



## Cognitive Radio Experimentation World



### Project Deliverable D2.2 Definition of the Federation

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**Abstract:** This document describes the basic functionality for creating the federation of cognitive testbeds in CREW and for executing meaningful experiments that allow fair comparison between cognitive radios and dynamic spectrum access techniques. It begins by providing a description of each of the CREW cognitive testbeds and example experiments which could be performed using each of these testbeds. It also defines what is meant by federation in the context of wireless network testbeds and discusses components of this federation, including: the CREW common portal, a methodology for the integration of testbed hardware platforms, a common data collection/storage methodology, and the CREW benchmarking framework.

The CREW federation will operate in three main modes. The first is single testbed usage, where external experimenters will be able to access the CREW testbeds individually through the CREW common portal. The second, heterogeneous usage, involves the physical relocation and combination of cognitive components. The third, sequential usage, involves the recording of wireless environments for replay in other cognitive testbeds. On top of this, the benchmarking framework outlined in this document is designed to allow a fair comparison between cognitive radio and cognitive networking

protocols and mechanisms implemented on a System Under Test (SUT). This will enable the CREW federated testbed to deliver reliable and reproducible research in the fields of cognitive radio and cognitive networks.

This document will also steer upcoming work packages 3 and 4: “Creating the Federation” and “Benchmarking the Federation”.

**Keywords:** network testbeds, federation, wireless networks, cognitive radio, cognitive network, benchmarking

## Executive Summary

This document presents and defines what is meant by the CREW federation of cognitive radio network testbeds.

The federated testbed is the combination of four existing cognitive radio testbeds in different European academic institutions, as well as two advanced sensing platforms. These testbeds are: the Iris reconfigurable software defined radio (SDR) testbed in TCD, the TWIST wireless sensor network test environment in TUB, the w-iLab.t heterogeneous 2.4 and 5 GHz ISM test environment in IBBT, and the EASY-C LTE testbed in TUD. The two advanced sensing platforms are an imec (SCALDIO/WARP DIFFS) prototype flexible low power sensing platform and a THALES multiple receiver antenna array. The descriptions of the testbeds and sensing platforms will serve as a means to match their individual capabilities and limitations to relevant experiments, ensuring that they are combined in ways that will be most beneficial to cognitive radio research.

This document outlines example experiments which could be performed by external experimenters using each testbed as well as the advanced sensing platforms that are part of the CREW federation. These include a real-time SDR reconfiguration example, the implementation of the experimenter's own sensing algorithms on an 2.4 GHz ISM band wireless sensor network, a vertical spectrum sharing DSA experiment with an LTE-like cellular primary user, the integration of imec's advanced sensing hardware into the external experimenter's own testbed, making use of samples from one of the advanced sensing engines to test cognitive adaptation algorithms and the visualization of node connectivity in a wireless network, among others. These example experiments range from very simple first experiences with a cognitive wireless testbed to more advanced usage. This document also outlines the research goals we expect to achieve by the end of the first year of the CREW project.

The CREW federation is defined based on its three main modes of operation. The first is single testbed usage, where external experimenters will be able to access the CREW testbeds individually through the CREW common portal. The second, heterogeneous usage, involves the physical relocation and combination of cognitive components. The third, sequential usage, involves the recording of wireless environments for replay in other cognitive testbeds.

This document presents a number of key tools which have been identified as requirements in enabling the creation of the federation. These include a common portal, a methodology for the integration of testbed hardware platforms, a common data collection/storage methodology, and a benchmarking framework. Descriptions of other relevant cognitive radio testbeds and a discussion of the relevance of the project to standardization bodies and RF spectrum regulators are also provided.

This document provides guidance for future work in the federation work packages 3 and 4: "Creating the Federation" and "Benchmarking the Federation".

## List of Acronyms and Abbreviations

API	Application Programming Interface
ARNS	Aeronautical Radio Navigation Systems
ASIP	Application-Specific Instruction-set Processor
ADC	Analogue to Digital Converter
BLER	Block Error Rate
BS	Broadcast Systems
CEPT	Conférence européenne des administrations des postes et télécommunications
CORBA	Common Object Request Broker Architecture
CORNET	Cognitive Radio Network Testbed
CoRTekS	Cognitive Radio test bed using Tektronix Off-the-Shelf Components
COTS	Commercial off-the-shelf
CRAWDAD	Community Resource for Archiving Wireless Data At Dartmouth
CR	Cognitive radio
CREW	Cognitive Radio Experimentation World
CROSS	Cognitive Radio Open Source System
CQI	Channel Quality Indicator
DIFFS	Digital Front-end For Sensing
DL	Downlink
DSA	Dynamic Spectrum Access
DSP	Digital Signal Processing
DVB-T	Digital Video Broadcast – Terrestrial
EADS	European Aeronautic Defence and Space Company
Easy-C	Enablers for Ambient Services and Systems — Part C Wide Area Coverage
ECC	Electronics Communications Committee
eNB	e Node B
ETSI	European Telecommunications Standards Institute
EUTRAN	Evolved UMTS Terrestrial Radio Access Network
FARAMIR	Flexible and spectrum-Aware Radio Access through Measurements and modelling In cognitive Radio Systems
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
FIRE	Future Internet Research and Experimentation
FPGA	Field Programmable Gate Array

FP7	Framework Programme 7
GENI	Global Environment for Network Innovations
GPP	General Purpose Processor
HAL	Hardware Abstraction Layer
HARQ	Hybrid Automatic Repeat reQuest
IBBT	Interdisciplinary Institute for Broadband Technology
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
imec	Interuniversity Microelectronics Center
I/O	Input/Output
I/Q	In-phase/Quadrature
ISM	Industrial Scientific Medical
ITU-R	International Telecommunication Union – Radio Communication Sector
LTE	Long Term Evolution
LTE+	Long Term Evolution Advanced
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
NSF	National Science Foundation
OEDL	OMF Experiment Description Language
OFDM	Orthogonal Frequency-Division Multiplexing
OMF	Control and Management Framework
OMG	Object Management Group
OML	ORBIT Measurement Library
ORBIT	Open Access Research Testbed for Next-Generation Wireless Networks
OSSIE	SCA-based Open Source Software Defined Radio
PBCH	Physical Broadcast Channel
PCB	Printed Circuit Board
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PHICH	Physical HARQ Indicator Channel
PHY	Physical Layer
PMR	Professional Mobile Radio
PMSE	Program Making and Special Events
QAM	Quadrature Amplitude Modulation
RAM	Random Access Memory
RAS	Radio Astronomy
RAT	Radio Access Technology or Technique

RF	Radio Frequency
ROM	Read Only Memory
RRS	Reconfigurable Radio Systems
RSRP	Reference Signal Receive Power
RSSI	Received Signal Strength Indicator
Rx	Receiver
SCA	Software Communications Architecture
SCC	Standards Coordinating Committee
SCALDIO	Scalable Radio
SDR	Software Defined Radio
SFF	Small Form Factor
SG	Study Group
SINR	Signal to Interference and Noise Ratio
SIMD	Single Instruction, Multiple Data
SSH	Secure Shell
SUT	System Under Test
SVN	Subversion
TC	Technical Committee
TCD	Trinity College Dublin
TCF	Thales Communications France
TUB	Technische Universität Berlin
TUD	Technische Universität Dresden
TWIST	TKN Wireless Indoor Sensor Network Testbed
Tx	Transmitter
UE	User Equipment
UHF	Ultra High Frequency
UL	Uplink
UML	Unified Modelling Language
US	Usage Scenario
USRP	Universal Software Radio Peripheral
WARP	Wireless Open Access Research Platform
WF	Waveform
WGSE	Working Group Spectrum Engineering
WHYNET	Wireless Hybrid Network Testbed
WiNC2R	Wireless Network Centric Cognitive Radio Platform
WinnF	Wireless Innovation Forum
WLAN	Wireless Local Area Network

WP	Work Package
WRAN	Wireless Regional Area Network
WRC	World Radio Conference
XML	Extensible Markup Language

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## 1 Introduction

Inefficiency in the usage of spectrum resources is a fast growing problem in wireless communications, with some areas of the frequency spectrum becoming seriously overcrowded while others remain largely unused for long periods of time. In fact, even in large metropolitan areas, such as Chicago and New York in the United States, studies have shown overall spectrum occupancy of as low as 17.4% and 13.1% respectively [1]. Similar studies in Europe [2], [3] and other parts of the world have shown similar results.

Cognitive radios, as envisioned for applications to dynamic spectrum access, are aware of the levels of spectrum occupancy in the wireless environment that surrounds them and use this information as a basis for reconfiguration of their transmissions. As such, they are seen as a solution to the spectrum inefficiency problem.

Through the federation of the CREW cognitive radio testbeds and components, each from existing European industrial and academic institutions, the CREW project aims to enable advanced experimental research in the area of cognitive radios and networks.

This document provides a description of the CREW common portal, the cognitive components, open data sets, and benchmarking, as well as how they fit into the CREW project. This information is to be used as a basis from which to steer the work of work packages 3 and 4 (Creating the Federation and Benchmarking the Federation). This document also provides a description of each of the CREW testbeds, with a view to enabling external experimenters to understand how they can make best use of the CREW testbed federation, as well as providing insight into the capabilities and limitations of each of the testbeds.

### 1.1 Redefining the role of federation: the CREW model

Unfortunately, conventional methods used in the federation of wired testbeds cannot be easily applied to wireless networks. The following paragraph outlining why it is necessary to redefine the role of the federation is reproduced from our publication [4].

*“The most common approach found in the literature to federate different testbeds is to define an interface on top of each testbed, to allow remote access and configuration from a single control point. In contrast, the main research efforts of our approach are not invested in creating a single uniform tool to reserve resources, but in optimally combining the available expertise and resources in a pragmatic way: federation is not seen as the goal, but as a means to facilitate advanced experiments in the field of cognitive radio and cognitive networks. Moreover, running simultaneous experiments on multiple interconnected wireless testbeds which are outside of each other’s interference range (e.g. in different countries) is different from interconnecting wired testbeds: while the location of wired servers is not necessarily important, wireless interference domains are completely separated when remotely interconnecting wireless networks. As a result, two remotely interconnected wireless networks cannot represent a single wireless domain. Since spectrum use is an important aspect of cognitive radio research, simultaneous use of different testbeds is not considered a priority.”*

As a result, we define the CREW federation based on its three modes of operation.

- Individual CREW testbed usage enables access to each CREW testbed individually through the CREW common portal.
- Single CREW heterogeneous testbed usage consists of the physical combination of hardware/software from different testbeds to form new network nodes with enhanced cognitive properties.
- Multiple sequential CREW testbed usage involves the recording of data/behaviours from one CREW testbed to then be replayed in another.

These modes of operation are described in greater detail in section 3.1.

## 1.2 High level objectives

The high level objectives of the CREW project are fourfold. They are the creation of:

### The CREW common portal

The CREW common portal will enable experimenters to externally access and use each of the CREW testbeds. It will operate as an extension of the CREW website and be accessible through the FIRE website, meaning that it will be highly visible as well as easy to use.

### Advanced cognitive components

Through federation of different components of the individual testbeds, advanced cognitive sensing techniques will be provided. This will be achieved through the linking together of software and hardware entities from the different partners using a standardized API.

### Open data sets

Increasingly large datasets of spectral, and other, measurements are being made available to the general research community online (examples include the repository of wireless data in [5] and the spectrum sensing results in various frequency bands and locations analyzed in [6]). These datasets enable researchers to save a lot of time in making use of already present recordings rather than taking measurements themselves.

Measurements recorded under benchmarked conditions according to a common data structure in the CREW project will be made available through online media. These data sets can be used in consistent reproducible research by external experimenters.

### The CREW benchmarking framework

In other fields of research, standardized benchmarking frameworks allow easy comparison between different solutions to some problem. The adoption of benchmarking frameworks in wireless and cognitive radio networks has been slow, due to the unpredictability of the wireless environment. A sample attempt to define a benchmark for wireless systems can be found in [7].

The lack of clear benchmarks causes problems when trying to perform a fair comparison between different cognitive radio and cognitive networking solutions. For this reason, a standardized benchmarking framework, laid out under controlled and reproducible test conditions, is one of the deliverables of this project.

Further information on each of the objectives above can be found in sections 3.1 through 3.5.

## 1.3 Relationship to FIRE, GENI

Experimentation facilities are critical for research and development of cognitive radio devices. Due to the large costs in setting up and running one of these facilities, this being done by individual academic institutions or research bodies is impractical. For this reason the creation of large experimentation facilities available to the wider research community is seen as a better option.

The FIRE initiative in Europe [8] and the GENI project in the United States [9] are both working towards the creation of such facilities. They cover the wide range of disciplines that make up future internet research.

The FIRE initiative began in 2007 and is funded under FP7. It consists of 26 projects, of which CREW is one. All FIRE projects will in the end be accessible through a common FIRE portal, which is one of the targets of the FIRESTATION support actions.

The NSF-funded GENI project is made up of approximately 46 subprojects across over 60 academic institutions. Of these projects, cognitive projects such as ORBIT [10] are of particular interest to CREW, as they deal with the deployment of cognitive radio testbeds.

## 2 The CREW federation

The CREW federation is built from four existing cognitive radio and cognitive networking testbeds in different academic institutions around Europe [11], as illustrated in Figure 1. These are:

- The w-iLab.t in IBBT [12], a heterogeneous ISM test environment which incorporates IEEE 802.11a/b/g/n, IEEE 802.15.1, IEEE 802.15.4, and USRP software radios;
- The Iris testbed in TCD [13], a cognitive radio testbed (which can operate in a variety of bands, including TV bands) based on the Iris reconfigurable radio platform and the USRP [14];
- The TWIST wireless sensor network test environment at TU Berlin [15], which incorporates Tmote Sky and eyesIFXv2 sensor nodes, Wi-Spy spectrum analysers, USRP software radios and BEE2 FFGA platforms;
- The LTE cellular test environment at TU Dresden [16], incorporating a complete LTE-equivalent base station infrastructure and SDR mobile user terminals.

In addition, advanced sensing platforms developed by imec and TCF will be integrated at several locations in the CREW federated platform, enabling high-sensitivity detection and identification of interference.

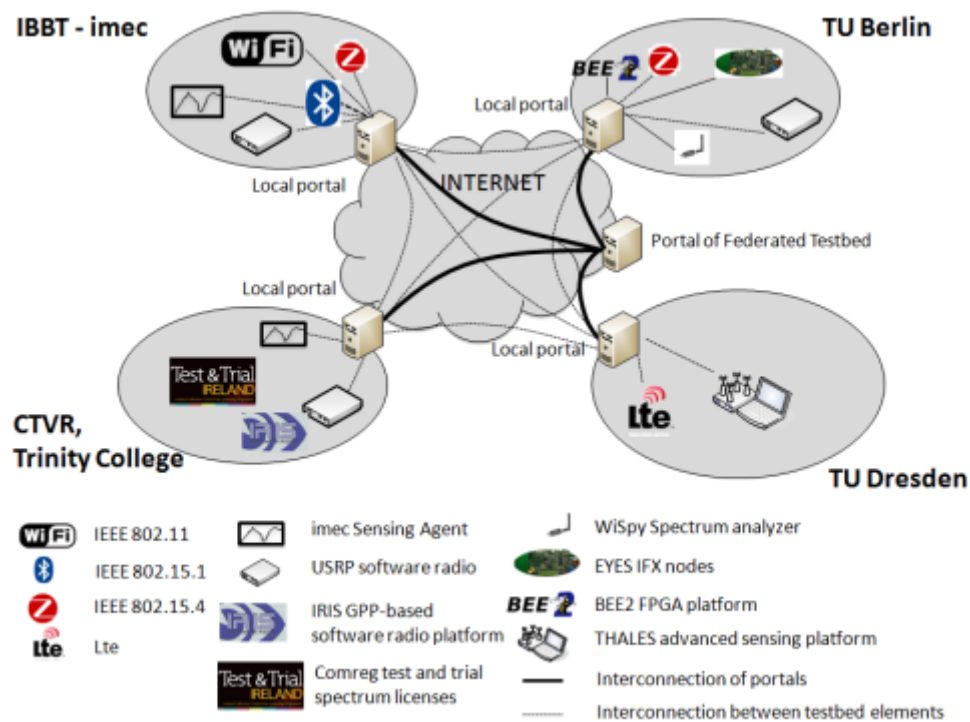


Figure 1: The CREW federated testbed

The next sections provide a brief description of each of the testbeds that comprise CREW, as well as the imec advanced sensing platform. For more detailed information on each of the testbeds and the most recent evolution, the interested reader is invited to consult the CREW portal, which will be made available soon via our public website (<http://www.crew-project.eu/>).

## 2.1 TCD - The Iris testbed

### 2.1.1 General description

Iris is a software radio architecture that has been developed by CTVR, The Telecommunications Research Centre at TCD. Written in C++, Iris is used for constructing complex radio structures and highly reconfigurable radio networks. Its primary research application is to enable a wide range of dynamic spectrum access and cognitive radio experiments. It is a GPP-based radio architecture and uses XML documents to describe the radio structure. This testbed provides a highly flexible architecture for real-time radio reconfigurability based on intelligent observations the radio makes about its surroundings.

Each radio is constructed from fundamental building blocks called *components*. Each component makes up a single process or calculation that is to be carried out by the radio. For instance, a component might perform the modulation on the signal or scale the signal by a certain amount. Each component supports one or more data types and passes datasets to other components, along with some metadata such as a time stamp and sample rate. There is a data buffer between each component to ensure the data is safe, even if one component is processing data much faster than another.

All components within the radio exist inside an engine. An engine is the environment in which one or more component operates. Each engine defines its own data-flow and reconfiguration mechanisms and runs one or more of its own threads. As with components, each engine is linked by a data buffer. Iris currently features two data types, the PN Engine and the Stack Engine. The PN engine is typically used for PHY layer implementations and is designed for maximum flexibility. It has a unidirectional data flow and runs one thread per engine. The Stack Engine is designed for the implementation of the network stack architecture, where each component is a layer within the stack and runs its own thread of execution. It also has a bidirectional data flow.

Iris's capability to reconfigure the radio on the fly lies in the *controllers*. A controller exists independently of any engine and runs in its own thread of execution. A controller subscribes to events within components and reconfigures parameters in other components based on the observation of these events. For instance, a controller could be set up to observe the number of packets passing through a certain component and, upon reaching a certain number of packets, change the operating frequency of the radio.

The Iris 2.0 architecture is illustrated in Figure 2.

A radio is constructed and configured using XML documents. Each component is named and has its inputs, outputs and exposed parameters explicitly specified. Engines are declared and components are placed in their relevant engines. Controllers are then declared at the top of the XML document and the links between each component are declared at the end of the document.

The hardware components of the testbed at TCD consist of four Quad core machines, each of which has either a USRP 1 or a USRP 2 and RFX2400 daughterboard connected to it. The USRP (Universal Software Radio Peripheral) is a family of hardware used as an RF frontend for software radios. The USRP 1's have an 8MHz bandwidth and the USRP 2's have a 24MHz bandwidth (using Gigabit Ethernet to communicate between the USRP and the computer). The daughterboards are capable of transmitting between 2 and 2.9 GHz.

Iris is available with either Linux or Windows on each machine.

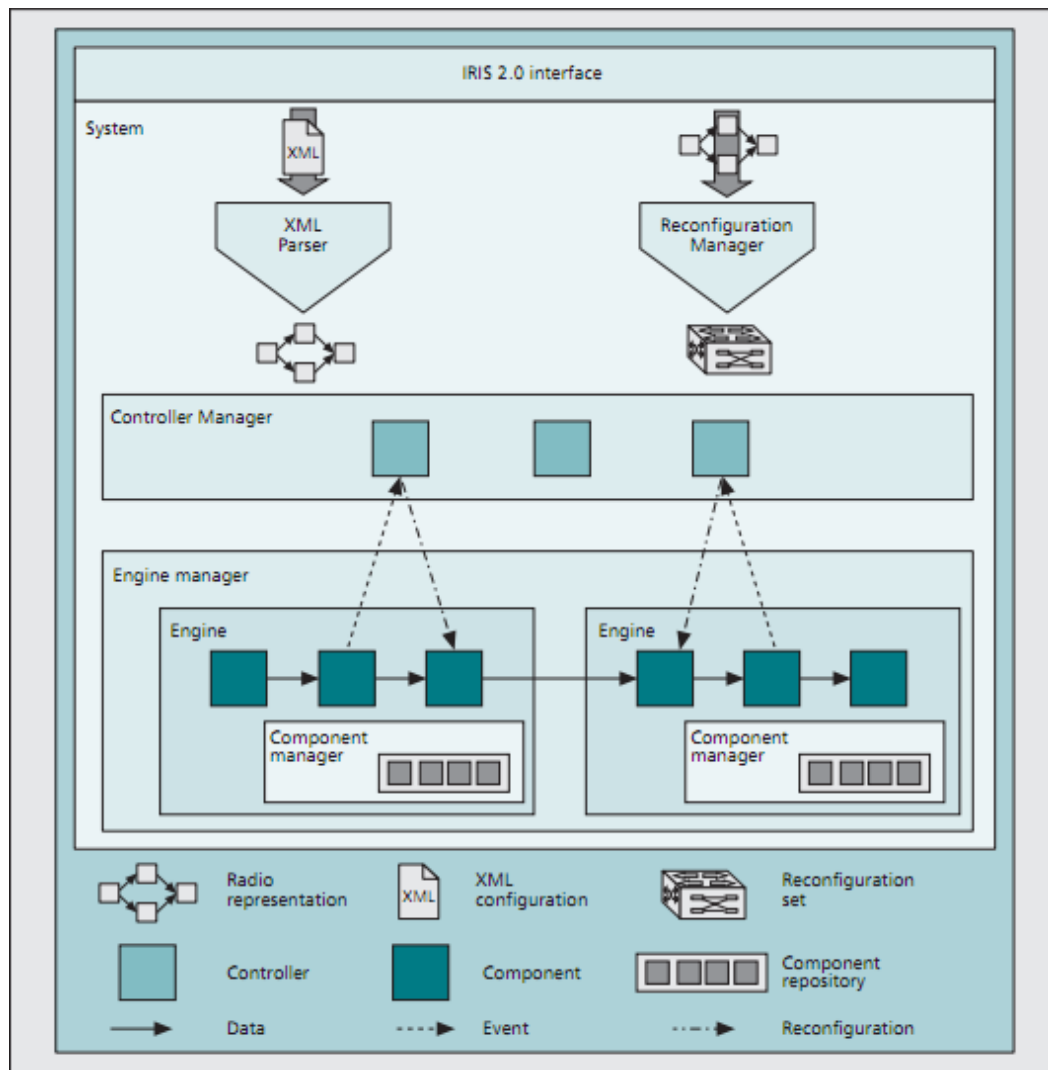


Figure 2: The Iris 2.0 architecture

### 2.1.2 Use by external participants - access

Both the testbed and the Iris software can be accessed remotely through SVN and SSH. The full instructions for downloading and installing Iris can be found on the Iris wiki [17].

The testbed is fully accessible using PuTTY. Radios and components can be uploaded and changed as needed onto any of the nodes and the USRPs can be powered on remotely.

### 2.1.3 Use by external participants - example experiment

In this sample experiment we will run a simple radio and then adapt a component and add a controller, with a view to exploring the basic functionality of both. The steps a researcher should follow to complete the experiment are outlined below.

1. Follow the instructions outlined on the Iris wiki to run radio [18], OFDMFileReadWrite.XML.
2. If this radio is functioning correctly, “radio running” will appear on the command line.
3. To add a controller to the radio, we must first create an event in one of the components to which the controller can subscribe. To do this, open the shaped OFDM modulator and register an event in the constructor function.
4. Once the event is registered we must create a condition that must be satisfied for the event to be activated. To do this, open the “process” function (as this is where all the calculations are carried out) and specify a condition that activates the controller whenever, for example, 100 packets have passed through.
5. Once this has been done the controller can be made. Open the “example” controller; this gives us a template to work with.
6. Within the controller we must do two things, subscribe to the event that has been set up in the component and specify the parameter that we wish to change as well as the value we wish to change it to.
7. To change the parameter, we specify the name of the parameter as well as the component and engine that it is in. These are assigned in the “ProcessEvent” function.
8. The logic that dictates what the parameter is changed to also goes in this function.
9. Recompile all the relevant code, include the controller in the XML file and run the radio as before.

If the radio is running properly, you should see the event being triggered on the command line and the new value of the parameter in question.

### 2.1.4 Expected achievements by the end of year 1

In our usage scenario deliverable for this project (deliverable 2.1), we discussed various experiments involving cooperation of heterogeneous networks in TV bands, specifically the detection and avoidance of a DVB-T signal.

What we hope to have achieved by the end of the first year of the project is the successful detection of a DVB-T signal using the imec sensing platform and the avoidance of this signal by an Iris link that was originally transmitting in the same band. The most important factor in this experiment is the successful integration of the two testbeds. After this experiment has been successfully carried out in its simplest form we would hope to adapt it so that it involved the Iris link moving in and out of the cell radius of the DVB-T signal, changing its operating frequency according to the varying channel availability.

Eventually this experiment will be undertaken in the TV bands so as to reflect signal strength, waveform, range, etc., accurately. In year one, however, we will aim to have this experiment successfully carried out in the ISM bands.

### 2.1.5 Why do we need the federation in order to perform these experiments?

The federation is essential if this kind of experiment is to be carried out successfully. The usage scenario requires the combination of the high accuracy sensing capabilities provided by the imec sensing platform and the on-the-fly radio reconfigurability provided by the Iris platform developed at TCD. When we are eventually able to have the imec hardware running directly on top of Iris it will dramatically improve the speed of the experiment, cutting out the need for an external node for the sensing equipment and allowing the sensor to exist as a component within the radio.

## 2.2 TUB – The TWIST testbed

### 2.2.1 General description

The TKN Wireless Indoor Sensor Network Testbed (TWIST) is a multi-platform, hierarchical sensor network testbed architecture developed at the *Technische Universität Berlin*. One instance is currently deployed at TUB campus: a total of 204 sensor nodes (102 eyesIFX and 102 Tmote Sky nodes) are distributed in a 3D grid spanning 3 floors of an office building, resulting in more than 1500 m<sup>2</sup> of instrumented office space. As can be seen in the following figure - which shows the layout of one floor (the other two are almost identical) - in the small rooms (~14 m<sup>2</sup>), two nodes of each platform are deployed, while the larger ones (~28 m<sup>2</sup>) have four nodes.

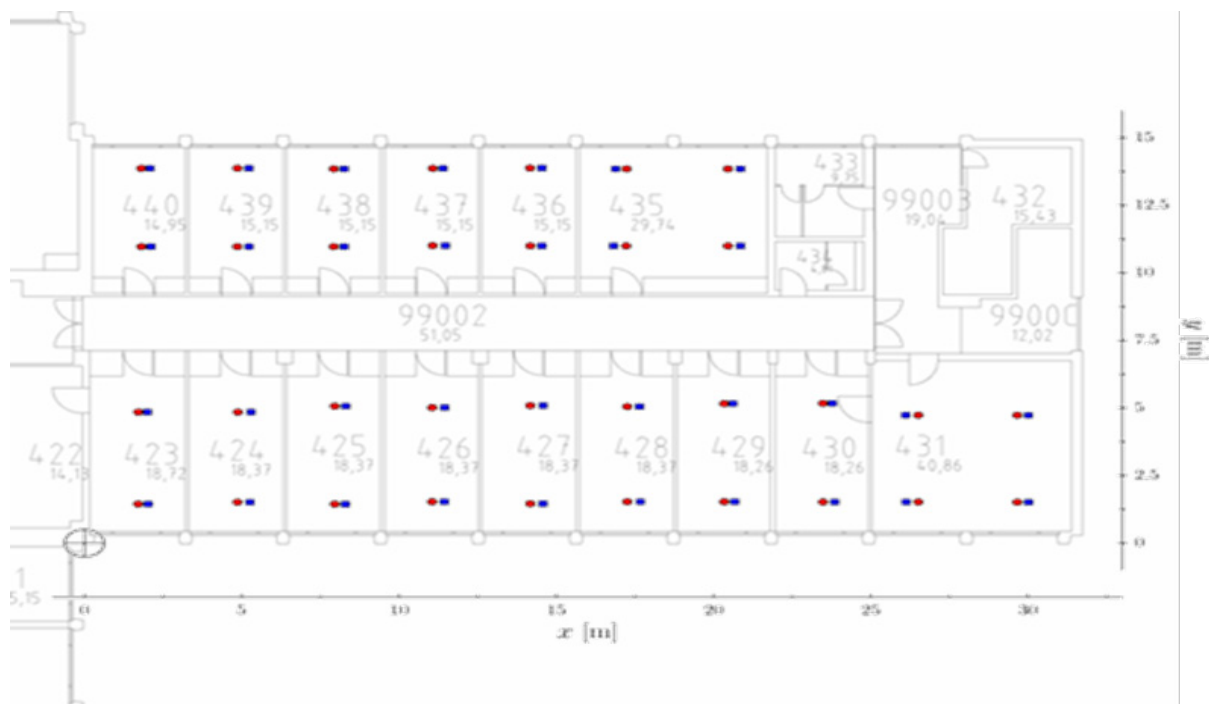


Figure 3: Layout of one floor of the TWIST testbed

This setup results in a fairly regular grid deployment pattern with intra node distance of 3m. Within the rooms the sensor nodes are attached to the ceiling as shown in the following figure (left + middle).



Figure 4: from right to left: Tmote Sky, eyesIFXv2, NLSU2 super node/USB hub

The TWIST architecture introduces a layer of “super-nodes” (Figure 4, right) between the sensor nodes and the testbed server, which manages sensor node reprogramming, configuration, or accessing debug information over the serial connection. TWIST relies on COTS hardware and fully leverages the features of the USB 2.0 standard. The sensor nodes are connected to the super-nodes via USB hubs, which act as concentrators and also provide a power supply management capability. This enables active topology control and node fault injection modelling through selective powering on and off of nodes. A schematic overview of the main components of the testbed architecture is shown in the following figure.

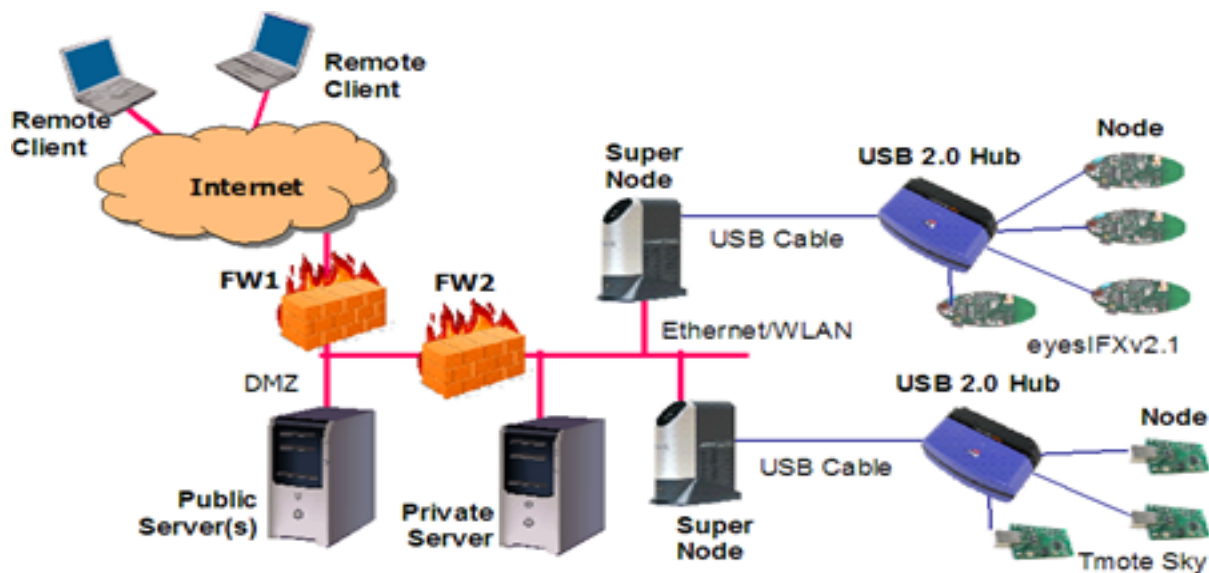


Figure 5: Hardware instantiation of the TWIST architecture

### 2.2.2 Use by external participants - access

External participants can conduct experiments in the TWIST testbed by installing their sensor node program images on an arbitrary set of the TWIST sensor nodes. For this purpose the TWIST instance at TUB provides remote access from the internet via a web-interface. The web-interface exports access control and resource (sensor node) reservation functions, it enables dynamic (re)programming of the sensor nodes, and active power control of single nodes. TWIST provides SSH connections to every single node, which allows the experimenter to control an individual node during an experiment, e.g. by sending specific control messages as well as gathering its experimental results. The SSH connections utilize the serial (USB) interface of the nodes. TWIST can also collect results from all nodes during an experiment and provide them for download after an experiment.



### 2.2.3 Use by external participants - example experiment

A basic experiment could be as follows:

1. The experimenter logs in via the web-interface and registers a *job* to be scheduled at a certain time in future. The job also includes the platform(s) that the experimenter will use.
2. When the job becomes active the experimenter will have exclusive access to the selected platforms. The experimenter can now upload binary program images to the corresponding sensor nodes.
3. After installation the experimenter may open SSH connections to some of the nodes, e.g. to inject a command over USB that will start the experiment (depending on the particular program that was installed). Alternatively the experimenter may have encoded in his/her program image that the experiment starts immediately or after a specific initial delay.
4. The experimenter can now enable the automatic tracing capabilities of the TWIST testbed: as a consequence all data that is output over USB by each sensor node during an experiment will be automatically stored in a trace file.
5. After the experiment the experimenter can log in again and download the trace file.

### 2.2.4 Expected achievements by the end of year 1

Access to the testbed via the web-interface as described in the example above will be available to experimenters before the first open call.

To support the more sophisticated features of CREW Usage Scenarios 2 (“Robust Cognitive Sensor Networks”) and 3 (“Horizontal Resource Sharing Between Heterogeneous in ISM Bands”) it is planned to extend TWIST by two functions: spectrum sensing capabilities and controlled mobility.

Spectrum sensing is important to understand the impact of other co-located wireless technologies and realize cognitive building automation wireless sensor networks (Usage Scenarios 2 and 3); controlled mobility is required for experiments involving Body Area Networks (Usage Scenario 3).

Spectrum sensing will be realized by extending the TWIST testbed with low-cost USB spectrum analysers that will be placed at dedicated points in the testbed. The spectrum analysers can be used by an experimenter to monitor spectrum usage in the 2.4 GHz band during an experiment. An experimenter may bring additional sensing equipment, such as an imec sensing agent, to the testbed premises to compare its performance with the low-cost spectrum analysers. In addition a software framework will be provided that can be used to utilize a subset of the TWIST sensor nodes for spectrum sensing: the software will essentially switch the transceiver of a sensor node to receive-mode and perform continuous energy-detection, hopping over a predefined set of frequencies. An experimenter will be provided with a corresponding pre-compiled program image that can be installed on some of the nodes to monitor spectrum usage during an experiment.

To conduct repeatable experiments with cognitive body area networks (Usage Scenario 3) the TWIST testbed will be extended before the first open call by a set of small mobile robots. The robots, each equipped with a sensor node, are used to emulate a mobile body area network and will be located in one room inside the TWIST building. An experimenter will be able to specify controlled, reproducible mobility patterns for a robot, thus emulating mobility of a person. At the same time the TWIST testbed or, for example, a static WLAN station can be used to generate traffic (emulating a primary or competing user). An experimenter can thus evaluate cognitive concepts, such as spectrum sensing and frequency agility, in reproducible mobile setups.

### 2.2.5 Why do we need the federation in order to perform these experiments?

The initial variant of the TWIST testbed does not include any particular cognitive (spectrum sensing) capabilities and the envisioned extensions will integrate low-complexity spectrum sensing devices. It

remains, however, unclear if the accuracy provided by those solutions is sufficient for the targeted usage scenarios. The federation will enable us to compare the performance of low-complexity/low-cost solutions with more sophisticated solutions, such as the imec sensing agent. This can be made possible via physical relocation (second mode of the federation) of sensing equipment, i.e. co-located measurements with different equipment and subsequent performance comparison; or “replaying” RF noise traces previously recorded (including a known detection performance by, e.g., the imec sensing agent) from other cognitive testbeds and qualitatively (for example in the time domain) evaluating the performance of the low-complex spectrum sensing devices in TWIST, which is realized by the third mode of the CREW federation.

## 2.3 TUD – The LTE Testbed

### 2.3.1 General description

Dresden's LTE/LTE+-like testbed was set up in 2008 as part of the Easy-C project ([www.easy-c.com](http://www.easy-c.com)).

The signal processing hardware includes:

- Sorbas602 eNodeB Simulators,
- Sorbas202 Test UEs, and
- Sorbas472 Radio Units,

which were supplied by Signalion ([www.signalion.com](http://www.signalion.com)). The eNBs and UEs are connected through IF interconnects at 70MHz with the radio unit frontend. The hardware supports up to two Tx and two Rx channels for MIMO capability. The testbed operates in EUTRAN band VII (DL @ 2670-2690 MHz / UL @ 2550-2570 MHz) with fixed bandwidth of 20MHz and in FDD mode.

For the CREW project, two experimentation setups are available.

The indoor lab (Figure 7) features 5 eNBs and 4 UEs. While the hardware itself is stationary, the Tx and Rx antennas can be positioned anywhere in the lab room. Further, four additional UEs are mounted on studio racks/carts and can be moved within the building. The approximate transmit power is 15 dBm.

The outdoor lab (Figure 8) consists of two base station sectors that are fixed on two opposing corners of the faculty building, approximately 150 m apart. In addition to the mobile indoor UEs from setup 1, three rickshaw UEs are available for outdoor experiments in the vicinity of the building. The transmit power is approximately 30 dBm.

All UEs in the testbed, as well as the indoor eNBs are equipped with *Kathrein 800 10431* omnidirectional antennas. The antennas of the outdoor eNBs are sectorized and of type *Kathrein 800 10551*.

Other testbed equipment includes six batteries that can power an individual UE for around 2-4 hours, GPS receivers for time synchronization, various cables, attenuators and splitters. Measurement equipment includes spectrum analysers of types *R&S FSH4*, *R&S FSQ8* and *R&S TSMW*.

The performance evaluation of experiments can be performed in real-time as well as semi real-time and offline. Real-time measures include

- Received Signal Strength Indicator (RSSI),
- Reference Signal Receive Power (RSRP),
- Path loss, and
- Channel Quality Indicator (CQI; derived from SINR).

In semi real-time, additionally QAM constellations and block error rate (BLER) can be monitored via file dump of I/Q samples and Matlab post processing. Further performance measures could be obtained in offline processing from those file dumps.

As the eNB and UE provide only minimal LTE release 8 (Rel 8) PHY/MAC functionality, it is particularly important to note that the DL frame structure and control channels differ slightly. Differences include:

- PDCCH is always in the second OFDM-symbol (position is variable according to Rel. 8);
- PHICH (HARQ Indicator Channel) is not in the first OFDM symbol and has a different structure/content;
- PCFICH (Control Format Indicator Channel) is not supported; and
- PBCH (Broadcast Channel) is not supported.

Further, the OFDM scheme is used in the uplink.

An overview of the uplink and downlink processing chains can be found in **Figure 6**.

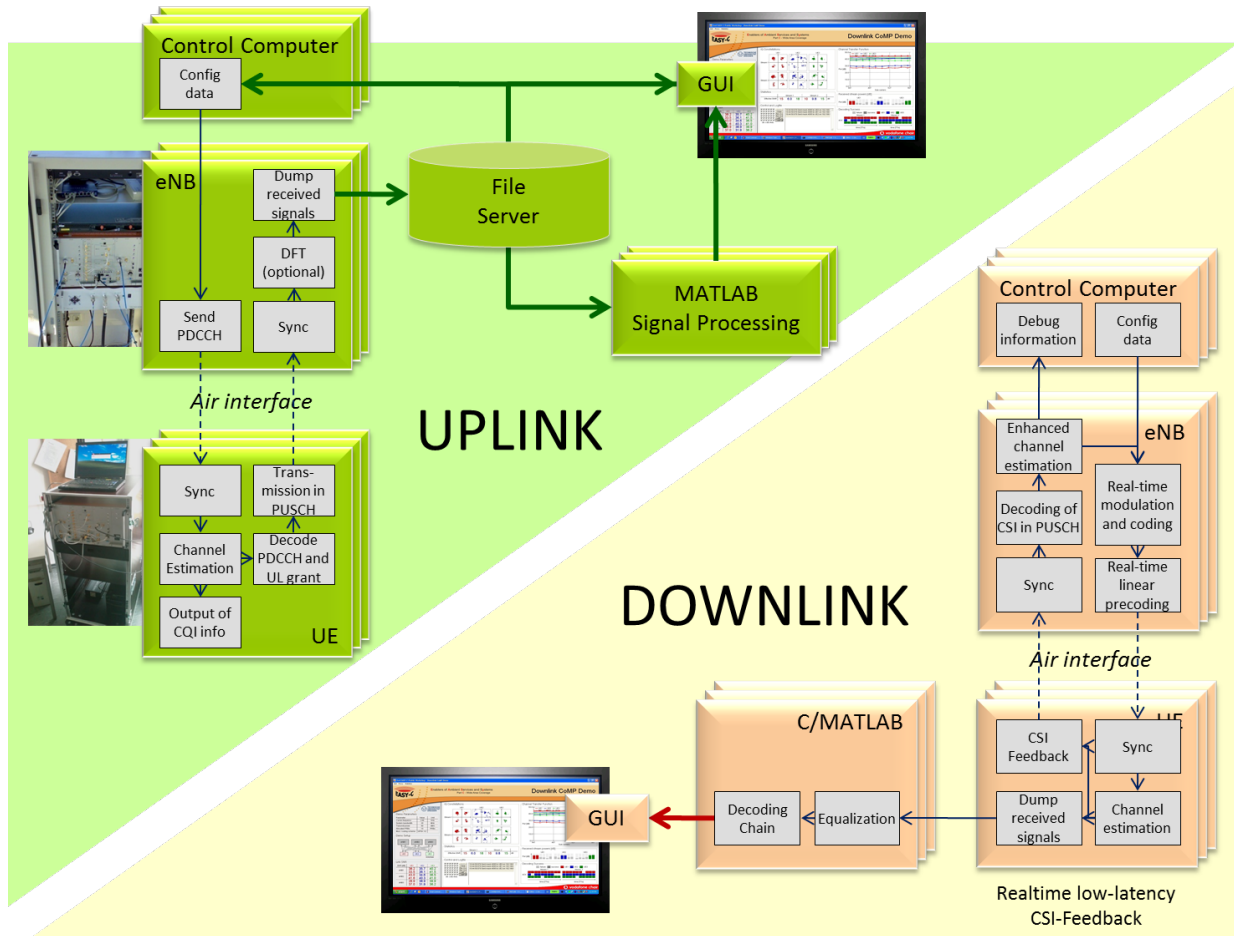


Figure 6: Uplink and Downlink Processing Chain

One important requirement in this project is that the CREW federation must ensure that the hardware-to-be-federated is compatible. In particular this means that host and guest systems must be able to operate in the same frequency bands. This is especially relevant for the TUD testbed, as the LTE frequency bands have been auctioned in Germany and it is foreseeable that the currently used EUTRAN band VII around 2.6 GHz will not be available for research purposes in the long term. For this reason various options for changing the frequency bands are currently under evaluation.

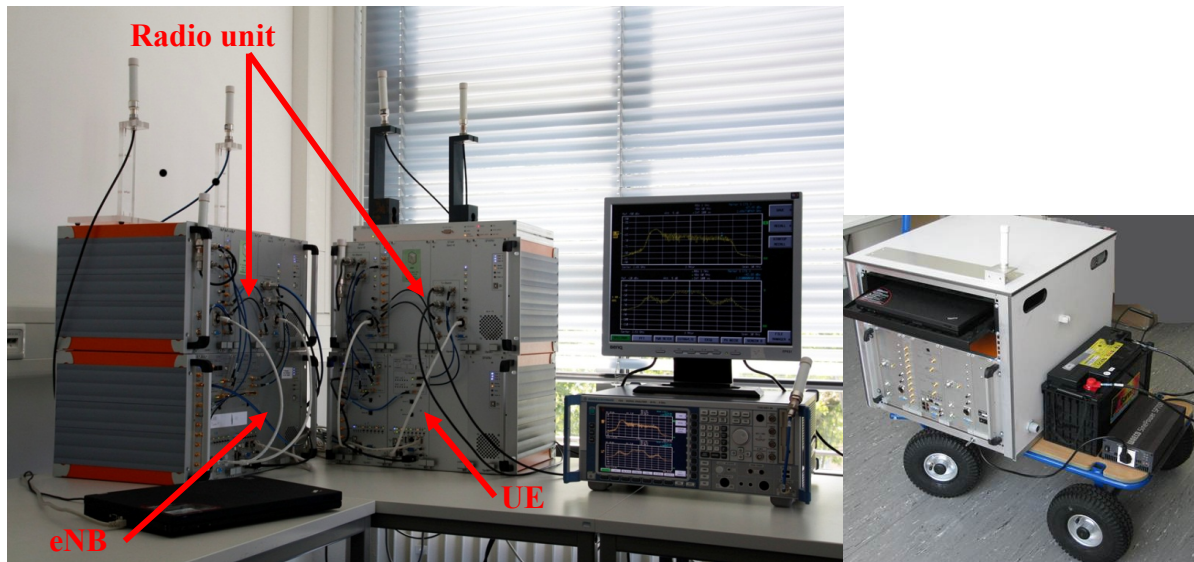


Figure 7: Indoor setup

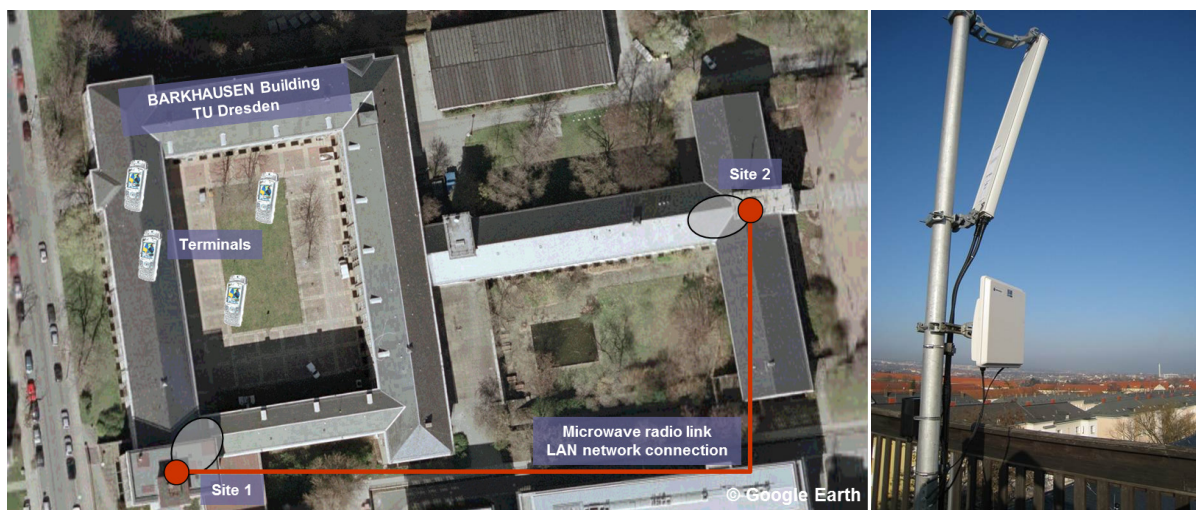


Figure 8: Outdoor setup

### 2.3.2 Use by external participants - access

In order to conduct experiments in the LTE testbed, participants are required to bring their spectrum sensing and/or secondary system hardware to Dresden. In order to pre-evaluate certain theories and algorithms, a testbed reference signal in the form of baseband I/Q samples can be provided. Further, during the experiments it is possible to dump transmitted and received signals in the same format. This allows for offline post-processing of the signals, evaluation of the signals and replay in other testbeds.

### 2.3.3 Use by external participants - example experiment

The testbed in Dresden contributes an LTE-like cellular system to the CREW federation, which can serve as a primary (host) system for cognitive radio and spectrum overlay related usage scenarios.

In a possible experiment setup, firstly, a cellular signal containing reproducible white space patterns is transmitted by the LTE testbed. The secondary (guest) system will then be able to attempt to

successfully detect and transmit within these white space resources avoiding the transmissions of the primary system. This setup is outlined in **Figure 9**. White space detection experiments aim to evaluate a participant's spectrum sensing algorithms and hardware in a realistic, LTE-like environment and thus support the refinement and validation of such algorithms and hardware. White space transmission provides the means to monitor the performance of the primary system while changing the transmission parameters of the secondary/guest system. This can be used to compare PHY layer schemes with respect to their impact on the primary/host system and optimize them in such a way as to produce minimal interference.

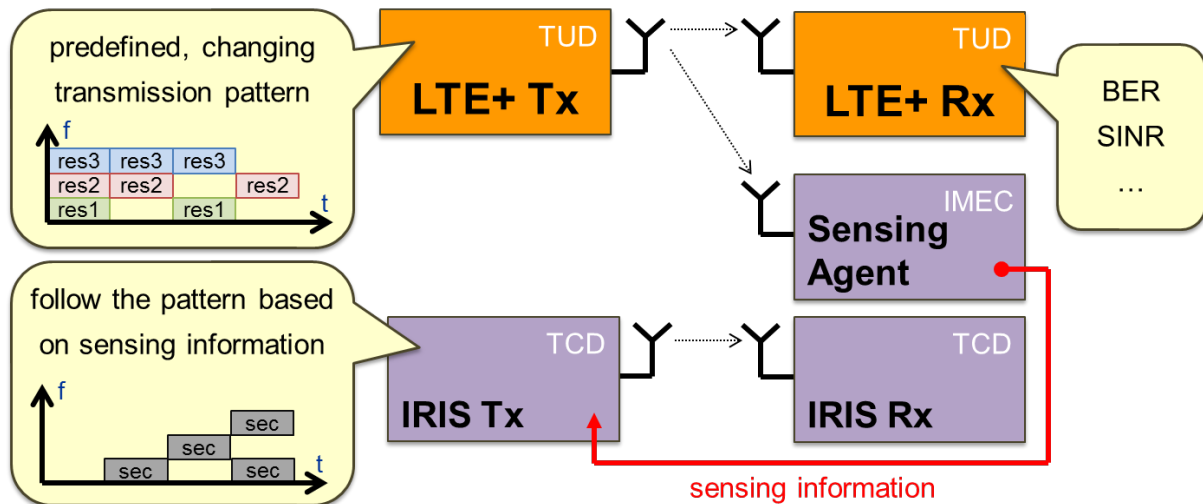


Figure 9: Example experiment setup

#### 2.3.4 Expected achievements by the end of year 1

By the end of year 1, we expect to implement and demonstrate use Case US13 ("Reliable Sensing of Cellular Systems") from deliverable D2.1.

#### 2.3.5 Why do we need the federation in order to perform these experiments?

TU Dresden's testbed was initially designed for LTE/LTE+-like experiments in the scope of the EASY-C project and as such it contributes a primary cellular system to the federation. However, it lacks the hardware and algorithms for spectrum sensing as well as reconfigurable radio functionality, which are both essential for cognitive radio and networking specific experiments. By creating the CREW federation, these missing components are introduced to the LTE testbed and a set of experiments are enabled that would not be possible individually.



## 2.4 Imec sensing platform

### 2.4.1 General description

The goal of this prototype is to show that a flexible sensing engine is possible within the power and cost constraints of a mobile device. The prototype is built around two core components: an analogue RF front-end SCALDIO [19] (SCALable raDIO) and a DIgital Front-end For Sensing (DIFFS) [20, 21]. Both these ICs are low-power and flexible, targeted towards implementation of a cognitive radio as a mobile device. A second version of this prototype is developed to facilitate easy usage of the prototype without in-depth knowledge of the RF IC, supporting a larger number of sensors and testing outside the lab. For this version a commercially available radio board is used instead the board containing SCALDIO: a WARP [22] radio board.

#### a. Core components

The SCALDIO IC, shown in Figure 10, handles the down-conversion, filtering and Analogue-to-Digital Conversion. The IC RF input frequency ranges from 100MHz up to 6GHz, the baseband channel bandwidth is programmable from 1 to 40MHz, the noise figure is 2.4 to 4dB below 3GHz and power consumption varies from 30 to 90mA. This makes this IC ideally suited for the scenarios described in section 2 (“Definition of Usage Scenarios”) of deliverable D2.1. The ADC sampling frequency is fixed to 40MHz and the resolution is 10 bits in the integrated prototype.

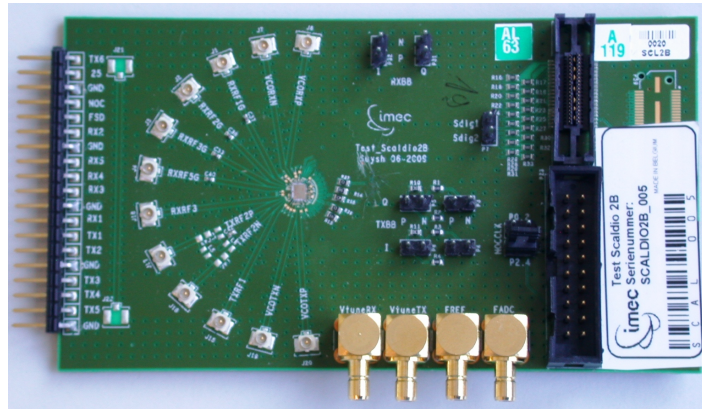


Figure 10: SCALDIO mounted on PCB

The WARP radio board, shown in Figure 11, is built around the MAXIM 2829 IC. Besides the radio chip, the board also contains ADCs for the baseband signal and the RSSI, band-pass filter and RF switch: a full receive chain. The ADC sampling frequency is fixed to 40 MHz and the resolution is 14 bits. Two frequency bands are covered: 2400-2500MHz and 4900-5875MHz. Also, a full transmit chain is present; however this will not be used for the integrated prototype.

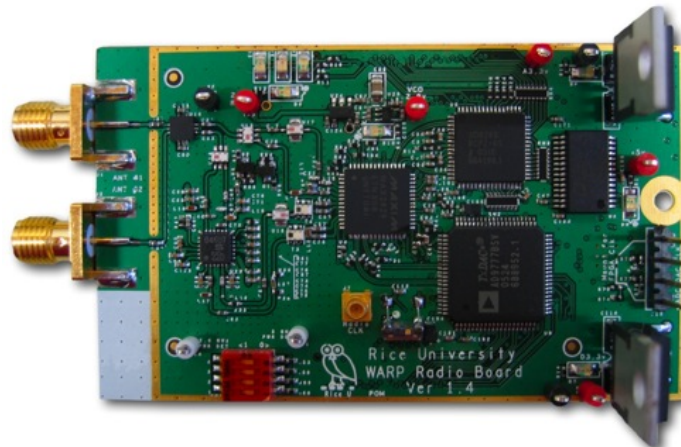


Figure 11: WARP radio board

The DIFFS chip, shown in Figure 12, is an ASIP specifically designed for sensing operations, signal conditioning and synchronization. The chip contains a flexible filter block, including re-sampling and a SIMD core, extended with multiple accelerator cores. The chip can be operated in two modes: as a sensing engine or, when connected to a baseband processor, as synchronization and filtering engine.

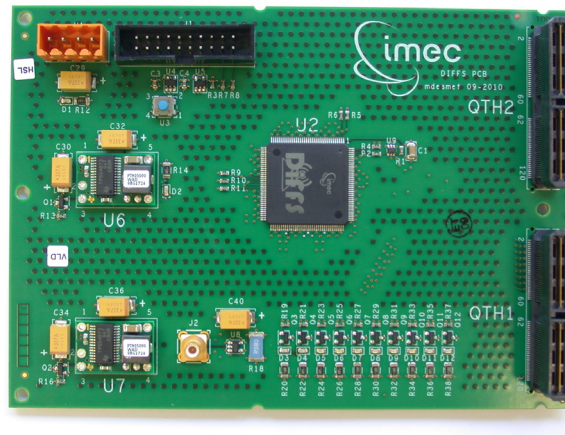


Figure 12: DIFFS mounted on PCB

### b. Sensing Engine

The core components will be integrated into a sensing engine that can be integrated into a PC by means of a USB interface. In the sensing engine an FPGA is used to connect the different components. This FPGA is connected to the analogue RF board (depending on the configuration this can be a WARP radio or SCALDIO board) on one side and on the other side a USB. The sensing engine is connected to a PC via a USB interface. A sensing engine driver running on the PC provides all the necessary functions to program the sensing engine whilst hiding all the low-level details from the user. The driver provides a limited amount of functions to control the RF frequency, channel bandwidth and sensing algorithm of the sensing engine and to acquire the result of the sensing operation. The result of the sensing operation depends on the requested measurement and can range from the raw time-domain samples over FFT output vectors to a single power value for a specific frequency band. An overview of the sensing engine is displayed in the following figure.

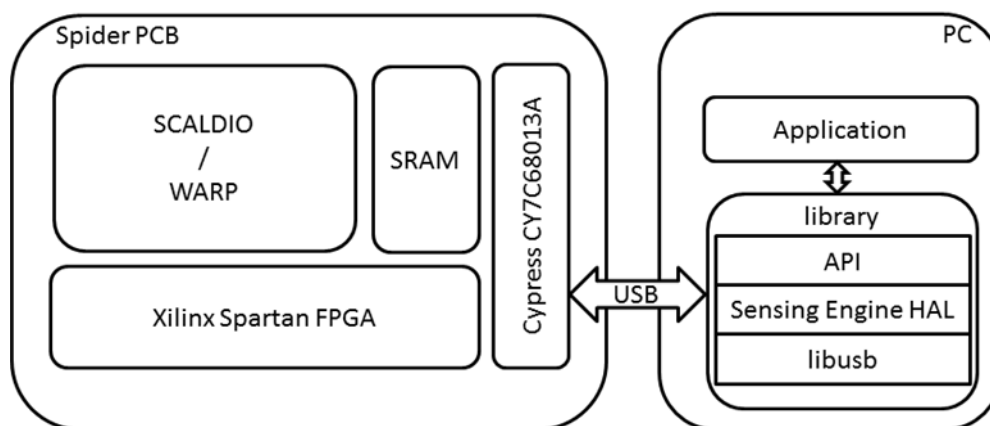


Figure 13: Schematic overview of sensing engine

### 2.4.2 Use by external participants - example experiments

Multiple scenarios are possible to make use of the sensing engine, including: (a) integrating the sensing solution in the external experimenter's own testbed through the USB interface and use the driver, (b) leveraging on the integration of the sensing engine in CREW testbeds, (c) reprogramming



the sensing engine with specific functionality, (d) making use of samples from the sensing engine to test algorithms, and finally (e) mixing and matching the hardware of the sensing engine with the experimenter's other hardware components.

**a. Integrating the sensing solution in the experimenter's own testbed through the USB interface and use of the driver**

The host PC should be capable of using the libusb library, which provides user applications a uniform access to USB devices on different operating systems, on top of which the sensing engine Hardware Abstraction Layer (HAL) and Application Programmers Interface (API) will be built.

**b. Leveraging on the integration of the sensing engine in CREW testbeds**

During the federation activities of the CREW project, the sensing engine will be federated with the CREW testbeds. This will allow new modes to use the sensing engine. For instance, when multiple sensing engines are integrated in the w-iLab.t testbed of IBBT, it will be possible to use the IBBT tools for creating a scenario, a test and benchmarking. This will enable testing a larger set of usage scenarios, such as, for instance, distributed sensing.

**c. Reprogramming the sensing engine with specific functionality**

The sensing engine is very flexible and programmable. While basic functionality is there, after the first year of the CREW project, one can envision that researchers will be interested in testing newly developed functionality on the platform.

**d. Making use of samples from the sensing engine to test algorithms to finally**

If it is not possible, or too much effort, to run the sensing functionality on the hardware, one could imagine testing functionality using I and Q samples obtained from the sensing engine. Compared to spectrum analysers, the sensing engine could allow testing distributed sensing algorithms that require samples taken at more than one location. It is assumed here that it is very expensive and cumbersome to obtain multiple spectrum analysers.

**e. Mixing and matching the hardware of the sensing engine with the experimenter's own hardware components**

The sensing engine, as used in the CREW federated testbed, can contain the SCALDIO or the WARP front-end. It could be possible to experiment with other front-ends, so as to compare the performance of different front-end solutions.

### **2.4.3 Expected achievements by the end of year 1**

To cover all sensing usage scenarios, many different technologies and sensing setups need to be tested. Indeed, in the CREW federated testbed, the goal is to cover licensed and unlicensed technologies, going from the DVB-T, to ISM, to LTE technologies. In addition, we plan to study local, distributed and database assisted sensing. By the end of year one, the goal is to focus on local sensing of various technologies in the DVB-T, LTE and ISM bands. This will be achieved and tested within the CREW federation. For instance, for the ISM sensing, the sensing engine will be integrated in the IBBT w-iLab.t testbed that is equipped with IEEE 802.15.4 and IEEE 802.11, both 2.4 GHz and 5 GHz ISM band technologies. Similarly, the LTE sensing and DVB-T sensing will be verified.

### **2.4.4 Why do we need the federation in order to perform these experiments?**

At the end of year 1, the federation will mainly have served to verify the sensing solution in a range of scenarios (including LTE, DVB-T and ISM) and to test the use of local sensing in cognitive control algorithms. However, since the sensing engine will be integrated into the CREW testbeds, it will be possible to also explore distributed sensing and database-assisted sensing. These usage scenarios are of key importance for the sensing research in the cognitive radio domain.

## 2.5 IBBT – The w-iLab.t testbed

### 2.5.1 General description

The w-iLab.t is a wireless Wi-Fi and sensor network testbed infrastructure, deployed across three floors of the IBBT office building in Ghent, Belgium. At 200 locations throughout the office spaces, meeting rooms and corridors, wireless hardware is mounted to the ceiling.

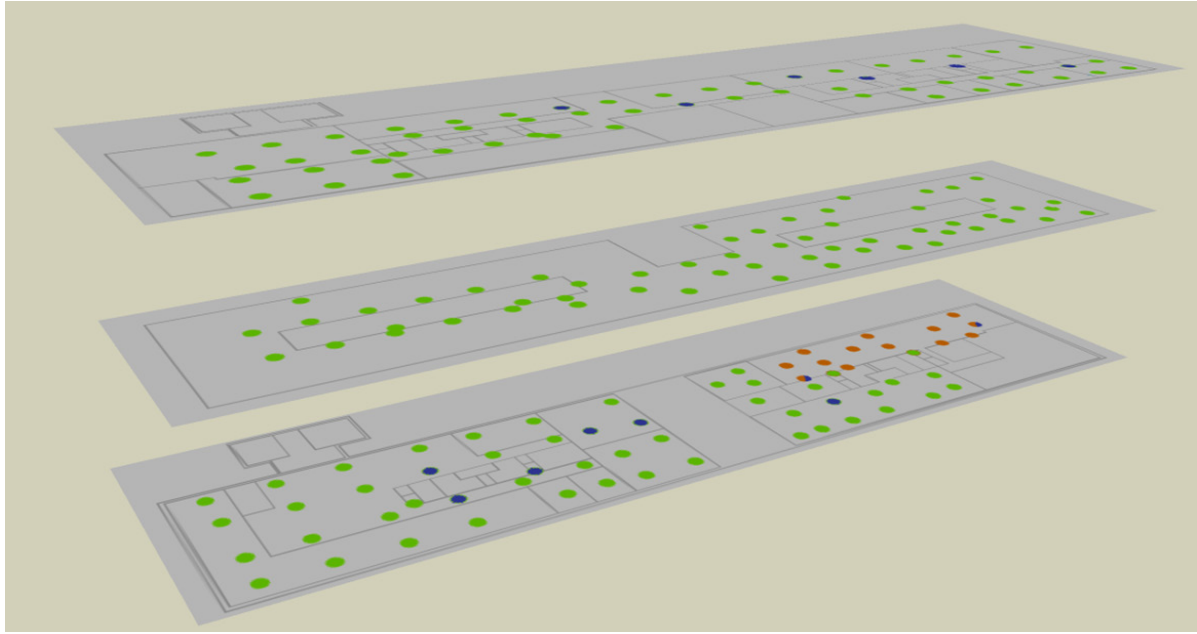


Figure 14 - The w-iLab.t nodes are installed across three floors of an 90mx18m office building. The dots indicate the location of wireless nodes.

Each of the 200 locations is equipped with one or multiple (heterogeneous) wireless sensor nodes, as well as two IEEE 802.11a/b/g WLAN interfaces. Wireless Wi-Fi based networks and IEEE802.15.4 based sensor networks can be operated at the same time, allowing complex and realistic experiments with heterogeneous nodes and multiple wireless technologies.

The w-iLab.t allows flexible testing of the functionality and performance of wireless networking protocols and systems in a time-effective way, by providing the means to install and configure firmware and software on (a selection of) nodes, schedule automated experiments, and collect, visualize and process results. Thanks to an in-house designed hardware control device, called the *environment emulator*, unique features of the testbed include the triggering of repeatable digital or analogue I/O events at the sensor nodes, real-time monitoring of the power consumption, and battery capacity emulation.

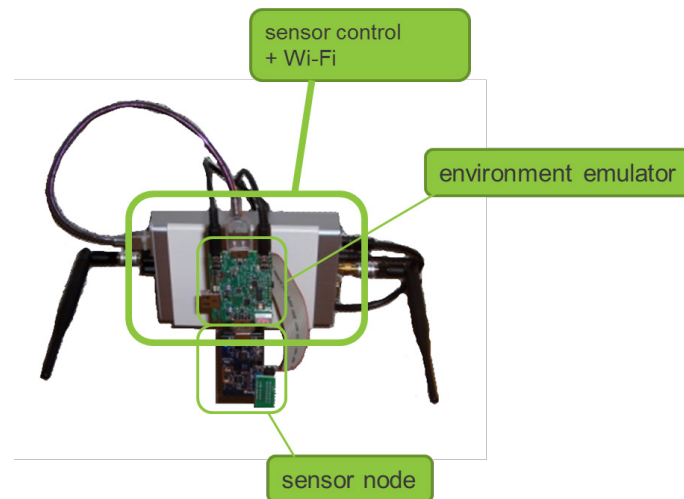


Figure 15 - Wireless nodes mounted to the ceiling.

Figure 15 depicts the hardware that is mounted to the ceiling at every location in the testbed. On the bottom of the figure, an IEEE802.15.4 compatible sensor node (TMote Sky) equipped with a temperature sensor, a humidity sensor, and a light sensor can be seen. This sensor node is connected via the environment emulator to an embedded platform [23], which is equipped with two IEEE802.11a/b/g based Wi-Fi cards. An experimenter using the w-iLab.t can install custom firmware to the sensor nodes, and/or install scripts, drivers, kernels, etc. to the embedded PC and control the behaviour of the environment emulator via a web-based interface. As such, an experimenter can run large-scale experiments to analyse the behaviour and performance of wireless networking solutions. Possible experiments include but are not limited to: MAC protocol development (e.g. interference avoidance schemes), routing protocol development (e.g. re-routing of traffic to avoid highly interfered parts of a network), and application layer development, either using sensing devices, Wi-Fi based devices, or a combination.

To aid experimenters in deploying their developments, monitoring the experiment and/or collecting, processing and visualizing data collected from a large number of wireless nodes, a set of tools is made available to the experimenter via the web-based interface. As an example, Figure 16 presents example output of the so-called visualizer (left) and analyser (right) functions of the management interface.

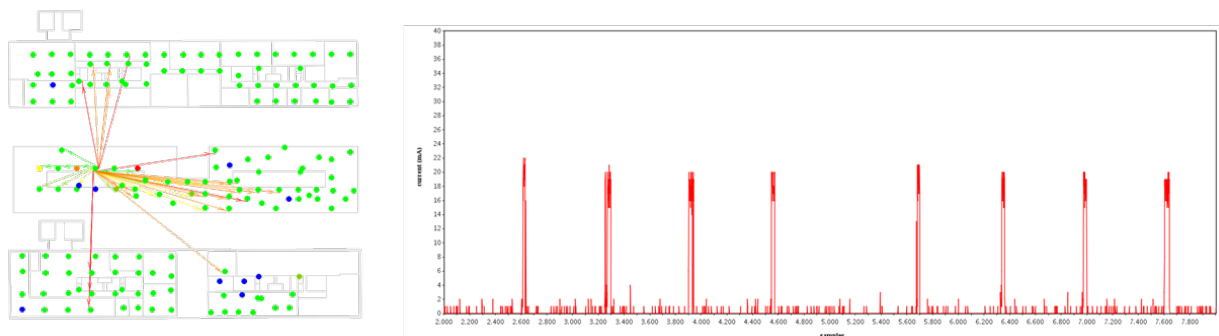


Figure 16 - Example output presented to the experimenter, available in real-time or post-experiment. Left: representation of the wireless packet flow. Right: power consumption of a sensor node (Y axis) sending beacons vs. time (X axis).

In addition to the nodes mounted to the ceiling, the w-iLab.t also offers shielded boxes in which nodes can be placed to shield them completely from outside interference. The antennas of these nodes are then decoupled, and connected over coax via RF splitters and computer-controlled variable attenuators, thus facilitating experiments that require reproducible emulated mobility.

Several extensions are planned to the w-iLab.t. First, an additional location will be added to the testbed, away from office environments, with 60 additional fixed nodes. This will allow experimenters to execute their wireless experiments in an environment with limited RF interference. At this new

location, more powerful embedded platforms will be available. These platforms will be equipped with Wi-Fi cards based on the IEEE802.11n standard. Additionally, more powerful sensor devices in terms of ROM and RAM memory will be available (according to an IBBT design, but backwards compatible with the TMote Sky sensor node), and the testbed will be extended with mobile robots to support experiments with moving wireless nodes.

Finally, in the scope of the CREW project, hardware updates include the addition of cognitive components such as the USRP2 and the imec sensing hardware. Software updates include the extension of a basic software solution to support benchmarking of wireless solutions (cf. Section 3.5).

## 2.5.2 Use by external participants - access

External users will get full access to the w-iLab.t testbed, i.e. usage of the testbed hardware and the w-iLab.t management interface including all tools to manage and monitor the experiments, and to collect, process and visualise the results. Experimenters will receive log-in information to access the management interface (over HTTP), the embedded devices (over SSH), and the results database and storage server. An OpenVPN connection is required – accounts will be provided.

At any time, experimenters may schedule a certain number of experiments bound to a certain quota. The quota indicates how many experiment-minutes can be scheduled; e.g. an example quota of 1000 minutes means that the experimenter is allowed to schedule a 1000 minute-experiment using only a single testbed location, or may use 200 testbed locations simultaneously for a duration of 5 minutes. The quotas are in place to keep a single experimenter from blocking access to the testbed for a prolonged period of time. This guarantees that everyone is able to get a fair share of access to the testbed. The quota is negotiable according to the specific needs of the user.

## 2.5.3 Use by external participants - example experiments

### *Simple experiment showcasing basic functionality*

To get a first feeling of how the testbed is used, a user can log in to the web interface at [www.wilab.atlantis.ugent.be](http://www.wilab.atlantis.ugent.be) (OpenVPN access to the test facility required) and browse through the different configuration tabs. The *toolbox* section of the w-iLab.t testbed, containing the visualizers and analysers, can be used even without scheduling an experiment: a default application running in the background when no experiments are scheduled collects temperature and humidity readings of all sensors in the office environment. The testbed topology and corresponding real-time sensor values can be visualized on a map of the testbed by launching the *[w-iLab\_t]\_Visual\_Temperature* visualizer. After the visualizer is started, a zoomable map is presented to the user. Double clicking disables the real-time mode; a time-line is presented with a slider that can be dragged to present past sensor values. Note that this is only a very basic example of how the visualizer can help the experimenter to maintain a view on what is happening inside the testbed. The XML configuration driving the visualizer can be downloaded by the experimenter to get a view on how the visualizer uses information stored in a database to render its view. During real experiments, most likely, it will not be temperature values that are of interest to the user, but e.g. a certain metric describing the state of the wireless nodes or wireless protocols under evaluation.

### *Running a first experiment*

On the CREW portal, a step-by-step guide will explain how a user can set-up a very basic experiment in which one node broadcasts beacons, which are then received (or not) by other nodes in its vicinity. The receiving nodes record the received signal strength and store this value in the database. The RSSI values will then be visualised using the visualizer.

#### **2.5.4 Expected achievements by the end of year 1**

Before the first open call, the imec sensing hardware is planned to be integrated in the w-iLab.t testbed (at the new location), meaning that at this point in time, experimenters will be able to complement the (already available) information collected at packet and system level with advanced information on the occupation of the spectrum. Additionally, a basic version of the benchmarking framework will be implemented which allows experimenters to collect information on the state of the spectrum during their experiment, and thus collect information on the occupancy of the wireless spectrum as an additional performance measure. When developing cognitive networking algorithms, e.g. to improve the co-existence of ISM networks as described in deliverable D2.1, such spectrum occupancy benchmark may help experimenters to judge the performance of their solutions.

#### **2.5.5 Why do we need the federation in order to perform these experiments?**

The current w-iLab.t testbed does not have advanced capabilities for RF spectrum scanning. This means that experimenters designing cognitive networking protocols currently only have packet and node level information available to help them in analysing the functionality and performance of their solution. The availability of advanced spectrum sensing hardware creates new possibilities for the experimenter. First, the output of the spectrum sensing hardware can be used as a way to monitor the solution under test and the environment, thus for example detecting unwanted external interference caused by devices such as microwave ovens, or enabling the specification of new performance metrics based on spectral information. Second, the output of the spectrum sensing hardware could be used by low-end devices (either via a direct connection or via a central entity), in an attempt to create more advanced cognitive networking protocols.

Furthermore, the output of the benchmarking framework will become especially relevant when comparing solutions in different testbeds, or comparing different solutions available in the consortium side-by-side.

### 3 Basic functionality

#### 3.1 Description of modes of operation

We envision the federation to be used in one of three main modes. The description of the modes of operation of CREW in this subsection of the report is reproduced from our publication [4]:

- **Single usage (portal description)**

A common portal website is created that holds a comprehensive and uniform description of the functionality and characteristics of each testbed and cognitive radio component, access information and usage guidelines. In this initial federation mode, access to individual testbeds – initially by all partners, later by the broader public – is enabled.

- **Heterogeneous usage**

Heterogeneous usage involves hardware and tools being physically relocated. For example, a software architecture for cognitive radio research developed at one location can be installed on top of sensing hardware developed at a second location, and then deployed in a controlled wireless experimentation environment at a third location. In this second federation mode, the individual partner sites remain operational, while the combined expertise and equipment now also allows more complete and more controlled experiments. For example we can envision a three-testbed hardware/software combination where every single part of the CR node (radio, network and system stack, testbed control) is fully under control of the experimenters.

- **Sequential usage**

We will develop solutions that allow recording wireless traces in one test environment, and replaying them, possibly in other test environments. The possibility to record and replay wireless traces is an enabler for repeatable tests, and allows re-creating interference patterns in a first test location that were recorded in a second test location. The recorded traces might contain interference patterns generated by equipment only available in the second testbed, but of interest to the experimenters using the facilities available at the first location. As such, the emulation of testbed components is possible, avoiding the necessity to physically co-locate equipment. We will create open data sets to enable this type of emulation and to allow performance results obtained in one experimental wireless environment to be compared with results in other environments. These open data sets are used to describe spectrum sensing data, packet traces, but also general wireless conditions in which experiments take place.

The following figure depicts the three federation modes.

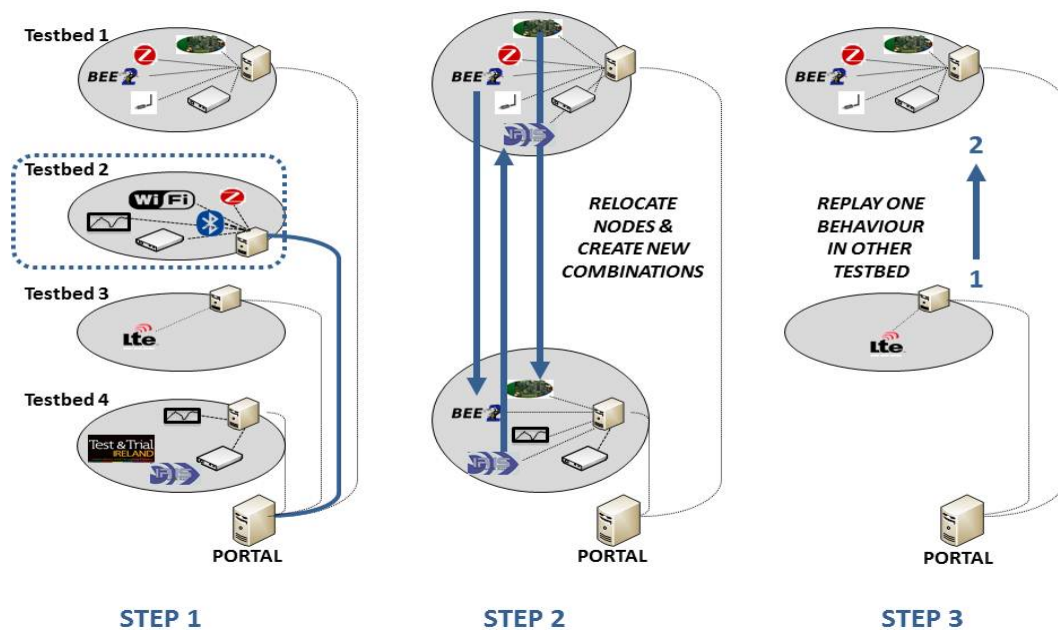


Figure 17: Federation modes of usage

### 3.2 Common Portal

In a recent sustainability questionnaire-based survey performed by the MyFire initiative [24] testbed owners and users were asked “why they never considered using a FIRE facility for their research”. Out of eight possible answers, by far the most popular one was: “we do not use the facilities, because there is not enough information available about the facility”. No less than 29 out of 33 respondents indicated that clear information on facilities was lacking.

To avoid this pitfall and make sure that the CREW facility will be used by external experimenters, a CREW portal will be established. The CREW portal is the primary way of getting information on the facility, and serves as a gateway through which external experimenters get all necessary details to get to know and access the facilities. The portal is implemented as a website.

In the roadmap of the CREW project, a first release of the federation is planned to be operational after the first year of the project (by end September 2011). This first, basic version of the federation opens up access to the different testbeds that were brought into the project and supports basic federation of testbeds and cognitive testbed components at a single testbed site. Therefore, similarly, the aim of a first release of the portal is to provide detailed information on all individual testbeds and testbed components.

#### 3.2.1 Organization of the portal

It is unlikely that a first time visitor to the CREW portal would be familiar with all components of the federation. In order to let the experimenters find the specific cognitive components and testbeds without having to go through all information in detail, the CREW portal will present the available info in different ways:

- An overview page containing a concise description of the different components. Full information is presented when selecting a specific testbed or cognitive component.

- The information pages on the portal will be tagged with keywords that classify the content according to technical criteria. For example, a testbed could be tagged with “LTE” and “Wi-Fi a/b/g”. This would then enable experimenters to quickly search for a testbed that is able to support LTE experiments, thus directly limiting the amount of portal information that needs to be read.

As soon as an experimenter, based on the concise descriptions or after searching for tags, knows which aspect of the CREW federation may be interesting to him or her, a more detailed factsheet of the individual testbed or cognitive component will be presented. This factsheet is illustrated in Figure 18.

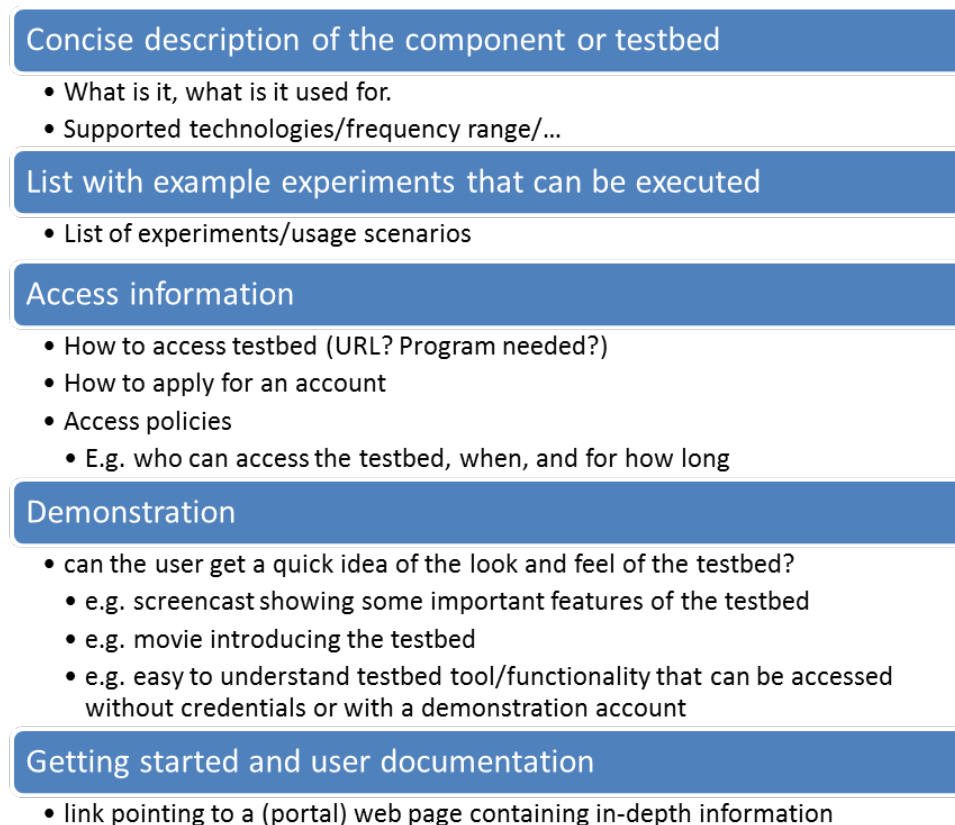


Figure 18 – Factsheet presented to the user on the CREW portal, used to describe the individual testbeds and cognitive components.

A final level of detail, accessed through the link in the “getting started and user documentation” section of the factsheet, will take the experimenter to a testbed (component) specific section, which is less formally structured, so as to provide sufficient flexibility to allow describing the heterogeneous cognitive components and testbeds in CREW. However, these full descriptions are likely to contain one or several of the items presented in **Figure 19**.



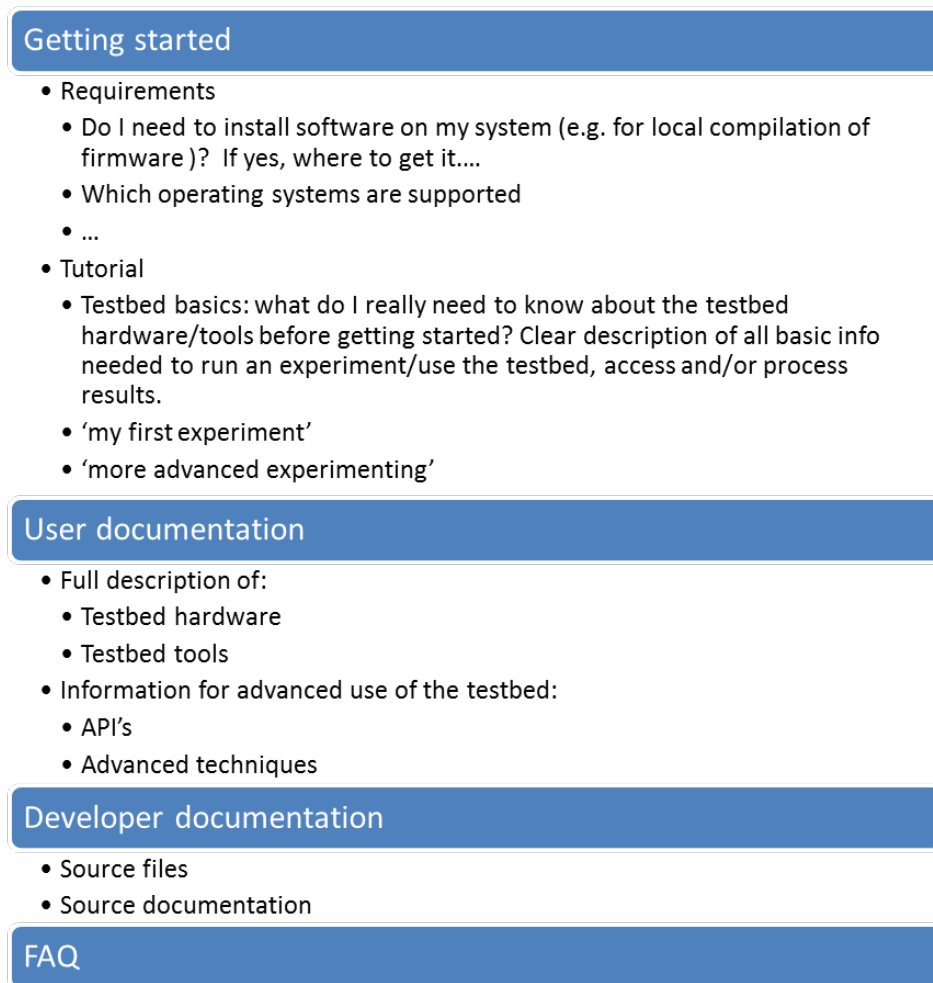


Figure 19 - Selection of example items to be included in the full description of the testbeds and cognitive components on the CREW portal

### 3.2.2 Extending the portal: advanced integration of cognitive components

Eventually, the portal will be extended to include information on how to realize advanced combinations of CREW testbeds and components. This description will be based on the template depicted in Figure 20. The template will be further adapted based on the feedback of the experimenters.

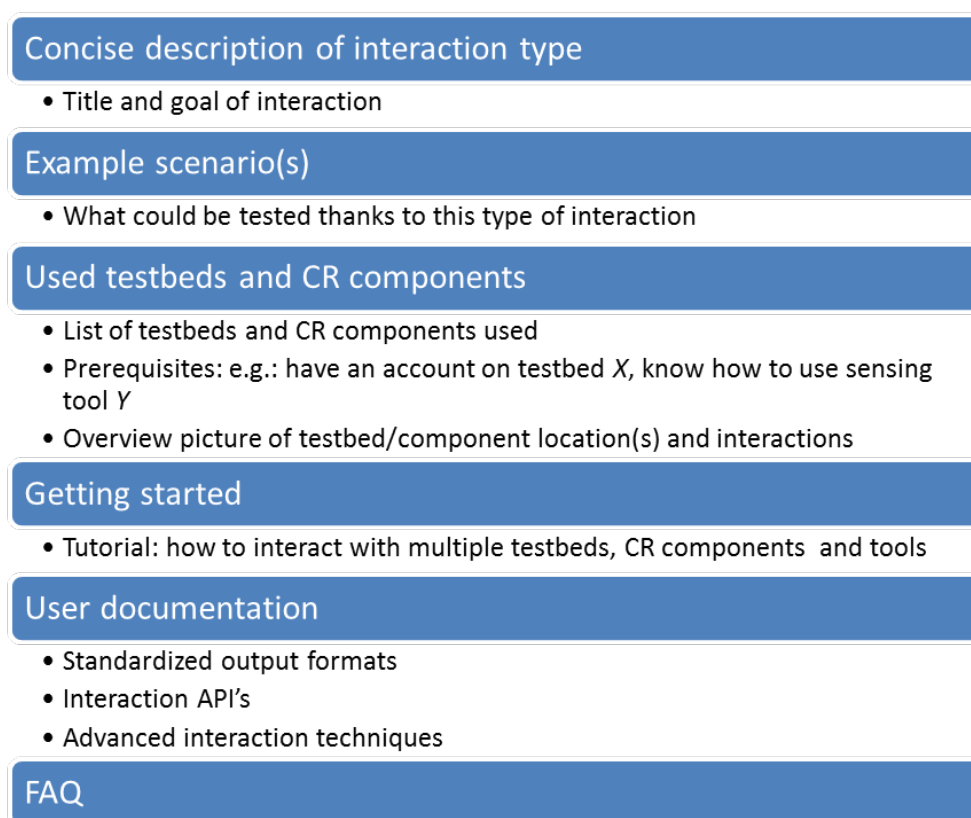


Figure 20 - Basic template for the portal description of testbed and component interactions.

### 3.2.3 Portal implementation and maintenance

The CREW portal will be presented as an extension to the current public CREW website at [www.crew-project.eu](http://www.crew-project.eu). As it is expected that the different cognitive components and testbeds will be continuously enhanced, it will be possible for every partner in the consortium to update the information, after logging in to the portal.

Note that the above paragraphs describe the initial design plans for the CREW portal. While this initial design is expected to lead to a user-friendly way of presenting all information needed to get to know and subsequently access and use the CREW federation, it is not excluded that updates will be made to the portal as to include more functionality, in order to comply with the demands of external experimenters.

Possible extensions to the CREW portal include an interactive forum, or a feature request tool. For an up-to-date overview of portal functionality, the reader can visit [www.crew-project.eu](http://www.crew-project.eu). As soon as the portal is publicly available, this will be clearly indicated on the website.

### 3.3 Testbeds hardware platform interface

The large and diverse set of hardware and software elements that the different testbeds bring together to build the federation, along with the ambitious goal of combining those to enable new functionalities, calls for the usage of a generic or standardized interface to provide a common framework.

An adequate existing interface to address the issues that this goal raises is the Transceiver Facility Specification defined within the Wireless Innovation Forum (WInnF).

From its inception, the SDR concept targets the definition and design of architectures enabling flexible radio platforms able to reconfigure and deploy different waveforms. This is the opposite of hardware radios dedicated to a specific radio access technology and protocol. The traditional SDR architectures, like the SCA, successfully addressed that problem of “reconfigurability” for the upper layers of a protocol stack (typically layer 2 or MAC). The processing performed in those layers is to some extent very similar to general purpose computing, not very platform specific and easily portable among different hardware platforms and processing units. On the other hand and from a historical point of view, RF and signal processing were and are tightly coupled with the available hardware (RF Front-End, signal processing ASICs, FPGAs). Separating hardware-independent features of a signal processing layer is much more difficult and things get worse each step we move closer to the antenna.

The Transceiver Facility Specification proposes a way to cope with this problem by defining a “frontier” in the signal path (from info to airwaves). The frontier is drawn between hardware specific features, “the platform” and the pure “waveform” that contains the radio access technology, the protocol (the standard). Thus the waveform can be ported with minor rework (ideally none) to other “platforms” provided that those offer the right performances and functionalities (such as carrier frequency, band, channelization, amplification). The next figure (extracted from the WInnF official released specification) depicts this frontier.

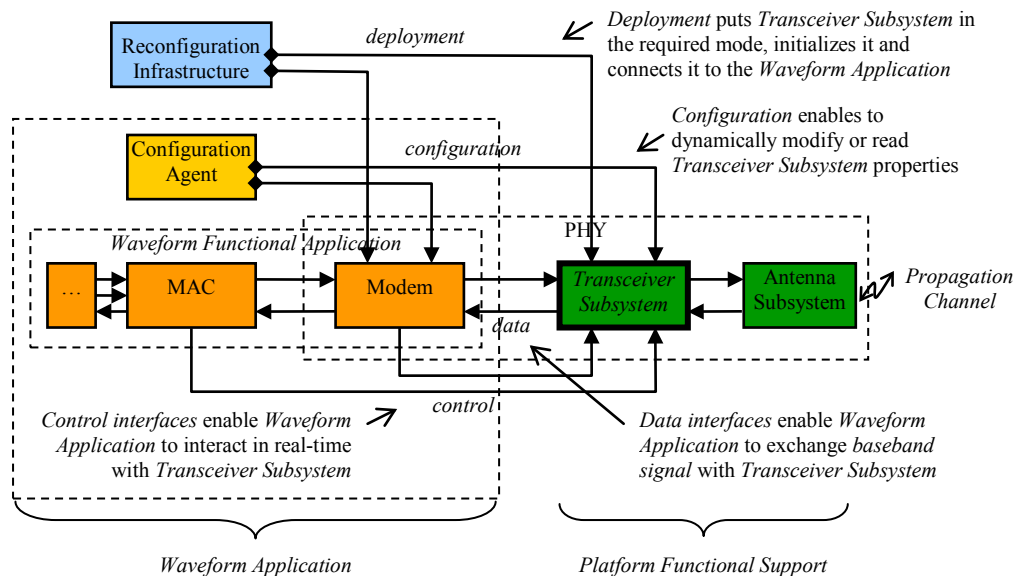


Figure 21: The “frontier” in the signal path between hardware specific features, “the platform” and the pure “waveform” that contains the radio access technology.

The figure represents an overall view of an SDR radio platform. The green boxes refer to the platform elements featuring the functionalities required by the signal path to access the propagation channel. The orange boxes encompass the pure waveform or platform independent processing for the signal path. Blue and yellow boxes are additional support of the SDR platform enabling reconfiguration and that could interface with both platform and waveform. In the figure the concept of Transceiver

Subsystem is highlighted as a functional block “encapsulating” all the platform dependencies and thereby being the sole interface for the waveform and any other additional elements. Note that several types of interfaces are potentially possible among the Transceiver Subsystem and its surrounding environment: data exchange, control and configuration.

Even if the definition of the methods, parameters and functional behavior of these interfaces may be highly waveform-dependent, the WInnF specification undertook the task of defining the interface with the modem (the lowest end of the layer 1 whose dependencies with the hardware may be removed). This is typically the level at which most waveforms access the underlying radio hardware.

The content and details of this interface will be provided in upcoming deliverables (particularly in WP3) together with its application in several selected cases of testbeds elements.

Within CREW the targets with regard to the WInnF specification are twofold:

First, a reference implementation of the current version of the API will be provided. This work will include the design and the implementation of the interface on a widely available COTS platform, the USRP2.

Second, it is expected that this specification could provide the right interface to combine CR elements from different testbeds. The typical example is using this interface between a sensing algorithm from one testbed with a radio platform from another. In order to achieve this goal it is very likely that modifications or extensions to the current version of the Specification document will be needed.

### 3.4 Common Data Collection/Storage Methodology Design

A crucial aspect for experimental research in general, and especially for the case of working with multiple, federated testbeds is to have a common methodology for collecting and storing input and output data. In CREW we address this by creating a storage methodology design, which will define data of interest, common structures for storing data and create a federation database for storage of any input / output data relevant for CREW. The availability of this 'fluid' data will also be of key interest in the benchmarking processes (described in the next section) as it will enable us to compare and contrast the performance of different approaches.

CREW will not necessarily develop its own data structure, but rather we will first explore whether we can adhere to existing standards or extend existing standards. A candidate for the common data format, to be further explored, is the OML framework for measurement collection, which is part of OMF (cOntrol and Management Framework). OMF is an open source Testbed Control, Measurement and Management Framework, which was originally developed for the ORBIT wireless testbed (for more information, the reader can refer to [omf.mytestbed.net](http://omf.mytestbed.net)). For the description of an experiment, the OMF Experiment Description Language (OEDL) could be considered.

Note that there are two main aspects in the CREW storage methodology. The first is to have a common data structure and representation of output data collected from experiments. Such an approach is essential for enabling the comparison and benchmarking of different approaches. It is even more important if the approaches to be compared are implemented and evaluated using different testbeds. Precisely defining the output data to be collected and a common format is the key for efficient benchmarking.

The second aspect is very important for the special federation approach taken by CREW and the special needs of experimental cognitive radio research. A common storage methodology is required to be able to efficiently use output data recorded in one testbed as input data in another testbed. The data will be accompanied by meta-data fully describing the experiment where the data was collected. Consider, e.g., the scenario of recording the spectrum occupancy in the LTE EASY-C testbed in Dresden. Such data can be used, e.g., in the TWIST testbed in Berlin to emulate the spectrum occupancy of a primary user. To enable such re-usage of data, it is crucial to have a common storage methodology and a federation database of recorded traces.

Whenever possible, we will contribute collected data to open repositories. The FP7 project FARAMIR plans to build environmental maps of primary users and the CREW data can potentially contribute to this. There is the potential to also contribute outside the EU to such repositories as CRAWDAD, a Community Resource for Archiving Wireless Data At Dartmouth, in the USA.

The detailed design and implementation of the CREW storage methodology will start in month 6 of the project.

### 3.5 Benchmarking framework

We will create a benchmarking framework for cognitive radio and wireless systems in general, considering the specific limitations and requirements of wireless experimentation. The framework will enable running experiments under controlled and reproducible test conditions, with the extension of offering automated procedures for experiments and performance evaluation. The benchmarking framework will allow a fair comparison between different cognitive radio and cognitive networking concepts or between subsequent developments on a System Under Test (SUT).

#### 3.5.1 What is wireless benchmarking?

We consider wireless benchmarking as the measurement and evaluation of wireless protocols, devices and networks relative to a reference evaluation.

This measurement comprises the primary performance metrics (e.g. application throughput, reliability) of the SUT, but also secondary metrics (e.g. interference, channel occupancy) collected by sensing agents to sufficiently characterize the wireless environment. Additionally, business metrics (e.g. cost, operational complexity) can be combined with the performance metrics.

To avoid confusion with terminology, several terms that are relevant for benchmarking are defined below:

**Comparability** requires that two benchmarks be compared in an objective fashion. This implies that two comparable benchmarks should be partially ordered by a binary relation  $\leq$ . The object of comparison will be the benchmark score(s).

**Repeatability** implies that the same benchmark run twice results in the same score under well determined conditions. This equality however is not strict in wireless benchmarking due to a certain level of indeterminism. For repeatability to apply, acceptable error margins should be formally defined.

**Reproducibility** is an extension on repeatability, where the same benchmark run twice on a different testbed or location should result in the same score. The same error margins on equality apply as in repeatability.

A **benchmark** is a reference evaluation, used to compare measured performance. A benchmark in wireless networks can be considered as a reference to which other wireless systems can be compared.

A **scenario** fully describes a benchmark, and consists out of a definition of the used metrics, the criteria of the evaluation and all the necessary parameters and traces to perform the experiment.

**Criteria** define the focus of a benchmark, and the characteristics to be examined. This will have an impact on the metrics that are used for evaluation, and how they are translated to a benchmark score.

A **metric** is a measure of performance of the SUT or any other entity relevant to the benchmark. Depending on the criteria, metrics can have different importance in a benchmark and can be classified as primary or secondary metrics.

A **primary metric** defines an important impact factor of a benchmark. These are most often the characteristics that directly affect the user.

A **secondary metric** is a performance measure that can impact a primary metric, but is not directly observable by the user. If it is included in the benchmark score it has a lower weight than a primary metric.

A **score** is the collection of potentially weighted metric results used for comparison, possibly aggregated to a single score or a fixed set of scores corresponding to the benchmark criteria.

### 3.5.2 Requirements for CREW benchmarking

Comparability is the most fundamental property of any benchmark: it will ensure that two independently executed benchmarks can be correctly compared to each other. In a wireless environment comparability puts additional requirements on benchmarking

Repeatability is a second cornerstone of benchmarking, defining the limits where the result of a repeated benchmark is considered equal. This is not a trivial requirement for cognitive radio benchmarking due to the fluctuation in the wireless medium and the autonomous aspects of the SUT.

A benchmark should not only be repeatable on a single testbed, but should be reproducible on different testbeds with the same capabilities. This is an extension on repeatability, requiring additional environment and testbed modeling.

Environment monitoring/sensing should define the external influences on the SUT so that an acceptable level of comparability can be achieved.

Common data structures are required to exchange benchmark configuration, metrics and results between partners.

### 3.5.3 A sustainable benchmarking framework

A benchmarking framework is to be created that fulfills the CREW benchmarking requirements, with optional additions of the described enabling factors. Due to the diversity of the different testbeds and cognitive devices the framework should be as generic as possible, but still allow maximal reuse when deployed on different testbeds.

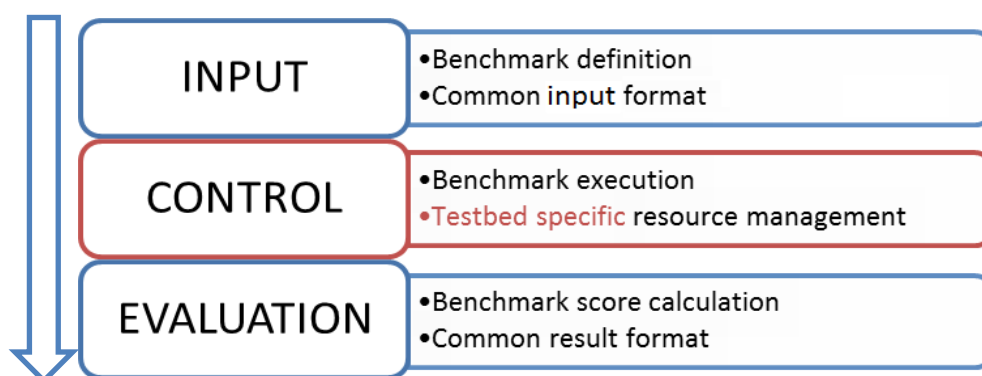


Figure 22: Benchmark framework flow diagram

We propose a workflow consisting out of generic components with a minimum of hardware and testbed specific tools. This will improve uniformity in experiment execution and analysis, together with enhanced comparability. Only parts of the control components should be adapted or rewritten to comply with the specific testbed architectures and tools.

The preceding figure describes the most important components of the benchmarking framework, with 3 types of components:

- Generic: reusable components that should not be adapted to a specific testbed: **scenarios, criteria, parameters, metrics, capability control**;
- Adaptors: interfacing components that help communicating with testbed specific components: **resource descriptors, benchmarking control, common result format**;
- Specific: testbed specific components that are present on most testbeds, but with different interfaces or implementations and capabilities: **resource manager, datastore**.

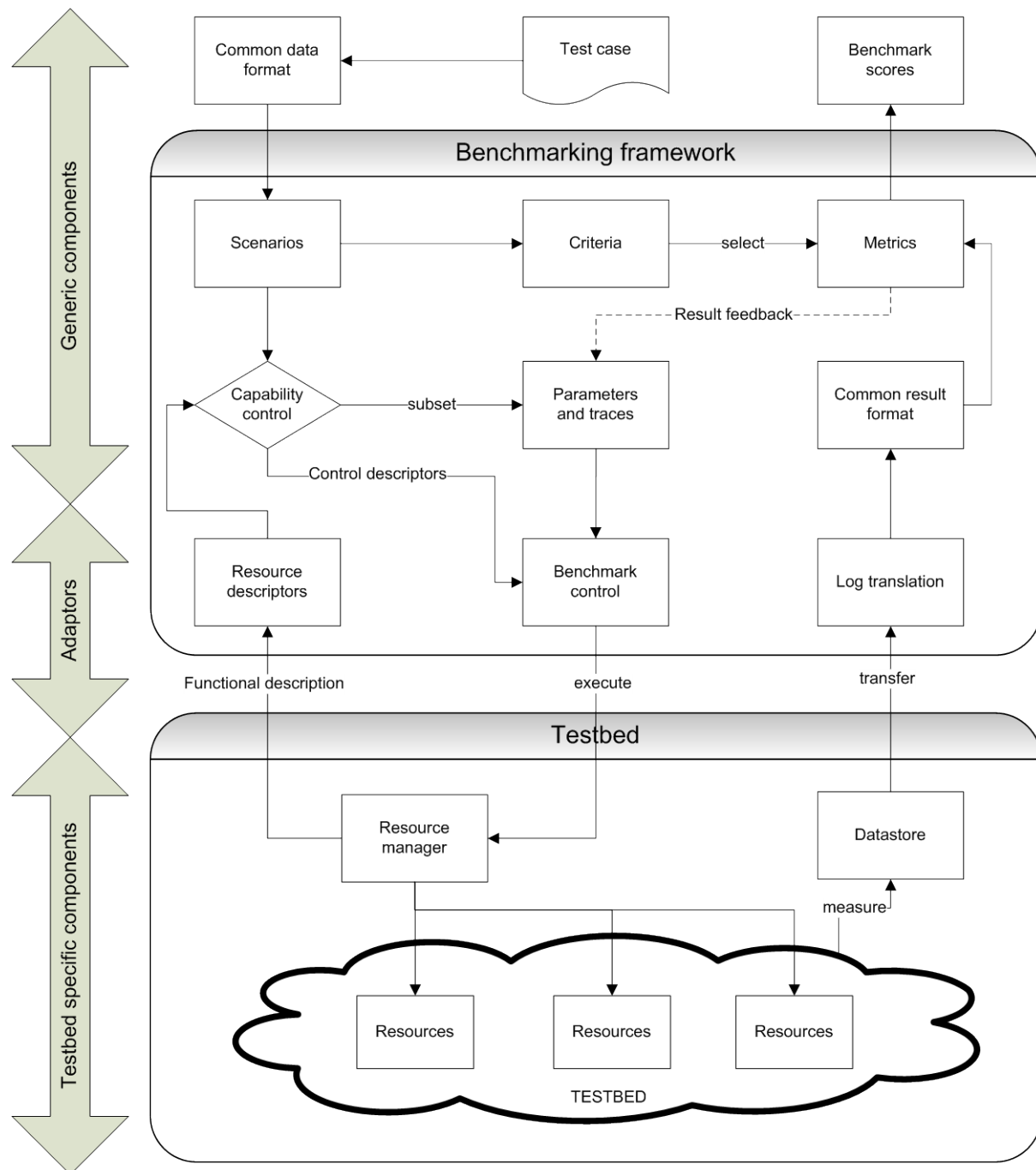


Figure 23: Overview of the benchmarking framework

The benchmark process starts with the **test cases** distilled from the different usage scenarios, where all descriptive elements are inserted in a **common data format** that is a full and sufficient description of the use case on the experiment level.

From this common data format, **scenarios** are distilled automatically that drive the entire benchmarking process. These scenarios define both evaluation **criteria** and the **parameter** space, together with additional **traces** that should be replayed.

Since each testbed has different capabilities and exposed functionality a **capability control** component is integrated that defines a subset of possible benchmarks on the current testbed. The capabilities are defined by a common **resource descriptor** data format, generated from the testbed specific resource manager (or manually defined).



After the subset of **parameters and traces** is defined, different benchmarks are defined in the **benchmark control** module. This module is responsible for executing the different benchmarks on the testbed through a **resource manager** or different management interface, using control methods defined in the **resource descriptors**.

The benchmark results should be stored in a testbed dependent **datastore**, which then can be translated to a **common result format**, still containing all the necessary data to perform the benchmark analysis. The benchmark **criteria** will then define which metrics should be applied as primary and secondary metrics on the benchmark results. Additionally, a result feedback could be implemented on the **parameters and traces**, allowing fully automated benchmarking and intelligent parameter space traversal.

Finally, the metrics are combined in a **benchmark score**, allowing a fair comparison between the Systems Under Test over multiple testbeds.

## 4 Outreach and other connections

The CREW team regularly interacts with research groups operating other cognitive testbeds, for cross-pollination of ideas on cognitive radio experimentation. We also expect research conducted using the facilities of the CREW federation to influence academic and industrial researchers, as well as regulators and standards bodies. Our advisory board provides us one way to disseminate the work to this broader group of stakeholders. This section outlines some of the groups that we expect to reach out to.

### 4.1 Other cognitive radio testbeds

The idea of cognitive radio and cognitive wireless networking exists for several years now and a number of testbeds for cognitive radio experimentation have been deployed in academia. This section lists a selection of the most commonly used cognitive radio platforms and testbed setups used for experimentation. The platforms used in the scope of the CREW project are omitted, since they are explained in detail in this and other deliverables.

#### Cognitive Radio Platforms

Hardware platforms suitable for cognitive radio experimentation are those commonly used for software defined radio, since they provide the required flexibility in frequency, bandwidth and signal shape for dynamic spectrum usage. The following list shows some SDR platforms commonly used in academics for cognitive radio research.

- RICE WARP (Wireless Open Access Research Platform)  
FPGA-based embedded modular platform; operates in 2.4 GHz and 5 GHz ISM bands, bandwidth up to 40 MHz; hardware and software are open source  
(<http://warp.rice.edu>)
- WINLAB WINC2R (Network Centric Cognitive Radio Platform)  
FPGA based embedded platform ; operates in 2.4 GHz and 5 GHz ISM bands, 40 MHz RF bandwidth  
(<http://www.winlab.rutgers.edu/docs/focus/WiNC2R.html>)
- WINLAB GENI CRKit  
FPGA based embedded platform modular platform; different frontend modules for frequency range from 100 MHz to 7.5 GHz, 25 MHz RF bandwidth; open source platform and application framework based on Matlab/Simulink  
(<http://groups.geni.net/geni/wiki/COGRADIO>)
- Lyrtech SFF SDR Development Platform  
FPGA/DSP-based embedded platform with integrated RF frontend; frequency range: 200 to 928 MHz, bandwidth up to 20 MHz; commercially available  
([http://www.lyrtech.com/Products/SFF\\_SDR\\_development\\_platforms.php](http://www.lyrtech.com/Products/SFF_SDR_development_platforms.php))
- CoRTekS (Cognitive Radio test bed using Tektronix Off-the-Shelf Components)  
Test setup based on arbitrary waveform generators, real-time spectrum analyzer and logic analyzer from Tektronix. Cognitive engine implemented using OSSIE open source SCA stack.  
(<http://ossie.wireless.vt.edu/trac/wiki/CORTEKS>)

## Testbed Configurations

Using the aforementioned platforms, testbeds for large scale cognitive radio developments and experimentation have been set up. The following list itemizes some of them.

- **ORBIT (Open Access Research Testbed for Next-Generation Wireless Networks)**  
Large-scale wireless networking testbed for research on next-generation wireless protocols, middleware and applications; located at WINLAB; comprises 400 radio nodes including USRP/USRP2, WARP, WINC2R and low-cost sensor nodes; accessible via web portal; used in US and international research projects;  
(<http://www.orbit-lab.org/>)
- **CORNET (Cognitive Radio Network Testbed)**  
Medium scale physical testbed deployed throughout campus building at Virginia Tech; comprising 48 radio nodes (USRP2 with customized RF daughter boards 100 MHz...4 GHz, 20 MHz bandwidth), MIMO 3TX 5RX; uses GNUradio, OSSIE SDR framework and customized CROSS cognitive radio framework; accessible via web portal;  
([http://wireless.vt.edu/research/Cognitive\\_Radios\\_Networks/](http://wireless.vt.edu/research/Cognitive_Radios_Networks/))
- **emulab**  
Hybrid virtual and physical testbed for emulation and experimentation; uses high-performance servers for network emulation and 802.11a/b/g nodes and USRPs for physical experimentation; located at University of Utah; accessible via web portal; used for experiments worldwide;  
(<http://www.emulab.net/>)
- **WHYNET (Wireless Hybrid Network Testbed)**  
Integration of simulation, emulation and physical components for wireless network experimentation; located at the University of California Los Angeles (UCLA); incorporating 802.11x, 3G cellular and sensor network technology;  
(<http://www.cs.ucla.edu/>)
- **KANSEI**  
located at Ohio State University. Heterogeneous testbed with physical hardware components and simulation for sensor network experimentation; access via director framework; comprises 210 customized static sensor nodes, 50 portable nodes and mobile robot nodes; uses 433 MHz band, 802.11b, 802.15.4;  
(<http://cast.cse.ohio-state.edu/kansei/>)

## 4.2 Standards bodies

The need for standardization in the field of cognitive radio results from the involvement of many different stakeholders, requiring harmonization among various technical, managerial and financial interests. Consequently, there is a need to standardize and harmonize processes, terminology, interfaces, etc. This section itemizes the most important standardization bodies and gives an overview of their particular focuses and activities. Within the CREW project, the activities and releases of the standards bodies will be monitored for alignment with research activities.

### IEEE

With the IEEE 1900 series, the IEEE Standards Coordinating Committee (SCC) 41 on Next Generation Radio and Spectrum Management has initiated a series of standards to harmonize cognitive radio developments. The focus is on an improved use of radio spectrum. The SCC41 comprises 6 working groups with the following scope of activities.

- **IEEE 1900.1**  
Standard definitions and concepts for spectrum management and advanced radio system technologies

- IEEE 1900.2:  
Recommended practice for interference and coexistence analysis
- IEEE 1900.3:  
Standard for assessing the spectrum access behaviour of radio systems employing dynamic spectrum access methods
- IEEE 1900.4:  
Standard for architectural building blocks enabling network-device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks
- IEEE 1900.5:  
Standard on policy language and policy architectures for managing cognitive radio for dynamic spectrum access applications
- IEEE 1900.6:  
Standard on interfaces and data structures for exchanging spectrum sensing information for dynamic spectrum access systems

One outcome of the IEEE activities on cognitive radio is the IEEE 802.22 standard for “Wireless Regional Area Network (WRAN) using White Spaces in the TV Frequency Spectrum”. It standardizes the reuse of unused spectrum allocated to TV broadcast services broadband access while avoiding harmful interference.

## ITU-R

The International Telecommunication Union (ITU) Radio Communication Sector (ITU-R) has the mission to ensure rational, equitable, efficient and economical use of radio-frequency spectrum. The outcome of ITU-R activities is rather recommendations than standards; these are called Radio Regulations (RR). Major ITU-R decisions are made on the “World Radio Conference (WRC)”, taking place every two or three years in order to revise the RR. The most important ITU study groups (SG) related to cognitive radio are SG1 and SG5 with the following activities.

- Study Group 1: Spectrum Management  
Studies on SDR and CR have been initiated at the WRC 2007 for the enabling of these technologies. Results of these studies are expected for the 2012 WRC.
- Study Group 5: Terrestrial Services  
This SG is working on cognitive radio systems in the land mobile service, including their deployment scenarios.

## ETSI RRS TC

The technical committee (TC) on Reconfigurable Radio Systems (RRS) of the European Telecommunications Standards Institute (ETSI) works on standardization of cognitive radio systems on a European basis for white spaces in the UHF band between 470 MHz and 790 MHz. Focus is on the usage of this band for public safety or professional mobile radio (PMR) applications, since these services currently only have very limited frequencies allocated to them and suffer furthermore from incompatibilities between different standards. The usage of SDR and CR is seen as a possibility to solve both of these issues.

## SDR-Forum / Wireless Innovation Forum

The Wireless Innovation Forum (WInnF), formerly known as the SDR Forum, is a non-profit “mutual benefit corporation”, bringing together a broad range of companies and institutes working on SDR and CR. Within the forum, several actions take place to standardize developments and architecture of SDR and CR systems. Examples for such standardization activities are the transceiver interface between radio system and frontend, as well as different activities concerning the Software Communications Architecture (SCA) for SDR systems. The WInnF here collaborates with other standards bodies by exchanging reports, recommendations and specifications.

It is expected that CREW will actively collaborate with the WinnF regarding the Transceiver Facility Specification. CREW will analyse, implement and extend the current version of the interface in order to address the specific requirements that might arise when performing Cognitive Radio experiments with SDR platforms.

### OMG

The Object Management Group (OMG) is an international, open membership non-profit consortium for the computer industry. With the Unified Modelling Language (UML) and the Common Object Request Broker Architecture (CORBA), the OMG specifies important building blocks for reconfigurable radio systems. The OMG closely collaborates with the WinnF.

## 4.3 Regulators

As for the standards bodies, there is a set of radio-frequency regulators responsible for different regions of the world that should be kept in mind when working on cognitive radio systems. Again the alignment of the CREW activities with their regulations and spectrum designations should be observed.

### CEPT / ECC

The **Conférence Européenne des administrations des Postes et Télécommunications** (CEPT) is the European Conference of Postal and Telecommunications Administrations, responsible for policy-making and regulation in the postal and telecommunication field. Formerly it was also responsible for European standardization in the field on telecommunication, but these activities have been transferred to ETSI in 1988. Within CEPT, the Electronics Communications Committee (ECC) is responsible for the development of policies in telecommunications on a European level, aligned with international legislation and regulations. Within Europe, the ECC harmonizes the efficient use of radio spectrum and is responsible for spectrum band designations in Europe, usually based on ITU-R recommendations.

Part of the ECC is the Working Group Spectrum Engineering (WGSE), project team SE43, dealing with the usage of white spaces in the 470 MHz to 790 MHz band for cognitive radio applications. The main focus here is on the coexistence of cognitive radio systems with primary users, which are broadcast systems (BS), program making and special events (PMSE), radio astronomy (RAS) and aeronautical radio navigation systems (ARNS).

### FCC

The Federal Communications Commission (FCC) is the main telecommunications regulations body of the United States of America. Regarding SDR and CR, the FCC has published a set of rules for system implementation. In 2009, the FCC allowed the usage of analogue TV bands between 54 MHz and 806 MHz for cognitive radio communication, with fixed requirements to avoid interference with TV broadcasts. The long-term vision of the FCC is to make the usage of RF spectrum more efficient. SDR and CR radio systems operating in the US also have to be certified by the FCC.

## 5 Alignment with other WPs

### 5.1 WP3: Creating the federation

Deliverable D2.2 provides a road map for WP3, Creating the Federation. Tasks such as the definition of a common portal and the familiarization of each CREW partner with all the testbeds are key in the progression of CREW. Firstly, the establishment of a portal that outlines the testbeds is of great importance in the context of encouraging external research groups to use the facilities made available by the federation. An all-encompassing and thorough description of each testbed, as well as examples of how it may be used, will go a long way towards encouraging others to become more familiar with the federated testbed and to participate in experimentation. The process of creating the portal will also facilitate the various partners becoming familiar with each other's testbed.

Another goal that is focused on in both WP3 and deliverable D2.2 is the creation of an API which caters for the integration of the different testbeds. It is imperative that compatible components be identified and ways of integrating these components be established and explored so that more complex and sophisticated cognitive systems can be constructed. The platforms available to CREW range from software to hardware to combinations of both; so effective interfacing between them is no small task. To facilitate this integration, we will draw on the work done by TCF on SDR XCVR API, which enables generic use of different Radio Platforms and Waveforms or RATs. This work is especially important when considering the possibility of external use of the testbed. If this federated testbed is to be utilized by external researchers then standardization of the interfaces must be a priority.

### 5.2 WP4: Benchmarking the federation

In this deliverable, a high-level description of the CREW benchmarking framework was given. This high-level architecture shows that the creation of a reliable benchmarking framework is a complex task, requiring interaction with several other work packages.

The generic component section of the benchmarking framework includes the “common result format” and “common data format” blocks. The creation of such common data and result formats is part of task 3.3 in WP3, “Common Data Collection/Storage Methodology Design”. The output of this task will thus help to fulfil the comparability requirement.

The actual implementation of the benchmarking framework, including (i) the definition of traffic and interference models (part of the benchmarking scenario), (ii) the actual definition of the benchmarks, and the (iii) methodologies that will enable reproducibility and repeatability of the benchmarks will be tackled in WP4.

From this high-level description, it is also clear that benchmarking of wireless cognitive solutions is a very broad topic. A first task in WP4 is devoted to deriving concrete test configurations from the Usage Scenarios that were previously defined in deliverable D2.1. These test configurations will include the specifications of the network conditions and interference sources.

Finally, in order to enable measurements of the wireless spectrum inside the CREW testbeds, some testbed environments (e.g. the IBBT testbed) will first be extended with hardware developed by other CREW partners. The integration of cognitive hardware and software components is part of WP3, “Creation of the federation”.

## 6 Conclusion

This document has outlined how we define the CREW federation and has discussed how we are creating this federation. The CREW federation definition is based on three modes of operation. The first, individual testbed usage, enables the access to each testbed through a single, common portal. The development of this portal is discussed in section 3.2. The second mode of operation for the federation is CREW heterogeneous testbed usage, which consists of the physical combination of different testbeds to form new platforms with enhanced cognitive properties. The third mode of operation, multiple sequential CREW testbed usage, involves the recording of data from one testbed to be replayed in another.

This document also provides a description of the basic functionality of each testbed, as well as an explanation of how these testbeds can be accessed by external users. It then describes example experiments that could be performed by outside researchers in order to familiarize themselves with the platforms. This deliverable also outlines what usage scenarios are expected to be completed by the end of year one and discusses the role of the federation in completing these goals.

The document also discusses how we will go about interfacing the different pieces of hardware within the testbeds, describes common data collection and storage methodology design, and then outlines how we are going to create a benchmarking framework for cognitive radio and wireless systems in general.

Before we can engage in collaborative experiments that incorporate several testbeds and make these testbeds available for external usage, we must first identify how we can get to the point where the testbeds and the methodology with which they are used are integrated properly. This document provides a roadmap for how the federation will be achieved, by breaking the overall goal into clear achievable steps and executing them correctly.

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