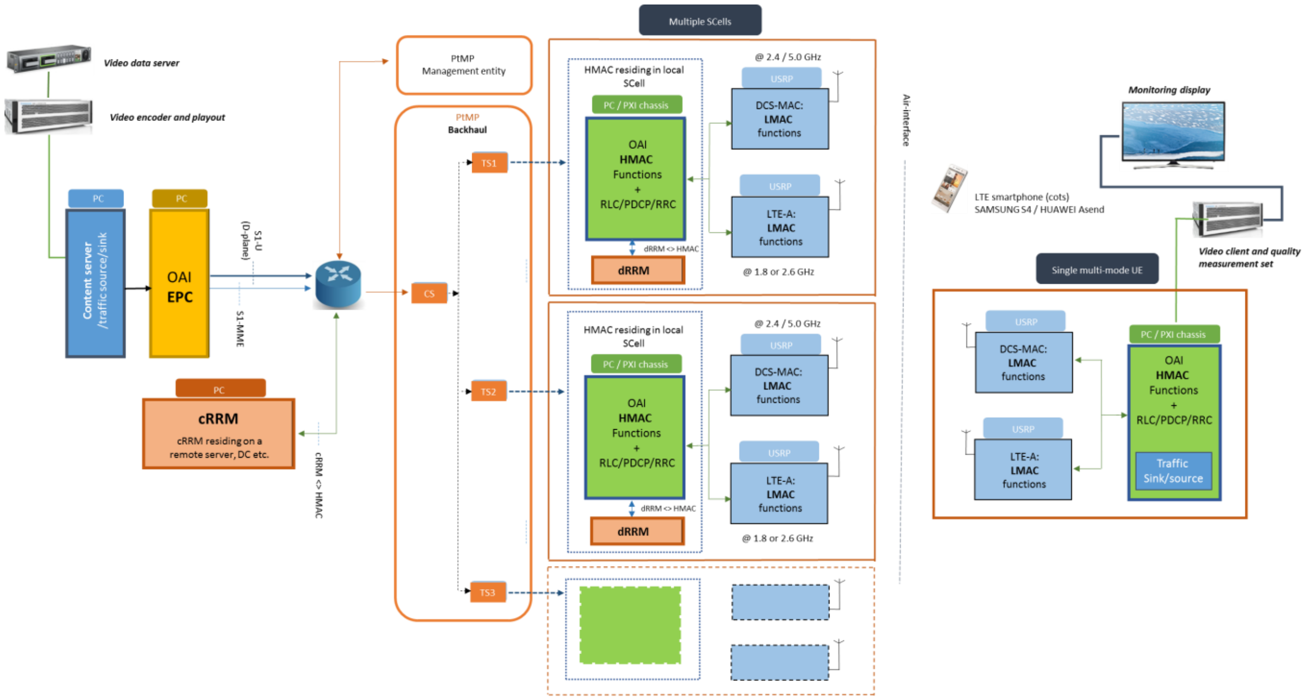

Figure 27: PoC 6A setup

7.2.2 Configuration B: DCS-MAC and LTE, in non-co-located scenario with RAN split @ MAC (PoC ID: 6B)

The configuration of Figure 28 allows for testing of:

- “Resource Aggregation” of UnL/LL carriers,
- “Offload/steering” to UnL/LL bands,
- "Hierarchical RRM".

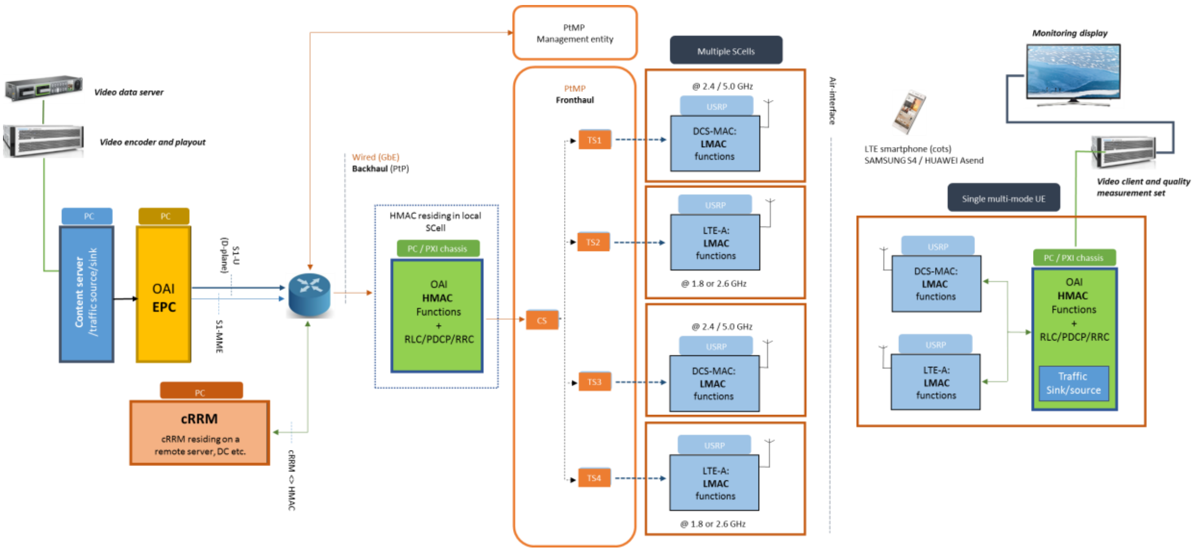

Figure 28: PoC 6B setup

7.2.3 Configuration C: FBMC-MAC and LTE, in co-located scenario (PoC ID: 6C)

The configuration of
Figure 29 allows for validation and testing of:

- “Resource Aggregation” of UnL and L/LL carriers,
- “Offload/steering” to UnL band,
- "Hierarchical RRM".

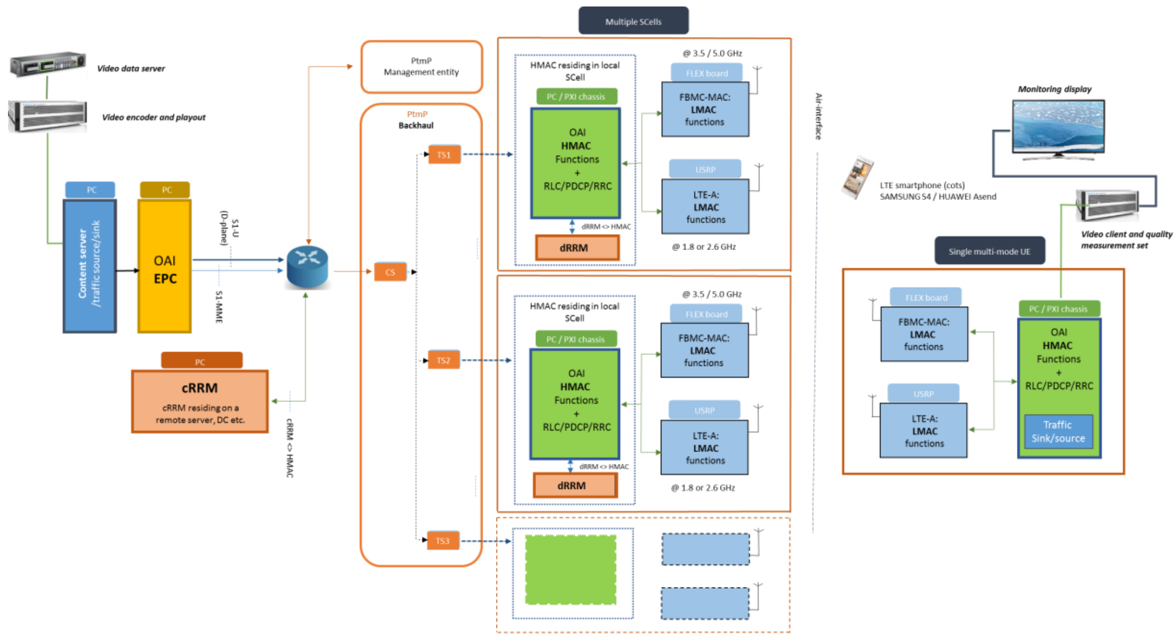

Figure 29: PoC 6C setup

7.2.4 Configuration D: FBMC-MAC and LTE, in non-co-located scenario with RAN split @ MAC (PoC ID: 6D)

The configuration of Figure 30 allows for validation and testing of:

- “Resource Aggregation” of UnL and L/LL carriers,
- “Offload/steering” to UnL band,
- "Hierarchical RRM".

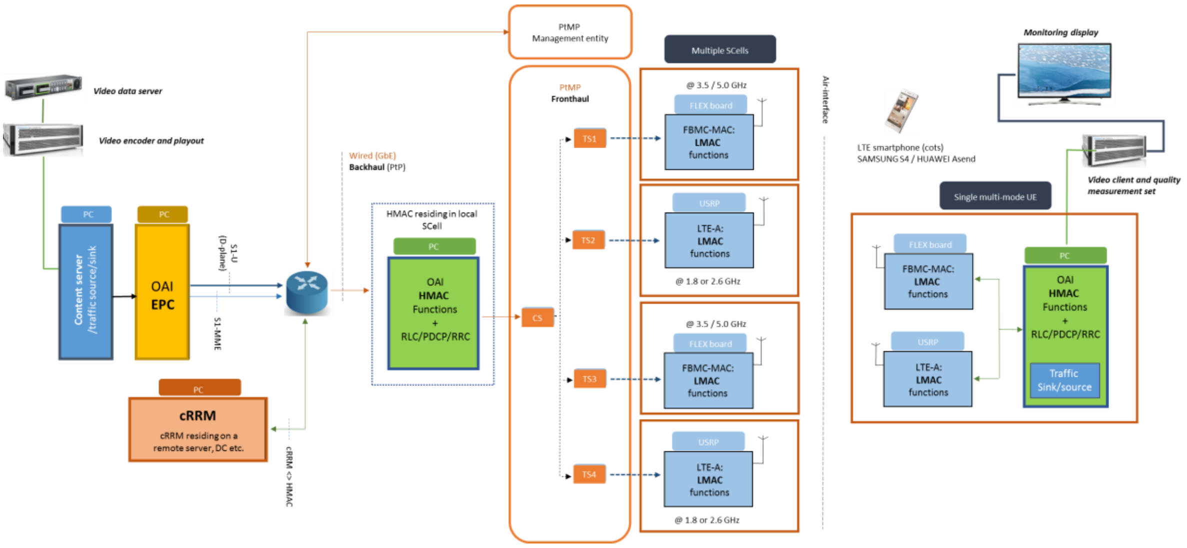

Figure 30: PoC 6D setup

7.2.5 Physical Architecture

The physical architecture of the PoC is presented in the following two figures. Figure 31 demonstrates the case in which the PtMP elements are used as a BH solution, while Figure 32 presents the FH case. In the first case, the testbed is composed of 3 DCS or FBMC small cells realized with DCS USRPs or FBMC boards respectively, 4 LTE cells realized by four USRPs supporting the OAI, 4 antennas forming the PtMP BH architecture and several switches and PCs. All the small cells (DCS/FBMC/LTE) are directly connected to a PC which is responsible for the higher layer procedures (e.g. HMAC). These PC are then connected to the PtMP links. On the other side of the PtMP, are located the EPC, the Content-server and cRRM servers. On the right side of the figure, one or several UE can connect simultaneously to the LTE and DCS/FBMC small cells. In this scenario, video traffic is generated in the Content-server and delivered to UE.

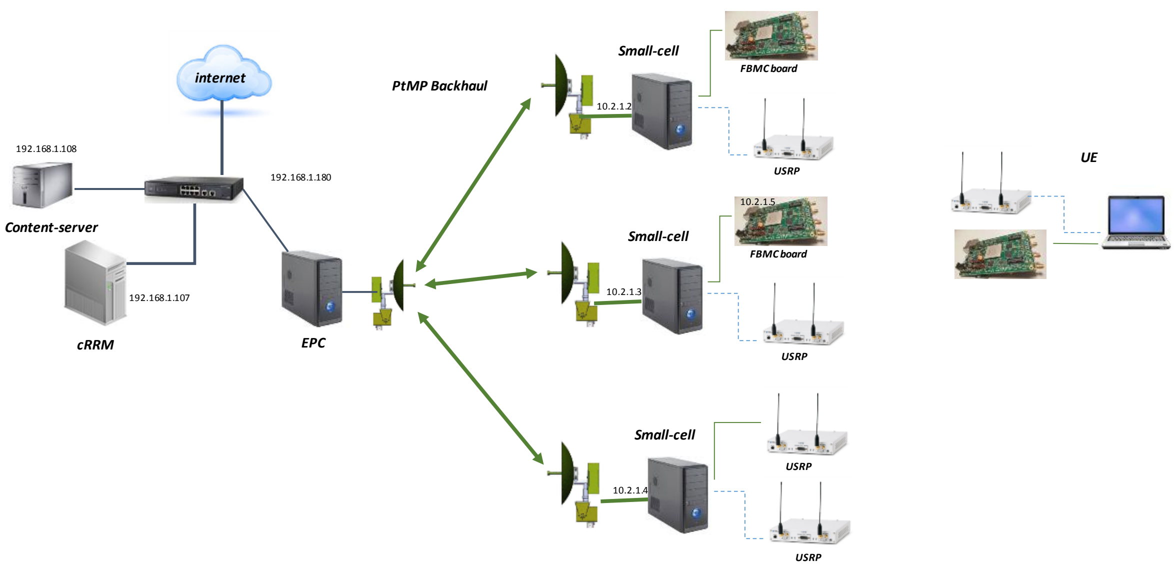

Figure 31: Physical view of the PoC#6A and PoC#6C demonstrator (PtMP used for BH)

The second scenario, illustrated in Figure 31 is similar to the first one, apart from the deployment of the PtMP links. In this case, the LMAC functionalities of DCS/FBMC are deployed into the USRPs and FBMC boards respectively, while the HMAC functionalities are located on the other side of the PtMP links (Small-cell PC in the figure). Similar to the first scenario, the EPC (OAI EPC), the Content-server and the cRRM are also present, while several UE can connected simultaneously to the LTE and DCS/FBMC small cells. In this case, the video server generate video flows which are delivered to LTE-A or to FBMC or DCS or to a selection of connections based on the decisions of cRRM and dRRM entities.

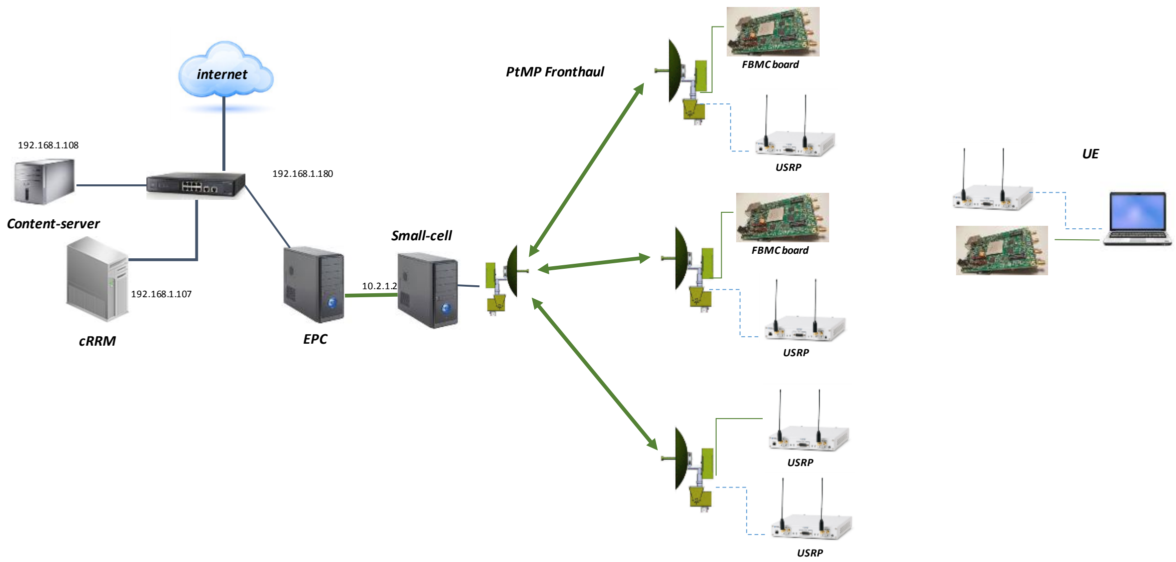

Figure 32: Physical view of the PoC#6B and PoC#6D demonstrator (PtMP used for FH)

7.3 SW/HW development plans

The required SW and HW components are already implemented during the realisation of the individual demonstrators (PoC 1-5). In this PoC the main focus is on the integration of the different modules from the different partners.

7.4 List of equipment and interfaces

The list of equipment and interfaces are depicted in Table 21 below.

Table 21: List of Equipment

Equipment type	Quantity	Vendor and model	Source
TV monitor	2	TBC	UNIS, R&S
USRPs	5	USRP 2954	UNIS
USRPs	2	USRP X310	WINGS
USRPs	2	USRP B210	WINGS
PC (Linux)	6	Dell	UNIS
PC (Ubuntu)	3	Dell	WINGS

Video Storage and Playout Device	1	Blackmagic Hyperdeck Studio	Rohde & Schwarz
Video Headend Compression and streaming device	1	Rohde & Schwarz AVHE 200	Rohde & Schwarz
Streaming Client and Video Quality Measurement System	1	Rohde & Schwarz Prismon	Rohde & Schwarz
Monitoring Device	1	Linux Notebook	Rohde & Schwarz
TV set	1	Samsung	Rohde & Schwarz
Tester	1	Spirent SPT-9000A or JDSU MTS-5800 (depends on lab availability)	ICOM
Ethernet switch	1	Cisco SG500x-24	ICOM
Ethernet switch	1	Cisco SG500x-24	ICOM
Management server	1	Common PC with management server installed	ICOM
Central Stations	2	Intracom Telecom's developed PtMP hardware configured as a Central Station	ICOM
RF testbed	1	28GHz splitters and attenuators between CSs and TSs	ICOM
Terminal Stations	3	Intracom Telecom's developed PtMP hardware configured as -Terminal Stations	ICOM

Table 22: List of Interfaces

Type	Parameter's / comments	Source
12G SDI or 4 * 3G SDI	12 Gigabit/s	Rohde & Schwarz
1G Ethernet	UDP /TCP	Rohde & Schwarz CEA / UNIS
HDMI	2.0	Rohde & Schwarz
10 GbE cable	-	ICOM
1 GbE cable	-	ICOM
28GHz RF waveguides	-	ICOM

7.5 Test case mapping to the "integrated PoC"

This section list the applicable TCs and the corresponding PoC 6 configurations, as depicted in Table 23. The full description of TCs in the table can be found in Appendix 1.

Table 23: list of TCs applicable to PoC 6

Test case ID	Test case title	Relevant PoC ID	notes
i1 (A1)	Aggregation of licensed LTE & LL (collocated SC scenario)	6A 6C	A: DCS-MAC operating on LL bands & LTE operating on licensed bands. B: FBMC-MAC operating on LL bands & LTE operating on licensed bands.
i2	Aggregation of licensed LTE & LL (non-co-located SC scenario), as in I1, w/ RAN split @ MAC	6B 6D	B: DCS-MAC operating on LL bands & LTE operating on licensed bands. D: FBMC-MAC operating on LL bands & LTE operating on licensed bands.
i3 (O1)	Offload/steering to UnL band (collocated SC scenario)	6A 6C	A: DCS-MAC operating on UnL & LTE operating on licensed bands. C: FBMC-MAC operating on LL bands & WiFi operating on unlicensed bands.
i4	Offload/steering to UnL band (non-co-located SC scenario) – as in I3, w/ RAN split @ MAC	6B 6D	B: DCS-MAC operating on UnL bands & LTE operating on licensed bands. D: FBMC-MAC operating on LL bands & LTE operating on licensed bands.
i5 (R2)	Hierarchical RRM	6A, 6B, 6C, 6D	DCS & FBMC setup as per PoC 1 or 2

8 Conclusion and next steps

This deliverable provided an overview of the planned PoC's in SPEED-5G. The planned demonstrations aim to showcase project innovations based on the four main demonstration categories: resource aggregation (high capacity), offload, dynamic channel switching & interference avoidance and coexistence, directly mapping to select UCs. Although the main scenario and service of interest is the eMBB, achieved through resource aggregation and supported natively by the proposed MAC/RRM designs, other important system aspects such as coexistence and traffic steering capabilities will also be evaluated, on the main trial testbed.

Five individual intermediate demonstrators are defined. These Individual PoCs serve to validate per-partner innovations and have been described by specifying the targeted UCs and the considered KPIs. Additionally, the selected techniques that will be adopted by each PoC are specified. Moreover, the platforms that will be developed or used for each PoC are described along with the PHY and MAC layer components, RRM algorithms and control functionalities. Demonstrators from CEA & UNIS (PoC 1 & 2) aim to showcase aggregation and offload and dynamic channel switching and coexistence capabilities of FBMC and DCS MAC designs, PoC 3 is used to validate the BH PtMP solution and advancements, from iCOM. PoC 4, from BT, is used to validate remote cRRM functionality/algorithms and communication with PoCs 1 and 2. PoC 5 is used to validate interworking of HD/UHD video traffic generation, monitoring and quality measurements.

The individual solutions are then combined and integrated into a single demonstrator platform (PoC 6), which is used as the main SPEED-5G integrated testbed, for final demonstrations and trials. PoC 6 is then used to showcase the main project innovations relating to capacity improvement, through aggregation and offload. The SW and HW components already available at the various partners' sites, as well as the defined demonstrators, constitute a solid foundation for the assessment and evaluation of the technology solutions being developed within SPEED-5G, based on identified test cases and under diverse setups and configurations.

In this deliverable, we present the physical and logical architectures of each demonstrator, as well as the configurations of the individual components comprising the demonstrators. For this reason, the present deliverable serves as a technical report that can be also used as a guide for outside parties interested in deploying all or part of the SPEED-5G technical solutions. The demonstrators described in the present document, currently under development, are subject to on-going refinements, during development phase. The final deliverable of WP6, D6.3, will report on the validation results of the aforementioned field and lab trials at the conclusion of the project in month 33.

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[4] Open Air Interface (OAI): http://www.openairinterface.org/

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Appendix A Test cases

This appendix provides details of various functional, protocol and performance related test cases.

A.1 Functional Tests

Functional testing exercises device capabilities with combinations of options, multiple connections, differing types of traffic, and many sequences of operations. Protocol and functional testing involves verifying the operation of elementary procedures defined in the standard specifications, possibly for each protocol layer individually, or the complete protocol stack as a whole. For example, operators want to test the 3GPP “attach” procedure by itself, using one UE, the Tracking Area Update (TAU) procedure etc. Each step of the procedure must be analyzed for correctness in terms of the signaling flow and content of each of the message Information Elements (IEs) and compliance to specifications laid out in D5.2 deliverable.

A.1.1 Test cases for basic signalling procedures

Resource (Random) Access (co-located SC scenario)

Test case ID: S1

Test objective:
The objective of this test case is to validate the correct operation (protocol compliance) of the random access procedure, and measure the success rate and delay, with a **single UE** under radio fading channels.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FMAC/DCS) SC, 1 x (FBMC/DCS) UE.
- Operational bands/freq./channel bandwidth: UnL (5 GHz) or LL (3.5 Hz) bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: variable step attenuator added at the small cell side (for both RX and TX paths) with attenuation set to 0 dB

Test metrics:
The metrics of interest are delay and success rate. The measurements are first performed with AWGN then fading channel (cabled mode) conditions. Tests shall provide the following results:

- Success rate of the procedure measured over repeated tests.
- Median & 95%-idle delay of the procedure averaged over repeated tests
- Test will be repeated with different settings of the variable attenuator to produce a variable S(I)NR until reaching the receiver sensitivity

Test PASS/FAIL criteria:
- Confirm correct operation sequence for random access per signaling flow diagram in D5.2
- PASS indicator: reception of a control message from the small cell notifying the device association. As an example for FBMC MAC, the PASS indicator will be the reception of a beacon with the device address in the list of associated devices like in MSC of figure 66 of D5.2. The same can be applied to DCS MAC.

Call setup/tear-down signalling procedure (co-located SC scenario)

Test case ID: S2

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of call setup/tear-down procedure, and measure the success rate and delay of both procedures (comprising: Attach, bearer setup, bearer release and detach sub-procedures) with a **single UE** under radio fading channels.

Test setup:
- As per PoC #1 and #2, with a minimum of: 1 x (FMAC/DCS) SC, 1 x (FBMC/DCS) UE.
- Operational bands/freq./channel bandwidth: UnL (5 GHz) or LL (3.5 Hz) bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: variable step attenuator added at the small cell side (for both RX and TX paths) with attenuation set to 0 dB

Test metrics:
The metrics of interest are delay and success rate. The measurements are first performed with AWGN then fading channel (cabled mode) conditions. Tests shall provide the following results:

- Success rate of the procedure (MO & MT) measured over repeated tests.
- Median & 95%-idle delay of the procedure (MO & MT) averaged over repeated tests
- Test will be repeated with different settings of the variable attenuator to produce a variable S(I)NR until reaching the receiver sensitivity

Test PASS/FAIL criteria:
- Confirm correct operation sequence for call establishment (MO & MT) per signaling flow diagram described in D5.2. Examples given here are valid for FBMC MAC design. Same approach is valid for DCS MAC.
- PASS indicator: successful execution of the following sequence of procedures
    - Attachment
    - Bearer Establishment : reception of message of service establishment sent by the small cell, in MSC of figure 70 of D5.2
    - U-Plane establishment : u-plane traffic flow following reception of the first data frame by the UE (message 8 and OTA frame, in MSC of figure 76 of D5.2)
    - Detachment: emission of a beacon with UE address removed from the list of associated devices (MSC of figure 67 of D5.2)

Dynamic channel switching (co-located SC scenario)

Test case ID: S3

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of the channel switching procedure, and measure the success rate and delay, with **single UE** under radio fading channels.

Test setup:
- As per PoC #1 and #2, with a minimum of: 1 x (FMAC/DCS) SC, 1 x (FBMC/DCS) UE.

- Operational bands/freq./channel bandwidth: UnL (5 GHz) or LL (3.5 Hz) bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: 2 power couplers
- Interference source/environment:
    a. 5GHz band: Off-the-shelf WIFI AP or arbitrary signal generator
    b. 3.5 GHz band: arbitrary signal generator

Test metrics:
The metrics of interest are delay and channel hold-time. The measurements are first performed with AWGN then fading channel (cabled mode) conditions. Tests shall provide the following results:

- Success rate (measured as "holding time" on new channel) of the procedure measured over repeated tests.
    - This test provides an indication of interference-avoidance performance, of channel switching
- Channel switching impact on traffic QoS/QoE
- Median & 95%-idle delay of the procedure averaged over repeated tests

Test PASS/FAIL criteria:
- Confirm correct operation sequence for channel switching (SC & UE initiated HO) per signaling flow diagrams in D5.2 (figure 62-63).
- PASS indicator: migration to a new channel and improvement of the QoS/QoE

Multiple Access (co-located SC scenario)

Test case ID: S4

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of the access procedure and traffic flow establishment, for **multiple UEs** under radio fading channels.

Test setup:
- As per PoC #1 and #2, with a minimum of: 1 x (FMAC/DCS) SC, 1 x (FBMC/DCS) UE.
- Operational bands/freq./channel bandwidth: UnL (5 GHz) or LL (3.5 Hz) bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: 2 power couplers

Test metrics:
The metrics of interest are throughput, comparing the UE throughput for a single UE operation. Throughput measurement when 2 UE are active shall be half of the single UE throughput. The measurements are first performed with AWGN and then fading channel (cabled mode) conditions. Tests shall provide the following results:

- Per-UE Median & 95%-idle throughput (CDF)
- Per-SC Median & 95%-idle throughput (CDF)
- Throughput vs (different) scheduling policies

Test PASS/FAIL criteria:
- Confirm correct operation sequence for multiple access per signaling flow diagrams in D5.2
- PASS indicator:

  - Emission of association request by the 2 devices and transmission of a beacon with the devices addresses in the list of associated devices like in MSC of figure 66 of D5.2.
  - Establishment of radio bearers for the 2 UEs like in figure 70 of D5.2
  - Modification of the scheduling policies at run time

A.1.2 Test cases for “Aggregation”

The tests where appropriate, consider LTE R10 and WiFi performance (non-MIMO) as baseline for comparisons and evaluation of gains.

Aggregation of licensed LTE & LL (co-located SC scenario)

Test case ID: A1

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of the aggregation procedure, and aggregate traffic flow establishment for **a single UE** under radio fading channels.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS/LTE) SC, 1 x (FBMC/LTE) UE, 1 x (DCS/LTE) UE.
- Operational bands/freq./channel bandwidth: LTE-A bands, UnL (5 GHz) or LL (3.5 Hz) bands, operating on a 10 MHz band.
- SC/UE TX power: 0 dBm
- Other[3]: HARQ (ON), RLC (AM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, before and after aggregation. The measurements are first performed with AWGN then fading channel (cabled mode) condition. Tests shall provide the following results:

- Per-UE (FBMC or DCS) with before & after aggregation:
  - Median & 95%-ile throughput (CDF)
  - Per-UE Throughput vs (different) MAC-PDU size
  - Per-UE Throughput vs (different) offered load

Test PASS/FAIL criteria:
- Confirm correct operation sequence for aggregation per signaling flow diagrams in D5.2
- PASS indicator: reception of the appropriate control plane messages & establishment of “aggregate” u-plane traffic flow

Aggregation of licensed LTE and LL (non-co-located SC scenario)

Test case ID: A2

[3] Other settings e.g. HARQ (ON/OFF), RLC mode (AM/UM), traffic type (UDP/FTP) and traffic direction (UL/DL), are subject to traffic metrics being measured.

This case is similar to A1 but for the non-collocated scenario. This test case is considered out-of-scope.

Aggregation of UnL WiFi and LL (co-located SC scenario)

Test case ID: A3

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of aggregation procedure, and aggregate traffic flow establishment for **a single UE** under radio fading channels. ***This test is not mandatory for the FBMC MAC.***

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (DCS/WiFi) SC, 1 x (DCS/WiFi) UE.
- Operational bands/freq./channel bandwidth: UnL (5 GHz) and LL (3.5 Hz) bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: HARQ (ON), RLC (AM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, before and after aggregation. The measurements are first performed with AWGN then fading channel (cabled mode) condition. Tests shall provide the following results:

- Per-UE (DCS) with before & after aggregation:
    - Median & 95%-ile throughput (CDF)
    - Per-UE Throughput vs (different) MAC-PDU size
    - Per-UE Throughput vs (different) offered load
- Per-UE (WiFi cots) with before & after aggregation:
    - Median & 95%-ile throughput (CDF)

Test PASS/FAIL criteria:
- Confirm correct operation sequence for aggregation per signaling flow diagrams in D5.2
- PASS indicator: reception of the appropriate control plane messages & establishment of "aggregate" u-plane traffic flow

Aggregation of UnL WiFi and LL (non-co-located SC scenario)

Test case ID: A4

This case is similar to A3 but for the non-collocated scenario. This test case is considered out-of-scope.

Aggregation of UnL WiFi and Licensed (co-located SC scenario)

Test case ID: A5

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of aggregation procedure, and aggregate traffic flow establishment for **a single UE** under radio fading channels.

Test setup:

- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS/LTE) SC, 1 x (FBMC/LTE) UE, 1 x (DCS/LTE)
- Operational bands/freq./channel bandwidth: UnL (5 GHz) and LTE-A bands, operating on a 10 GHz band.
- SC/UE TX power: 0 dBm
- Other: HARQ (ON), RLC (AM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, before and after aggregation. The measurements are first performed with AWGN channel (conducted mode) and then over the air to consider fading. Tests shall provide the following results:

- Per-UE (FBMC or DCS) with before & after aggregation:
  - Median & 95%-ile throughput (CDF)
  - Per-UE Throughput vs (different) MAC-PDU size
  - Per-UE Throughput vs (different) offered load
- Throughput CDF (after aggregation) w/ dynamic rate adaptation
- Throughput measurements (after aggregation) w/ different sensing thresholds

Test PASS/FAIL criteria:
- Confirm correct operation sequence for aggregation per signalling flow diagrams in D5.2
- PASS indicator: reception of message 7, in MSC of figure 8 of D5.2 (to confirm resource/channel aggregation) & establishment of “aggregate” u-plane traffic flow

Aggregation of UnL WiFi and Licensed (non-co-located SC scenario)

Test case ID: A6

This case is similar to A5 but for the non-collocated scenario. This test case is considered out-of-scope.

A.1.3 Test Cases for “Offload”

Offload/steering to UnL band (co-located SC scenario)

Test case ID: O1

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of offload procedure, and traffic offload for **a single UE** under radio fading channels (offload of u-plane & optionally of c-plane traffic, with DCS-MAC).

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS/LTE) SC, 1 x (FBMC/WiFi) UE, 1 x (DCS/LTE/WiFi) UE.
- FBMC UE has ongoing traffic established over LL channel
- DCS UE has ongoing traffic established over LL or L channel
- Operational bands/freq./channel bandwidth: UnL (5 GHz) and LTE-A bands operating on a 10 GHz band
- SC/UE TX power: 10 dBm
- Other: HARQ (ON), RLC (AM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, before and after offload. The measurements are first performed with AWGN then fading channel (cabled mode) condition. Tests shall provide the following results:

- Per-UE (FBMC or DCS) with before & after offload:
  - Median & 95%-ile throughput (CDF)
  - Per-UE Throughput vs (different) MAC-PDU size
  - Per-UE Throughput vs (different) offered load

Test PASS/FAIL criteria:
- Confirm correct operation sequence for aggregation per signaling flow diagrams in D5.2
- PASS indicator: reception of message 7, in MSC of figure 8 of D5.2 (to confirm offload)

Offload/steering to UnL band (non-co-located SC scenario)

Test case ID: O2

This case is similar to O1 but for the non-collocated scenario. This test case is considered out-of-scope.

Offload/steering to LL band (co-located SC scenario)

Test case ID: O3

Test objective:
The objective of this test is to validate the correct operation (protocol compliance) of offload procedure, and traffic offload for **a single UE** under radio fading channels.

Test setup:
- As per PoC # 2 with a minimum of: 1 x (DCS/LTE) SC, 1 x (DCS/LTE/WiFi) UE.
- DCS UE has ongoing traffic established over UnL or L channel
- Operational bands/freq./channel bandwidth: LL (3.55 GHz) and LTE-A bands operating on a 10 GHz band
- SC/UE TX power (dBm): 10 dBm
- Other: HARQ (ON), RLC (AM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, before and after offload. The measurements are first performed with AWGN then fading channel (cabled mode) condition. Tests shall provide the following results:

- Per-UE (DCS) with before & after offload:
  - Median & 95%-ile throughput (CDF)
  - Per-UE Throughput vs (different) MAC-PDU size
  - Per-UE Throughput vs (different) offered load

Test PASS/FAIL criteria:
- Confirm correct operation sequence for aggregation per signaling flow diagrams in D5.2
- PASS indicator: reception of message 7, in MSC of figure 8 of D5.2 (to confirm offload)

Offload/steering to LL band (non-co-located SC scenario)

Test case ID: O4

This case is similar to O3 but for the non-collocated scenario. This test case is considered out-of-scope.

A.2 Performance Tests

Performance testing measures raw capacity, such as the maximum number of connections, maximum rate of connection establishment, and maximum uplink and downlink throughput, delay, jitter and packet loss.

A.2.1 Physical DATA channel tests

Test case ID: P1

Test objective:
The objective of this test is to measure the u-plane PHY/MAC/RLC throughputs versus SNR performance for uplink/downlink over a range of SNR for a **single UE** with various radio fading channels. This test is conducted with the radio link control (RLC) operating in UM & AM and HARQ enabled, using UDP traffic.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS/LTE) SC, 1 x (FBMC/DCS/LTE) UE
- Operational bands/freq./channel bandwidth: UnL (5 GHz), LL (3.5 Hz) and LTE-A bands operating on a 10 GHz band.
- SC/UE TX power: 10 dBm
- Other: HARQ (ON), RLC (AM/UM), UDP DL only.
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput (PHY/MAC/RLC), FER, BLER and BER. The measurements are first performed with AWGN channel then fading conditions (cabled mode). Tests shall provide the following results:

- FER vs Eb/No (or Es/No) ; different MCS
- PHY Tput vs Eb/No (or Es/No) ; different MCS
- PHY Tput vs SNR ; different MCS – indicator of AMC performance
- MAC Tput vs SNR ; different MCS
- BER vs SNR ; different MCS
- BLER vs SNR ; different MCS

Adaptive Modulation & Coding (AMC) tests - In this test, the performance of a single user HARQ and AMC with IP/UDP and RLC in UM Mode is presented for various radio channels and different Doppler's at a fixed/high SNR. Performance metrics include both comparison of offered traffic data rate to UE and measured data rate. Another performance metric is the uplink Frame Error Rate (FER) to determine any impact to UE data throughput due to radio link errors. In these tests, the closed-loop power control is turned off, so the adaptivity of the scheduler to varying channel and SNR conditions is not exercised.

Test PASS/FAIL criteria:

PASS indicator: FFS.

A.2.2 Throughput, Delay, Packet Loss tests

Test case ID: P2

Test objective:
The objective of this test is to measure the application-level throughputs, delay (CDF) for uplink/downlink over a range of SNR for a **single UE** with various radio fading channels. This test is conducted with the radio link control (RLC) operating in AM and HARQ enabled, using FTP (over TCP-IP) & UDP (over-IP) traffic.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS/LTE) SC, 1 x (FBMC/DCS/LTE) UE.
- Operational bands/freq./channel bandwidth: UnL (5 GHz), LL (3.5 Hz) and LTE-A bands operating on a 10 GHz band.
- SC/UE TX power: 10 dBm
- Other: HARQ (ON), RLC (AM), UDP DL / FTP, TTI/frame format (variable).
- Interference source/environment: No

Test metrics:
The metrics of interest are throughput, packet delay, error and loss. The measurements - First with AWGN only, then including fading – shall provide the following results:

- Throughput CDF
- DELAY/ ERROR / LOSS CDFs
- RLC BSR reporting delay
- PMF (Prob. Mass Function) of TCP RTT (using FTP-o-TCP traffic)

Test PASS/FAIL criteria:
The tests consider LTE R10 and WiFi as baseline for comparisons
PASS indicator: FFS.

A.2.3 Coexistence Test Cases – Duty Cycle based

The following tests have been developed based on LTE-U coexistence specifications in [14].

Clean channel selection

Test case ID: C1

Test objective:
This test is to verify that (FBMC/DCS) SCell (DUT) selects the clean channel (least loaded) among available channels in UnL spectrum.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS) SCell, 1 x (FBMC/DCS) UE, 1 x WiFi AP, 1 x WiFi STA
- Operational bands/freq./channel bandwidth: Test shall assume the two available channels for SCell in UnL spectrum to be CH1 and CH2 each of 20MHz bandwidth.
- SCell/UE TX power: 10 dBm
- Interference source/environment: No
- A WiFi link (between an AP and a STA) with full buffer UDP traffic shall be configured on CH1.

- Test layout shall ensure that the WiFi RSSI from the WiFi AP on DUT is above CCA-ED threshold (= -62 dBm) and shall ensure a line of sight between all the nodes in the test. This test is performed in OTA. DUT shall be turned on with 20 MHz SCell in UnL spectrum. Only available channels for SCell in DUT shall be CH1 and CH2.

Test metrics:
The metric of interest channel selection delay and traffic delay. The measurements - First with AWGN only, then including fading – shall provide the following results:

- Median & 95%-ile of channel selection delay + delay CDF.

Test PASS/FAIL criteria:
PASS indicator:

- DUT shall choose CH2 for SCell operation
- The success rate of observed events during repeated tests, shall be at least 90%.

Co-channel coexistence - Channel sharing with one DL full buffer WiFi link

Test case ID: C2

Test objective:
This test is to verify the maximum medium occupancy for (FBMC/DCS) SCell (DUT) when the *channel is shared with one full buffer WiFi link.*

Test setup:

- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS) SCell, 1 x (FBMC/DCS) UE, 1 x WiFi AP, 1 x WiFi STA
- Operational bands/freq./channel bandwidth: Test shall assume a single available channel for SCell in UnL spectrum of 20MHz bandwidth.
- SCell/UE TX power: 10 dBm
- Interference source/environment: WiFi interference
- DUT shall be configured with 20 MHz SCell on that channel with a UE. Full buffer UDP traffic shall be configured for DUT. The distance between DUT and UE shall not exceed 12 feet and not be less than 1 foot.
- A WiFi link (between an AP and a STA) with full buffer UDP traffic shall be configured on that channel. The distance between the AP and STA shall not exceed 12 feet and not be less than 1 foot.
- Test layout shall ensure that the WiFi RSSI from the WiFi AP on DUT is above CCA-ED threshold (= -62 dBm) and shall ensure a line of sight between all the nodes in the test. In each test, DUT shall meet the following requirements (after warm-up period):
- DUT SCell duty cycle (= integral of Ton/integral of (Ton+Toff)) ≤ 50 %.
    - Ton: SCell ON-state duration
    - Toff: SCell OFF-state duration
- DUT SCell Ton,max ≤ 20 msec.
    - Ton,max is defined as the maximum continuous ON duration within SCell ON-state.

Test metrics:
The metric of interest for both the WiFi AP and SCell, is throughput. Traffic delay is also be considered as a metric.

Test PASS/FAIL criteria:
PASS indicator:

- WiFi AP throughput ≥ 4Mbps.
- (FBMC/DCS) SCell throughput ≥ 4 Mbps.

- WiFi AP traffic delay should fall within range of ≤ 20% above (FBMC/DCS) SCell traffic delay[4].
- The success rate of observed events during repeated tests, shall be at least 90%.

Co-channel coexistence - Channel sharing with a DL full buffer + DL VoIP over WiFi links

Test case ID: C5

Test objective:
This test is to verify the performance of *multiple VoIP links over WiFi under interference from a full buffer traffic of (FBMC/DCS) SCell (DUT) when the channel is shared*. In addition to VoIP the WiFi AP also runs downlink full buffer traffic.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 1 x (FBMC/DCS) SCell, 1 x (FBMC/DCS) UE, 1 x WiFi AP, 4 x WiFi STA
- Operational bands/freq./channel bandwidth: Test shall assume a single available WiFi primary channel for SCell in UnL spectrum of 20MHz bandwidth.
- SCell/UE TX power: 10 dBm
- Interference source/environment: WiFi interference
- A WiFi link (between an AP0 and a STA0) with downlink full buffer UDP traffic shall be configured on that channel. WiFi VoIP links from extra 4 STAs (STA1, STA2, STA3, and STA4) to the same AP shall be configured such that the WiFi AP is serving 5 links with one full buffer and rest are VoIP.
- For the baseline setup, AP1 that is same vendor/model as AP0, shall be configured with 20 MHz primary on that channel with a WiFi STA5 instead of the DUT (a FBMC SCell and a UE). Downlink full buffer UDP traffic shall be configured for AP1. The distance between AP1 and STA5 shall not exceed 12 feet and not be less than 1 foot.
- For the final test setup, DUT (a FBMC/DCS SCell) shall be configured with 20 MHz SCell on that channel with a UE. Downlink full buffer UDP traffic shall be configured for DUT. The distance between DUT and UE shall not exceed 12 feet and not be less than 1 foot.
- Test layout for the baseline shall ensure that the RSSI from AP1 on WiFi AP0 and associated STAs is above CCA-ED threshold (= -62 dBm for 20MHz). The final test layout shall ensure that the RSSI from DUT on WiFi AP0 and associated STAs is above CCA-ED threshold (= -62 dBm for 20MHz). This test is performed in OTA and shall be run for 120sec [13].
- The required WiFi (AP0 & AP1) shall be the Cisco Aironet 3700e or similar AP and the required STAs shall be the Samsung Galaxy S5 devices or similar.
- The following voice configuration shall be used to configure voice QoS profile:
  - Voice codec: Enterprise grade G.711 (64kbps) voice codec shall be used
  - Jitter Buffer: A nominal de-jitter buffer delay of 40ms shall be set

Test metrics:
The metrics of interest for both the WiFi AP and SCell, are packet delay, jitter and loss rate.

Start with baseline having AP1-STA5 as the interferer and collect the following results for DL AP0-STA1 VoIP link:

- The one-way delay
- The packet jitter
- The packet loss rate

[4] The proposed measurement for traffic delay measuring impact of maximum channel occupancy.

- The probability of 4 or more consecutive packet loss

Test PASS/FAIL criteria:
PASS indicator: Repeat the test with DUT replacing AP1. The following test results are expected:
- The one way delay and packet jitter should not exceed the maximum of baseline results and 50msec more than 5% of the time
- Packet loss rates should not exceed the maximum of baseline results and 1%
- The probability of 4 or more consecutive packet loss shall not exceed baseline
- DUT (FBMC/DCS) SCell throughput ≥ 4 Mbps.
- The success rate of observed events during repeated tests, shall be at least 90%.

Co-channel coexistence - Channel sharing between intra-operator SCells

Test case ID: C7

Test objective:
When (FBMC/DCS) SCell transmissions cannot be orthogonalized in time, this test verifies that same operator SCells (DUT) are able to operate on co-channel basis.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 2 x (FBMC/DCS) SCell, 2 x (FBMC/DCS) UE
- Operational bands/freq./channel bandwidth: Test shall assume a single available shared channel for SCell in UnL spectrum of 20MHz bandwidth.
- SCell/UE TX power: 10 dBm
- Interference source/environment: no external interference sources (only co-channel interf. considered)
- Two FBMC/DCS links (between a SCell1 (DUT) and a UE1, between a SCell2 (DUT) and a UE2) with full buffer UDP traffic shall be configured on that channel. Both SCell1 and SCell2 shall have the same PLMN ID and shall be from the same vendor.
- DUT (SCell1 and SCell2) shall be configured with 20 MHz SCell on that channel with a FBMC/DCS UE.
- Test configuration shall have the following setting.
    - FBMC/DCS1 link SNR (SCell1 RSSI at UE1 / WGN) = FBMC/DCS2 link SNR (SCell2 RSSI at UE2 / WGN) = 30 dB
    - FBMC/DCS1 link INR (SCell2 RSSI at UE1 / WGN) = FBMC/DCS2 link INR (SCell1 RSSI at UE2 /WGN) = -10 dB
    - SCell1 RSSI at SCell2 = SCell2 RSSI at SCell1 = -60 dBm

In each test, DUT shall meet the following requirements (after warm-up period):
- 80% ≤ DUT SCell duty cycle < 100 %.
- FBMC/DCS Ton,max ≤ 20 msec.
    - Ton,max is defined as the maximum continuous ON duration within SCell ON-state.

Test metrics:
The metrics of interest is duty cycle.

Test PASS/FAIL criteria:
PASS indicator:
In each test, DUT shall meet the following requirements after warm-up period:
- 80% ≤ DUT SCell duty cycle < 100 %.
- FBMC/DCS Ton,max ≤ 20 msec.

  Ton,max is defined as the maximum continuous ON duration within SCell ON-state.

- The success rate of observed events during repeated tests, shall be at least 90%.

A.2.4 Coexistence Test Cases – LBT based

DL-only LAA sharing of UnL spectrum with one (DL) full buffer WiFi (collocated SC scenario - intra-operator)

Test case ID: C8

Test objective:
The objective of this is to check the performance of FBMC/DCS systems and WiFi as they share the UnL spectrum, with the FBMC/DCS employing LAA LBT techniques.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 2 x (FBMC/DCS) SC, 2 x (FBMC/DCS) UE, 1 WiFi AP
- Operational bands/freq./channel bandwidth: Test shall assume a single available channel for SCell in the 5GHz UnL spectrum of 20MHz bandwidth
- SC/UE TX power: 10 dBm
- Interference source/environment: WiFi
- Test Configurations:
  - LBT Algorithm: Implement LAA channel access procedures according to 3GPP TS 36.213 Rel. 13.
  - CCA-ED: Energy detection threshold should be according to threshold adaptation procedure in 3GPP TS 36.213 Rel. 13.

Test metrics:
The metrics includes, but not limited to User Perceived Throughput (UPT) CDF and Delay CDF.

Test PASS/FAIL criteria:
PASS indicator:

- WiFi AP performance should not degrade sharing the spectrum with the DCS/FBMC-based systems, any worse than if the DCS/FBMC-based was another WiFi AP.
- Fair Access of the spectrum by both systems. (Fair channel access defined either based on throughput fairness or channel access fairness between DCS/FBMC-based systems and WiFi AP).

DL-only LAA sharing of UnL spectrum with two (DL + UL) full buffer WiFi (collocated SC scenario - intra-operator)

Test case ID: C9

Test objective:
The objective of this is to check the performance of FBMC/DCS systems and WiFi as they share the UnL spectrum, with the FBMC/DCS employing LAA LBT techniques.

Test setup:
- As per PoC #1 and 2 with a minimum of: 2 x (FBMC/DCS) SC, 2 x (FBMC/DCS) UE, 1 WiFi AP.
- Operational bands/freq./channel bandwidth: Test shall assume a single available channel for SCell in the 5GHz UnL spectrum of 20MHz bandwidth.
- SCUE TX power: 10 dBm
- Interference source/environment: WiFi
- Test Configurations:

- LBT Algorithm: Implement LAA channel access procedures according to 3GPP TS 36.213 Rel. 13.
- CCA-ED: Energy detection threshold should be according to threshold adaptation procedure in 3GPP TS 36.213 Rel. 13.

Test metrics:
The metrics includes, but not limited to User Perceived Throughput (UPT) CDF and Delay CDF.

Test PASS/FAIL criteria:
PASS indicator:

- WiFi AP performance should not degrade sharing the spectrum with the DCS/FBMC-based systems, any worse than if the DCS/FBMC-based was another WiFi AP.
- Fair Access of the spectrum by both systems. (Fair channel access–defined either based on throughput fairness or channel access fairness between DCS/FBMC-based systems and WiFi AP).

Adjacent channel interference in Wi-Fi-LAA scenario

Test case ID: C11

Test objective:
The objective of this Test case is to check the performance of WiFi with FBMC/DCS when there is adjacent channel interference, and the vice versa.

Test setup:
- As per PoC # 1 and 2 with a minimum of: 2 x (FBMC/DCS) SC, 2 x (FBMC/DCS) UE, 1 WiFi AP
- Operational bands/freq./channel bandwidth: Test shall assume a single available channel for SCell in the 5GHz UnL spectrum of 20MHz bandwidth.
- SC/UE TX power: 10 dBm
- Interference source/environment:
    - WiFi is the aggressor whilst the FBMC/DCS Systems are the victims
    - FBMC/DCS Systems are the aggressors and the WiFi AP the victim

Test metrics:
Includes, but not limited to Adjacent Channel Interference Ratio (ACIR), Adjacent Channel Selectivity (ACS) and Adjacent Channel Rejection (ACR).

Test PASS/FAIL criteria:
PASS indicator:

- Adjacent Channel Interference introduced by FBMC/DCS-based systems should be lower than what WiFi Systems introduced, if they are the aggressors.

A.2.5 BH tests

Throughput test case

Test case ID: B1

Test objective:
The objective of this test case is to evaluate the throughput achieved at the BH segment of SPEED-5G.

Test setup:

- The test uses the configuration of PoC #3.
- Downstream traffic:
  - Downstream traffic is injected from Tester e1, interface i1.
  - Traffic follows the path e1 → e2 → e5/e6 → e7 → e8/e9/e10 → e3 → e1.
- Upstream traffic:
  - Upstream traffic is injected from Tester e1, interface i2.
  - Traffic follows the path e1 → e3 → e8/e9/e10 → e7 → e5/e6 → e2 → e1.
- Throughput is measured by Tester e1 and inside CS and TS.

Test metrics:

Criterion / KPI	**Target Value**	**SotA**	**SotA (ICOM)**
Link data rate DL per sector	≃ 1060 Mbps	300 Mbps	540 Mbps
Link data rate UL per sector	≃ 800 Mbps	300 Mbps	415 Mbps
Aggregate area capacity per sector	≃ 1900 Mbps	600 mbps	955 Mbps

Test PASS/FAIL criteria:

- PASS condition : the target values are achieved or significant improvement over max {SotA (generic), SotA (ICOM)}
- FAIL condition: neither the target values are met nor significant improvement over max{SotA(generic), SotA(ICOM)}

Latency test case

Test case ID: B2

Test objective:

The objective of this test is to evaluate the latency improvement at the BH segment of SPEED-5G, after applying the relative techniques.

Test setup:

- The test uses the configuration of PoC #3.
- Downstream traffic:
  - Downstream traffic is injected from Tester e1, interface i1.
  - Traffic follows the path e1 → e2 → e5/e6 → e7 → e8/e9/e10 → e3 → e1.
- Upstream traffic:
  - Upstream traffic is injected from Tester e1, interface i2.
  - Traffic follows the path e1 → e3 → e8/e9/e10 → e7 → e5/e6 → e2 → e1.
- Latency is measured by Tester e1.

Test metrics:

Criterion / KPI	**Target Value**	**SotA (ICOM)**
Latency DS	≃ 1.3 ms	1.9ms

Criterion / KPI	Target Value	SotA (ICOM)
Latency US	0.8ms - 1.4ms (depends on frame load)	1.2ms - 1.8ms (depends on frame load)

Test PASS/FAIL criteria:

- PASS condition : the target values are achieved or significant improvement over SotA(ICOM)
- FAIL condition: neither the target values are met nor significant improvement over SotA(ICOM)

Network availability test case

Test case ID: B3

Test objective:
The objective of this test is to evaluate the failsafe capabilities at the BH segment of SPEED-5G that were developed in order to increase network availability.

Test setup:

- The test uses the configuration of PoC #3.
- Downstream traffic:
  - Downstream traffic is injected from Tester e1, interface i1.
  - Traffic follows the path e1 → e2 → e5/e6 → e7 → e8/e9/e10 → e3 → e1.
- Upstream traffic:
  - Upstream traffic is injected from Tester e1, interface i2.
  - Traffic follows the path e1 → e3 → e8/e9/e10 → e7 → e5/e6 → e2 → e1.
- One of the two Central Stations is switched off (e.g. CS1) to emulate failure.

Test metrics: N/A

Test PASS/FAIL criteria:

- PASS condition :
  - Traffic interruption will occur for approximately one minute.
  - The TSs assigned to CS1 should automatically switch to CS2.
  - Traffic from the TSs previously assigned to CS1 should be resumed. Due to the loss of CS1 and hence its capacity, degrade in performance (throughput) is possible but acceptable.
- FAIL condition :
  - Traffic from the TSs previously assigned to CS1 is not resumed after approximately five minutes.

Resource balancing test case

Test case ID: B4

Test objective:
The objective of this test is to evaluate automatic TS entry during provisioning based on the load of the CSs.

Test setup:

- The test uses the configuration of PoC #3.

- Both CSs are switched on and all TSs are switched off.
- TS1 is switched on and automatically assigned to one CS (e.g. CS1).
- Traffic (both DS and US) is injected from Tester e1.
- TS2 is switched on; it should automatically be assigned to CS2 (because CS2 is less busy than CS1),
- Traffic for TS2 (both DS and US) is injected from Tester e1.
- The procedure is repeated for more TSs (e.g. TS3 and TS4).
- Each TS should automatically assigned to the best CS at the time of its powering.

Test metrics: N/A

Test PASS/FAIL criteria:
- PASS condition : if behaviour described in test setup is observed
- FAIL condition : if behaviour different from the one described in test setup is observed

A.2.6 RRM tests

Communication test case

Test case ID: R1

Test objective:
The objective of this test is to test communications between a centralized RRM server and client software running in remote hardware.

Test setup:
- A standard RPC protocol will be used over the internet.
- BT will run an RRM server at its Adastral Park R&D site.
- Client software (in python or similar language) will be provided to PoC developers at other sites.
- A set of standard tests will be incorporated into both ends of the software, with automatic logging of results.
- Tests will include registration of cell with RRM, reporting KPIs to RRM, and receiving and acknowledging RRM instructions.

Test metrics:

The metrics of interest are:
1. Server uptime and reliability.
2. Round-trip time.

Test PASS/FAIL criteria: FFS.

PASS will be considered to be achieved if registration of cell with RRM, reporting KPIs to RRM, and receiving and acknowledging RRM instructions at the client side are successful. Actual server response times are not critical at this stage.

Hierarchical RRM test case

Test case ID: R2

Test objective:
The objective of this test is to validate the correct communications between the HMAC, dRRM and cRRM modules and to present the gains of a hierarchical RRM scheme.

Test setup:

The testbed is comprised of one SC supporting both Licensed (LTE-A) and LL technologies (collocated scenario) and one UE operating on both on LTE-A and LL bands. Initially the UE is connected to the LTE, receiving streaming video from the video server. The LTE cell is underutilized. The HMAC module communicates with the dRRM module in order to apply the appropriate channel selection and scheduling.

Then, the traffic load in the SC is gradually increased and therefore the delivered QoS of the UE is starting degraded. The HMAC module realizes the degradation of the provided QoS through the analysis of the real time measurements. The HMAC decides to switch to the CRRM module, which has a global view of the network/RATs in order to retain the high QoS. After switching to the CRRM module, the CRRM module becomes then responsible for the channel and RAT selection. The CRRM module examine all the alternative available technologies (including both LTE and LL) through its dynamic RAT/channel selection procedure and decides to move the user to a LL band by using the available LL technology (e.g. FBMC) supported by both SC and LTE. This decision is then delivered to the HMAC modules of both LTE-A and LL in order to realize a smooth transmission from the licensed to the lightly licensed channel.

Test metrics:

The metrics of interest are:

- Correct generation of the appropriate messages
- Correct delivery of the appropriate messages
- Latency for the whole eDSA cycle (monitoring, analysis, switching to cRAN, generation of decision, enforcement of decision, and actual UE transition to the new band).

Test PASS/FAIL criteria:

PASS will be the correct communication between HMAC, dRRM and cRRM modules (e.g. the appropriate decisions are generated correctly and the appropriate messages are delivered correctly).

Hierarchical RRM - Coexistence test case

Test case ID: R3

Test objective:

The objective of this test is to validate the correct communications between the HMAC, dRRM and cRRM modules and to present the gains of a hierarchical RRM scheme.

Test setup:

The testbed is similar to the previous test case (R2), but in this case the switch from the dRRM to the cRRM is triggered because of the high interference.

Test metrics:

Identical to test case R2

Test PASS/FAIL criteria:

PASS will be the correct communication between HMAC, dRRM and cRRM modules (e.g. the appropriate decisions are generated correctly and the appropriate messages are delivered correctly).

A.2.7 Video quality tests

Quality test case

Test case ID: V1

Test objective:
The objective of this test is to verify the assumption that even small transmission errors will result in reduced video quality.

Test setup:
- As per PoC # 1 or 2 with a minimum of: 1 x (FBMC/DCS) SCell, 1 x (FBMC/DCS) UE.
- Video test setup as described in chapter 6.2 (PoC Demonstrator Setup).

Test metrics:
The metrics of interest are Picture Freeze, PSNR values and MOS-V.

Test PASS/FAIL criteria:
- Pass if transmission errors will produce picture freezes, reduced PSNR values and a reduced MOS-V

Offload impact on video test case

Test case ID: V2

Test objective:
The objective of this test is to verify the assumption that resulting effects of re-organizing the network by initializing the offloading function will show up in reduced video quality.

Test setup:
- As per PoC # 1 or 2 with a minimum of: 1 x (FBMC/DCS) SC, 1 x (FBMC/DCS) UE.

Video test setup as described in chapter 6.2 (PoC Demonstrator Setup).

- Test metrics :

The metrics of interest are Picture Freeze, PSNR values and MOS-V.

Test PASS/FAIL criteria:
- Pass if errors will produce picture freeze, reduced PSNR values and a reduced MOS-V
- If no change in transmission conditions can be determined, the video parameters should stay on maximums.

A.3 Mapping PoCs to test cases

Table 24: PoC-ID to test-case mapping summary table

Test case ID	Test case title	Relevant PoC ID
S1	Resource (Random) Access	1A & 2A
S2	Call setup/tear-down signalling procedure	1A & 2A
S3	Dynamic channel switching	1A & 2A
S4	Multiple Access	1A & 2A

A1	Aggregation of licensed LTE & LL (collocated SC scenario)	2B 1B
A2	Aggregation of licensed LTE & LL (non-collocated SC scenario)	Considered out-of-scope
A3	Aggregation of UnL WiFi & LL (collocated SC scenario)	2D 1D
A4	Aggregation of UnL WiFi & LL (non-collocated SC scenario)	Considered out-of-scope
A5	Aggregation of UnL WiFi & Licensed (collocated SC scenario)	2D 1D
A6	Aggregation of UnL WiFi & Licensed (non-collocated SC scenario)	Considered out-of-scope
O1	Offload/steering to UnL band (collocated SC scenario)	2B 1B
O2	Offload/steering to UnL band (non-collocated SC scenario)	Considered out-of-scope
O3	Offload/steering to LL band (collocated SC scenario)	2B 1B
O4	Offload/steering to LL band (non-collocated SC scenario)	Considered out-of-scope
P1	Physical DATA channel tests	1A 2A
P2	Throughput, Delay, Packet Loss tests	1A 2A
C1	Clean channel selection	1F 2F
C2	Co-channel coexistence - Channel sharing with one DL full buffer WiFi link	1F 2F
C5	Co-channel coexistence - Channel sharing with a DL full buffer + DL VoIP WiFi links	1F 2F
C7	Co-channel coexistence - Channel sharing between intra-operator SCells	1F 2F
C8	DL-only LAA Channel sharing with one (DL) full buffer WiFi link (collocated SC scenario - intra-operator)	1F 2F
C9	DL-only LAA Channel sharing with two (DL + UL) full buffer WiFi links (collocated SC scenario - intra-operator)	1F 2F
C11	Adjacent channel interference in Wi-Fi <> LAA scenario	1F 2F
B1	Throughput test	3
B2	Latency test	3

B3	Network availability test	3
B4	Resource balancing test	3
R1	Communication test	4A & 4B
R2	RRM algorithm test	1B
R3	Hierarchical RRM - Coexistence	1F
S1	Quality test	5
S2	Offload video impact test	5
i1 (A1)	Aggregation of licensed LTE & LL (collocated SC scenario)	6A 6C
i2	Aggregation of licensed LTE & LL (non-co-located SC scenario) w/ RAN split @ MAC	6B 6D
i3 (O1)	Offload/steering to UnL band (collocated SC scenario)	6A 6C
i4	Offload/steering to UnL band (non-co-located SC scenario) w/ RAN split @ MAC	6B 6D