Quality Of Service and MObility driven cognitive radio Systems

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QoSMOS

D7.4

QoSMOS Prototype - version 2

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Abstract:

Deliverable D7.4 is the definitive version of the prototype. This document is a companion document to D7.4, listing the final blocks implemented in the QoSMOS prototypes and explaining how they relate to and perform the Proofs Of Concepts presented in D7.1 and D7.2.

Keyword list:

Proof of concept, Demo, Cognitive Radio, Scenario, System architecture.

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Abbreviations

3G	Third Generation
ACLR	Adjacent Channel Leakage Ratio
ADC	Analogue-to-Digital Converter
AL	Adaptation Layer
CM-RM	Cognitive Manager for Resource Management
CM-SM	Cognitive Manager for Spectrum Management
CN	Core Network
CR	Cognitive Radio
DAC	Digital-to-Analogue Converter
DB	DataBase
DTV	Digital TV
FAP	Femto Access Point
FBMC	Filter Bank Multi Carrier
FMT	Frequency Mask Triggering
HW	HardWare
IU	Incumbent User
ME	Master Entity
OFDM	Orthogonal Frequency Division Multiplexing
OS	Operating System
OU	Opportunistic User
PoC	Proof of Concept
PSE	Primary Scene Emulator
QoS	Quality of Service
RF	Radio Frequency
RSTP	Real Time Streaming Protocol
SW	SoftWare
TVWS	TeleVision White Space

UHF	Ultra High Frequency
WP	Work Package

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1 Executive Summary

This document summarizes the work that has been done on the four QoSMOS proofs of concepts (PoCs) setups since the issue of [D7.3], QoSMOS prototype – v1. This document acts as a companion of the actual deliverable which is the prototype itself, presented in the final review.

Previous QoSMOS deliverables [D7.1][D7.2][D7.3] state that in the end the project will demonstrate four test setups, used to showcase different aspects coming from the technical work packages 2 to 6. The work in these proofs of concepts has evolved during the course of the project.

The PoC #1 demonstration aims at showcasing the radio environment and the sensing engine modelled in WP3.

The PoC #2 demonstrations serve the purpose of testing the novel concept developed for flexible transceiver architecture in WP4.

The PoC #3 validates the data fusion and distributed algorithms developed for cooperative sensing within the scope of WP3.

The PoC #4 is an integrated demonstration setup that is designed to validate various CR concepts that have been developed for link and upper layers. Thus, the initial input for this setup comes from WP5 and WP6, while at the same time it validates concepts like the Adaptation Layer, the spectrum management and decision making mechanism.

This report is comprised of 4 sections, organized as follows: Section 2 gives an overall introduction, alongside a summary of the goals for each PoC. Section 3 is devoted to compile the most relevant information regarding the different setups, depicting their architecture as well as their building blocks. Finally, Section 4 focuses on providing some interesting observations related to the implementation of these tests. Between them, the PoCs show all of the enabling technologies for a live cognitive radio system.

2 Introduction

The main goal of this deliverable is to act as a companion of the QoSMOS prototype and at the same time providing a status of its final version.

QoSMOS defines the prototype as set of hardware (HW) and software (SW) platforms that showcase key project concepts derived from the technical work packages, WP2 to WP6. The so called proofs of concepts have been refined during the course of the project and the final set, comprising 4 categories, was presented on [D7.2] and is summarized below.

- The PoC #1 demonstration aims at showcasing the radio environment and the sensing engine modelled in WP3.
- The PoC #2 demonstrations serve the purpose of testing the novel concept developed for flexible transceiver architecture in WP4.
- The PoC #3 validates the data fusion and distributed algorithms developed for cooperative sensing within the scope of WP3.
- The PoC #4 demonstration is designed and envisaged to validate various CR concepts that have been developed for link and upper layers. Thus, the initial input for these test setup comes from WP5 and WP6, while at the same time it validates concepts like the Adaptation Layer, the spectrum management and decision making efforts. In the end, the integration among these concepts and others coming from the previous three categories will aim to showcase a live cognitive radio system.

Bear in mind that all PoCs may involve more than one demonstration, compiling inputs coming from different WP7 partners.

Preliminary versions of PoC #1, #2 and #3, as well as concepts related with PoC #4, were demonstrated at the project review in March 2012, and thereby presented the status of the QoSMOS prototype. Since then, several updates have been included in the different PoCs and the mission of this document is to present them all.

3 Prototype status

The following sections within this chapter provides a brief description of the four QoSMOS Proofs of Concepts, which will serve to better comprehend the different setups.

3.1 Proof of Concept #1: Primary scene and sensing engine

3.1.1 Reminder of PoC #1 goal and functional architecture

Primary scene and sensing engine proof of concept demo was defined in [D7.1], and its objective consists of showcasing the radio environment modelled in WP3, implementing and testing the algorithms presented there on a real platform.

In this PoC, the primary radio scene engine feeds the sensors developed within WP3 in order to test their accuracy in both time and frequency dimensions. The radio environment that is emulated by the primary radio scene engine consists of incumbent user (IU) waveforms modelled over a wide frequency band. Channel fading effects are then multiplied onto the waveforms before the faded signals are finally delivered to the sensors, which operate in high dynamic range in order to be able to detect very weak signals.

Furthermore, with the intention of improving the test and adjusting it to the context of the project, the channel emulation also involves the Doppler spread effect in order to evaluate the performance of the sensing engine in a mobile environment.

3.1.2 Final status of PoC #1 platform

The following entities compose PoC#1 test bed:

- Primary scene emulator (PSE) – PSE is required to generate the IU signal that particular detection devices should receive according to the defined IU service and the channel model considered.
- Sensors – Hardware sensor is in charge of listening to Radio Frequency (RF) signals and making a sensing decision based on a local decision algorithm.
- Spectrum analysis – Experimental setup for performing wideband real-time spectrum analysis with Frequency Mask Triggering (FMT).

The analogue interface between these high-level entities is in the RF wave domain. In practice it is realized by means of standard RF coaxial cables (BNC- and/or SNA-type). A rough block scheme of this sensing test bed is given in Figure 3-1, while the functionality of the particular blocks is thoroughly explained in the final WP7 report [D7.5].

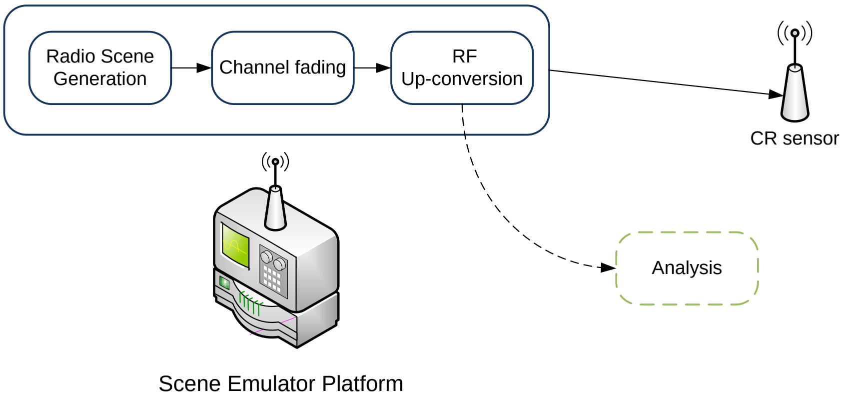

Figure 3-1: PoC #1 platform

3.2 Proof of Concept #2: Flexible Transceiver Proof of Concept [CEA]

3.2.1 Reminder of PoC #2 goal and functional architecture

The main goal of PoC #2 is to demonstrate some of the Flexible Transceiver concepts investigated in QoSMOS WP4. One element of the demonstration is the usage of TVWS as an application of the algorithms and design developed in WP4, notably the implementation of a Filter Bank Multiple Carrier (FBMC) transceiver. It was selected from a range of generalized OFDM-like options as the most promising solution for low Adjacent Channel Leakage Ratio (ACLR) performance.

This PoC focuses on measuring the out-of-band performance of FBMC in a complete radio system, where RF impairments, such as a practical transmitter power amplifier, are accounted for. This is performed without compromising the flexibility of the transceiver, notably its frequency agility. One element that has been considered is to measure performance of the newly developed FBMC and the interference it may generate to incumbent users and may be compared against results simulated in WP4. A comparison with Orthogonal Frequency Division Multiplexing (OFDM) performance is also made.

3.2.2 Final status of PoC #2 platform

The architecture of POC #2 can be divided into 3 steps, which correspond to the test plan of the PoC. The most important criterion for which FBMC was selected is ACLR. In the TVWS, it is recommended by regulators that ACLR shall be at least of 55dB relative to the in-band channel of the opportunistic user. This constraint, which is 10dB above the recommendation for LTE, is hard to achieve with classical air interfaces, particularly whenever frequency agility is desired. For instance, it was shown that reaching such ACLR values with OFDM would require hardware consuming filtering circuitry.

Furthermore, it was shown in WP4 that filtered OFDM is not compatible with the will to address simultaneously several discontinuous channels through spectrum pooling. On the other hand, FBMC offers the flexibility of high ACLR and spectrum pooling techniques. So far, this ability was evaluated on digital signals by simulation.

In the end, PoC #2 has as its foundation the QoSMOS T-Flex digital baseband board presented in [D7.3], which counts with the following components:

- 1 FPGA Xilinx XC7K325T-1FFG676C (Kintex7 Family)
- 1 ARM microcontroller DM3730CBP100 (cortex A-8 at 1GHz + DSP TMS320C64x)
- 2 dual ADC AD9643 14 bits / 250 MHz, the ADC using a differential interface allows for receiving intermediate frequency up to 400 MHz.
- 1 quad DAC AD9148 16 bits / 1 GHz: interpolation is performed inside the digital-to-analog converter and allows for a good compromise between input interface throughput requirements and output sampling frequency.

The digital board is interfaced to the RF TX and RX daughter-boards in order to generate Ultra High Frequency (UHF) signals from 470MHz up to 860MHz in a flexible way. The ARM processor controls the digital board and the RF Boards and interfaces to an external PC via either a USB, an Ethernet or a Wi-Fi connection.

The setup depicted in Figure 3-2 has been proposed to evaluate the performance of the implemented flexible transceiver in terms of both transmitter flexibility and performance. A QoSMOS T-Flex transmitter, controlled by a Personal Computer, is generating a FBMC signal, while at the same time a DVB-T modulator is used to transmit a television service. DVB-T and FBMC transmitted signals are combined and then divided and directed to a Digital TV (DTV) receiver and a spectrum analyzer.

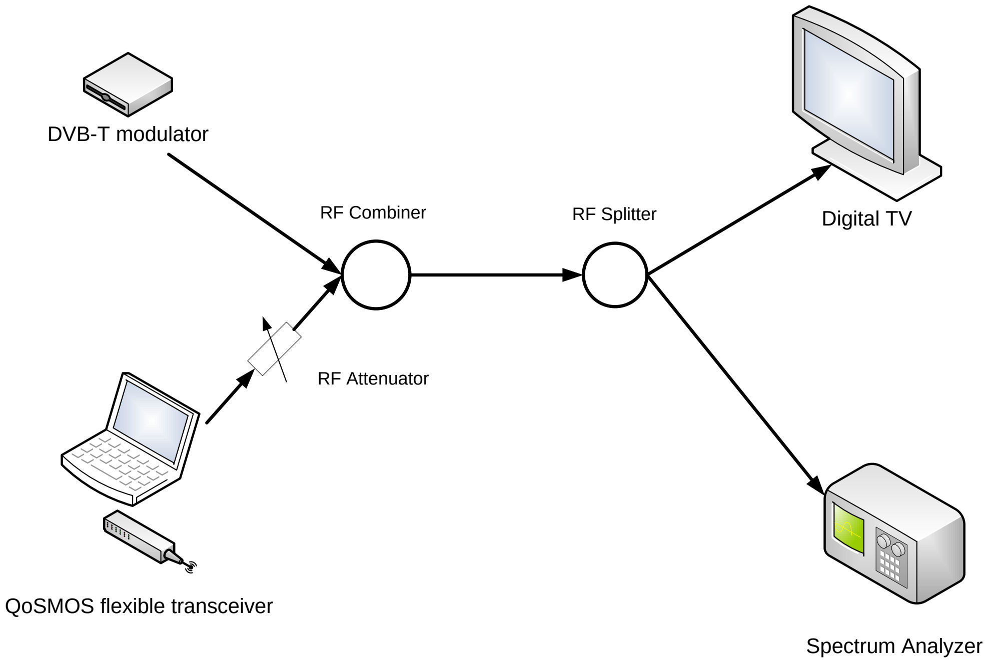

Figure 3-2: PoC #2 platform

A picture of the flexible transceiver is shown in Figure 3-3 below.

Figure 3-3: Transceiver hardware

3.3 Proof of Concept #3: Distributed/Collaborative Sensing

3.3.1 Reminder of PoC #3 goal and functional architecture

The main objective of this PoC consists of demonstrating the benefit of the distributed sensing algorithms proposed and developed within WP3 and thoroughly detailed in [D3.5]. In order to do so, a sensing scenario has been designed, including hardware sensors and a data fusion unit, where multiple sensing devices work together to achieve a high level of confidence in the detection of the Incumbent User (IU).

The challenge in spectrum sensing is the ability of detecting IUs that are located beyond the single Opportunistic User (OU) interference range but can still be disturbed by the OU network, in a scenario where the propagation environment adds additional uncertainties, like deep channel fading or shadowing.

Taking as a reference the work developed in WP3, investigating and evaluating novel collaborative/distributed sensing algorithms via computer simulations, the aim of this demonstration is to prove the worthiness of the developed algorithms in scenarios as close to reality as possible.

3.3.2 Final status of PoC #3 platform

The setup designed for PoC #3 is composed of three main entities:

- Primary scene emulator (PSE) - The emulator is required to generate the IU signal that each detection device should receive according to the IU service to be detected and the channel model considered;
- Sensors - The hardware sensors (or CR) are in charge of listening to the RF signals and sending the result of a locally implemented decision algorithm to the data fusion unit;
- The data fusion unit (DFU) is responsible for collecting sensing data from various CR users in the network and generating the final decision on the presence of the IU.

The PSE generates the IU signal that each sensing device should receive according to the IU service to be detected and the considered channel model. The hardware sensor is in charge of performing RF sensing and applying a local decision algorithm, as well as sending the final decision to the DFU. The DFU is responsible for the generation of the decision on the presence of an IU, gathering the sensing data from the diverse sensing devices present in the scenario and generating accordingly the final decision.

A block scheme of the PoC#3 sensing test bed is offered in Figure 3-4 below.

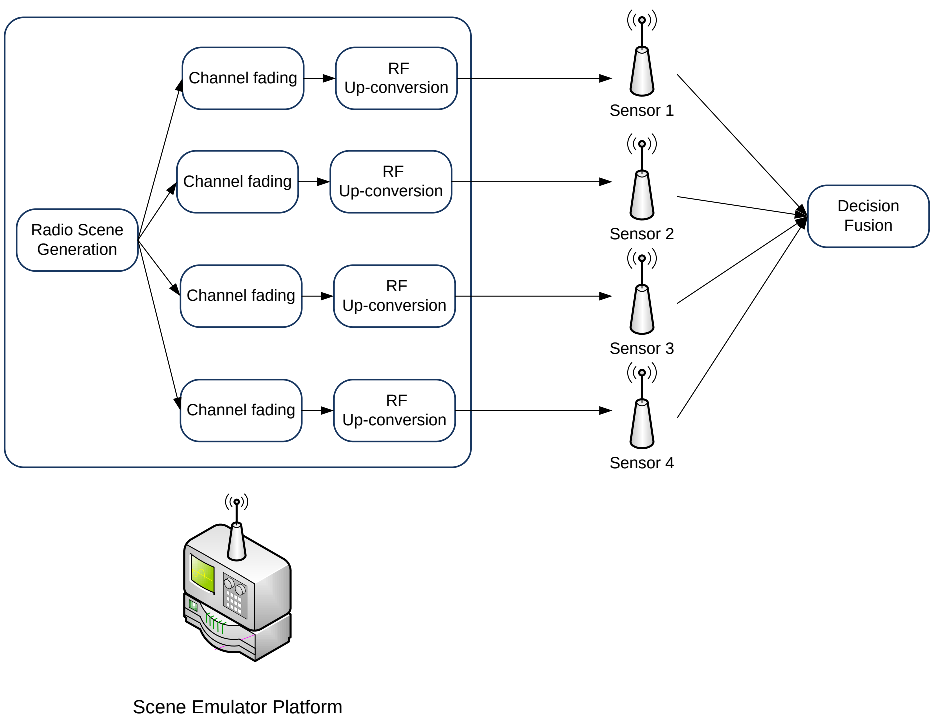

Figure 3-4: PoC #3 platform

Figure 3-5 shows a practical realization of this setup employed during QoSMOS industry briefing event in London in December 2012.

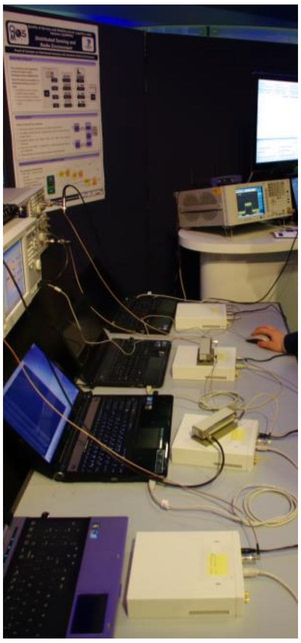

Figure 3-5: PoC #3 practical realization

3.4 Proof of Concept #4: Integrated Platform

3.4.1 Reminder of PoC #4 goal and functional architecture

The PoC #4 integrated platform is designed to perform the validation of certain cognitive radio concepts developed for link and upper layers such as different spectrum management concepts or the decision making algorithms, thus providing relevance to QoSMOS. To do so, diverse developments achieved in the previous PoCs are integrated, showcasing to a large degree a real cognitive system.

In essence, the proposed use case implies a sequence of interactions taking place between the QoSMOS system and some of its actors, involving a TVWS environment, where a cellular legacy system and a TVWS opportunistic system are combined.

3.4.2 Final status of PoC #4 platform

Following a period of evaluation and analysis, a complete group of QoSMOS entities have been selected as they represent a reliable sample of the system architecture, them all coming from the developments carried out within the rest of work packages. These building blocks set up a scenario that has been previously hinted in [D7.3] and which comprises the following components:

- A Primary Scene Emulator used to generate opportunistic user signals.
- A mesh of sensors, employed to carry out distributed sensing duties and get a proper frequency to work with based upon the results offered by the data fusion unit.
- A spectrum portfolio repository emulated in the so called Master Entity (ME) devoted to provide access to the databases. This ME is the centralizing point in the scenario, presenting features of the Adaptation Layer and of some other QoSMOS architecture entities not fully developed for this test bed.
- A CM-SM instance specially configured for PoC #4 scenario which enables to demonstrate the exchange of spectrum portfolios between entities.
- A cellular network is deployed in order to work within two different environments.
    - Cell 1 uses the flexible transceiver, operating in a TVWS band

  - Cell 2, in form of a femtocell, operates in a licensed band (Third Generation, 3G).
- A User Equipment (UE) with cognitive features, composed of a Smartphone and an additional feature for white space operation, provided by the flexible transceiver.

Regarding the PSE, it depends upon triggers to control data transmission by controlling when the signal generator transmits the modulating signal. Figure 3-6 shows the functional diagram of PSE with independent triggering signals controlling the gated start and stop of the emulation of different scene elements.

Directly related to the PSE, and also to the aforementioned Master Entity, are the sensors and the data fusion unit. Their functions include configuring some parameters of sensing, making the interference with the PSE triggers (to start Incumbent transmissions) or even defining the destination where to send the collected sensing data. This data is processed by the DFU to make a final decision on the occupation of each channel, and is further sent to the ME for future processing and analysis.

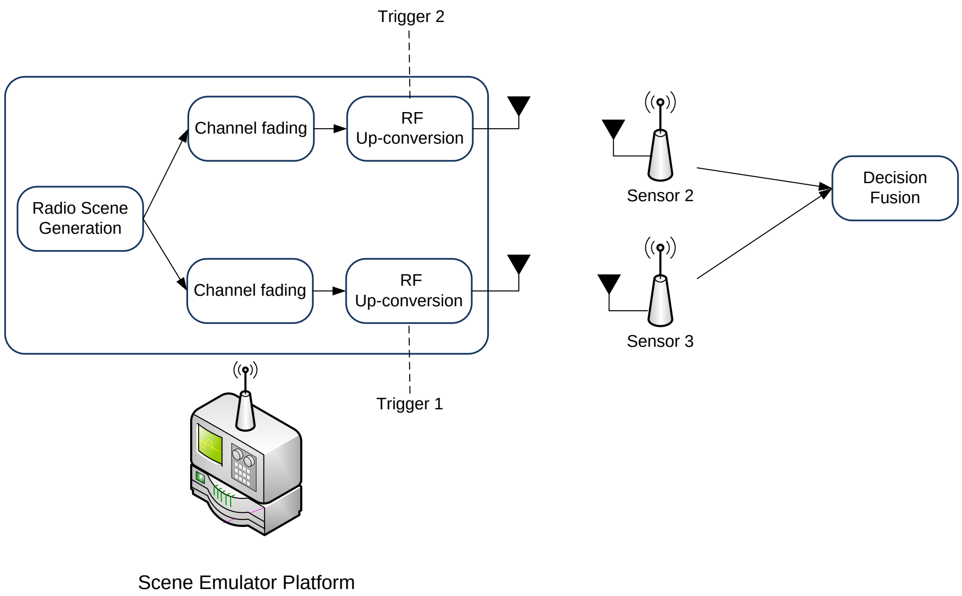

Figure 3-6: PSE and triggers in PoC #4 scenario

Meanwhile, the Master Entity has been created to address the different gaps that need to be filled for setting the whole PoC#4 scenario. Originally conceived as the Adaptation Layer (AL), some instances of other entities have been also included into its architecture, with the clear intention to achieve a more close to real life scenario.

The role played by the ME in the integrated PoC comprises different aspects such as:

- Detection of connected QoSMOS entities, AL functionality extensively documented in [D2.3].
- Synchronization of the execution of the test, launching all entities at the same time.
- Selection of the operating technology and channel, since the ME emulates a Portfolio database (DB) where the information regarding channel status is stored, and thanks to the processing of the changes produced in that DB, it is able of warning the UE it must change its configuration.
- Configuration of Access Point (AP) - UE connection, done trough the different commands the Master Entity sends for reconfiguring both AP and UE.
- Forward sensing reports from Data Fusion Unit to CM-SM instance, in order to fill the Portfolio for exploiting this information by third parties in a technology-agnostic manner.

Figure 3-7 below depicts how the different modules comprising the Master Entity are placed, as well as their relationship with the rest of entities involved in PoC#4 scenario.

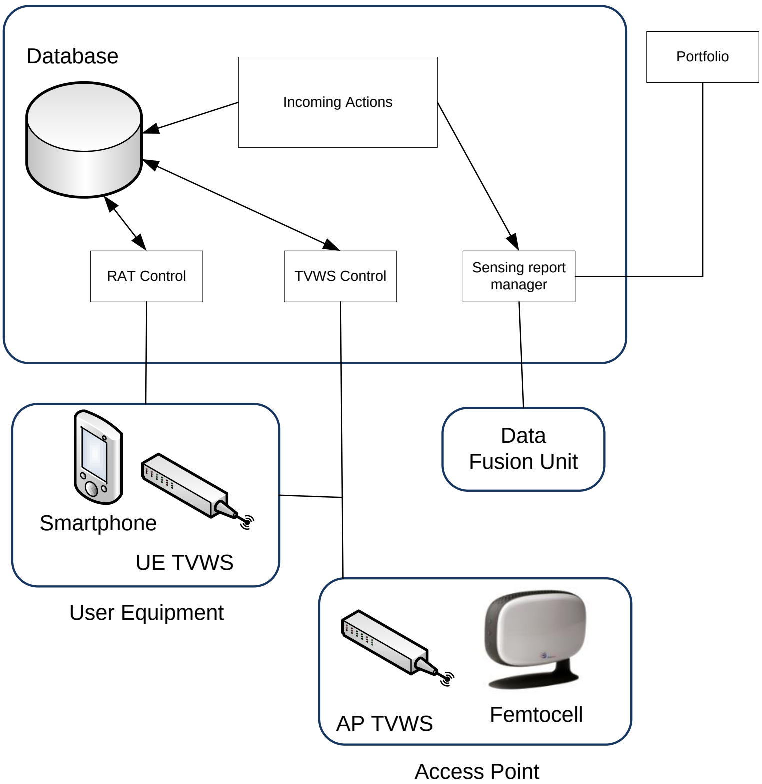

Figure 3-7: Master Entity relationships

When talking about the CM-SM instance implemented and configured for this setup, it enables to demonstrate the exchange of spectrum portfolios between entities as documented in detail in WP6. The implementation provided consists of three entities, namely a partial implementation of a CM-RM focused on the communication protocols, a CM-SM entity in charge of managing spectrum requests originating from the CM-RM, and a CM-SM interfacing a TVWS database managing white space spectrum in terms of spectrum portfolios. Its structure is depicted in Figure 3-8.

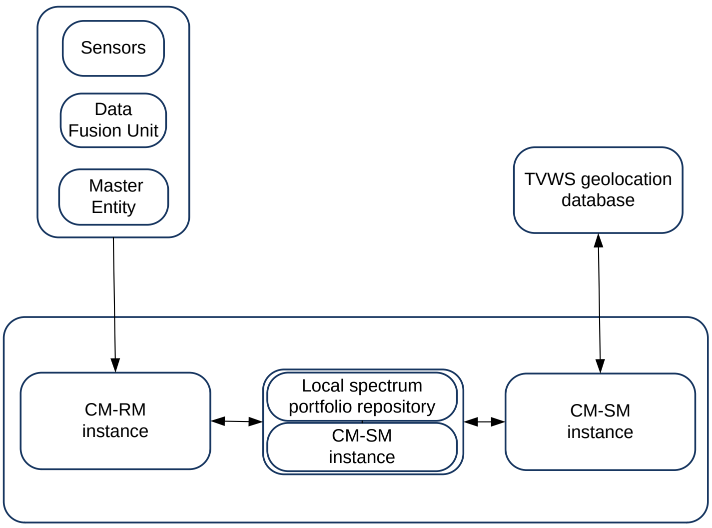

Figure 3-8: CM-SM instance for PoC #4 scenario

Going into the part of the scenario involving the Core Network (CN) entities, first of all the AP and UE flexible boards designed for this test and taking as a reference the ones employed in PoC #2 are both controlled by an embedded ARM Cortex A8 processor, while a Linux Operating System (OS) is running on the platform. In addition, a light MAC interface has been developed in the embedded Linux in order to make the cognitive data link transparent to the user, and it allows for frequency channel selection and data transfer. It interfaces to the Master Entity, which is the block acting as anchor for the sub-scenarios that give form to this setup, to enable the link, disable the link and choose the TVWS channel where the link is performed.

Furthermore, the cognitive UE, which contacts the AP/CN section in the test setup, is a NEC Smartphone working with an Android OS, which is the device connecting to the different TVWS channels and/or the legacy system, depending on the communication channel employed. This UE equipment connects to NEC Femto Access Point (FAP) which provides the 3G legacy network, and connects to the simulated operator's CN over by using an Ethernet connection.

Meanwhile, to access the TVWS channel the UE will connect to the transceiver board using a wireless link, provided by a Wi-Fi AP present in the scenario.

Figure 3-9 below provides a clear view of all the blocks and their interactions taking place in this part of the PoC #4 scenario.

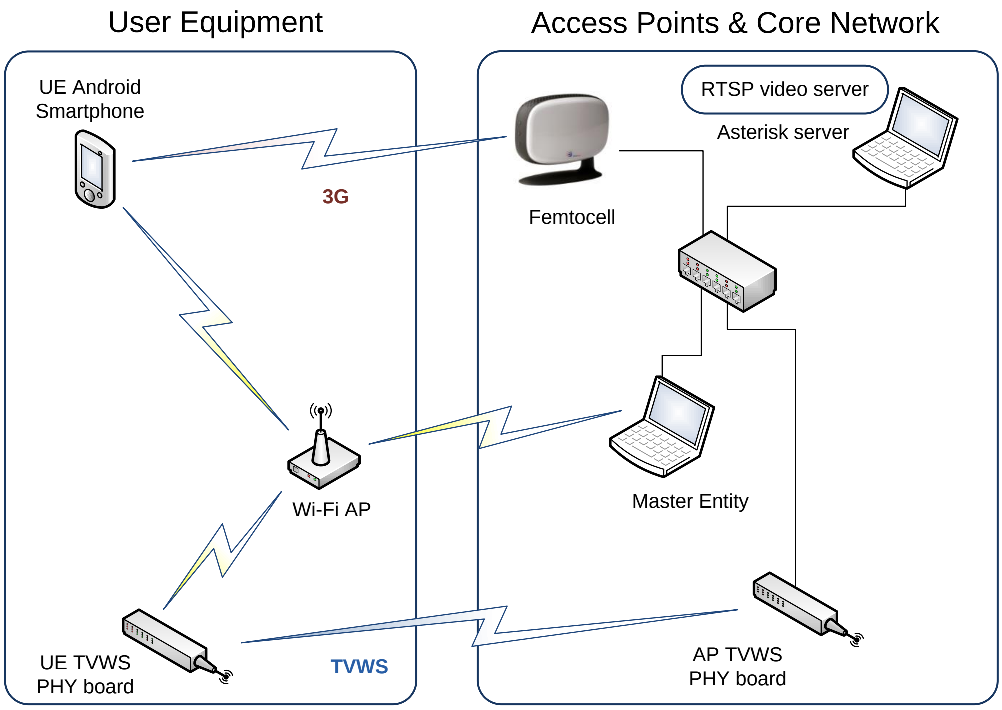

Figure 3-9: Interactions in Core Network and User Equipment section in PoC #4

The totality of this equipment is deployed according the QoSMOS architecture described in the technical work packages and having the ME as the centralizing point.

Figure 3-10 depicts all the building blocks finally present in the scenario and specifies the interactions happening among them.

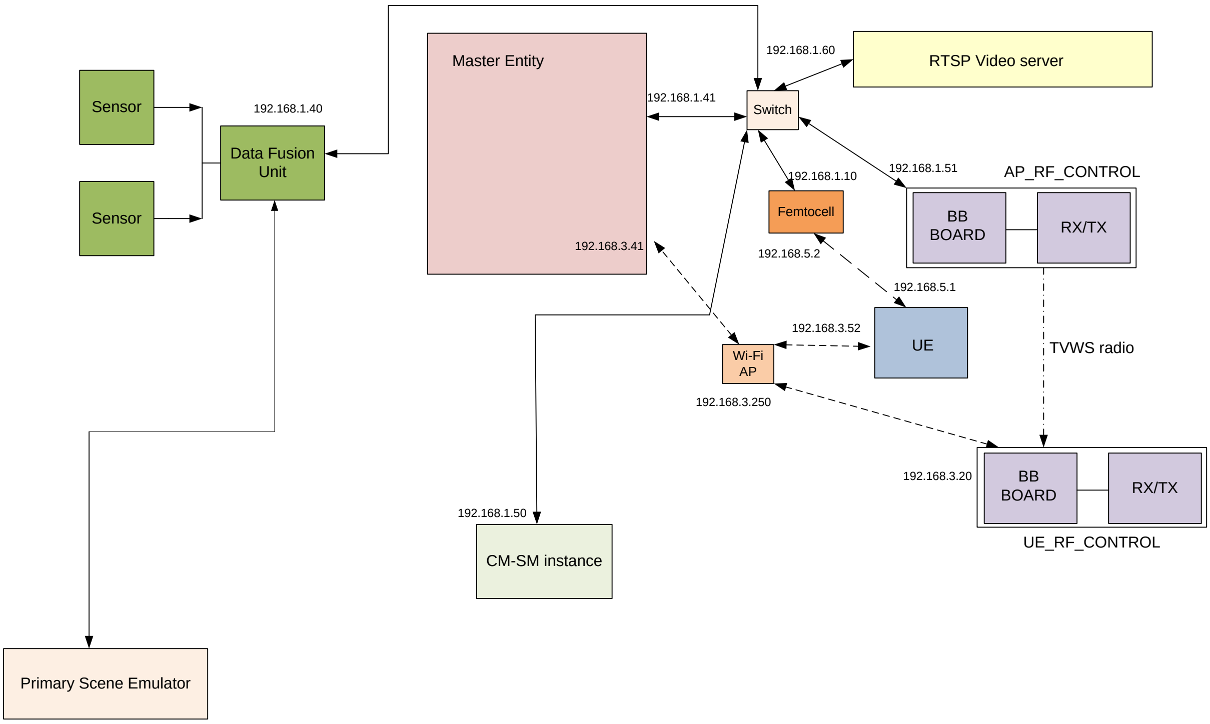

Figure 3-10: PoC #4 platform

Going into the flow of the test, the goal consists in having the UE play a video sent from a Real Time Streaming Protocol (RTSP) server through a couple different TV white space channels and, after an eviction process is executed, using a legacy 3G connection.

The test begins when an opportunistic transmission is carried out using TV Channel 1. After a while, an Incumbent User is going to appear in that same TV channel, thus making it necessary to change to another TV channel to continue the video streaming.

The sensors deployed in the scenario inform the ME that TV Channel 2 is not in use, so the transmission can be changed to that channel, and thus the UE is properly informed.

Moments later, another Opportunistic User is going to make use of that same TV Channel 2, thus producing the Quality of Service (QoS) suffer a certain decline. This event pushes the system to switch to a legacy channel in order to continue the video streaming transmission, being 3G the communication selected to do so.

After having successfully switched between TVWS and from them to a legacy channel, streaming continuously the video from the RTSP server to the UE, the test is finished.

4 Conclusions

The QoSMOS project has successfully achieved in portraying its activities into a set of demonstrators. These consisted of a set of 4 Proof of Concepts which showcase relevant findings and developments.

The Spectrum Sharing enabling technologies developed by the project range from spectrum management architecture and design, right down to a novel physical layer technology; all of these have been demonstrated as prototypes.

The demonstrations have been shown in part at the project period 2 review (in March 2012), at FuNeMS in July 2012 and in a more advanced state in two industry briefing events, one in London on December 12th 2012 and the other in Washington DC on March 22nd 2013.

Feedback received from the earlier demonstrations has spurred WP7 partners first to improve their setups and later to deploy quite valid test beds which demonstrate cognitive radio functionalities and pave the way for further evolution of the architecture proposed by QoSMOS project.

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