



Cognitive Radio Experimentation World



Project Deliverable D2.3 Definition of Use of the Federation

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Abstract:

This deliverable contains the definition of use of the CREW federation. It is shown how to make beneficial use of the heterogeneous CREW testbeds for cognitive radio and networking experimentation. Three meaningful modes of operation are defined, and it is shown by illustration how to define experiments for each of those modes for each of the five CREW usage scenarios. This deliverable can hence be used as a starting manual in view of the open call. It is also explained how CREW experiments can be defined beyond the open call.

Keywords:

network testbeds, federation, wireless networks, cognitive radio, cognitive network, use of a federated testbed

Executive Summary

Cognitive radio and networking solutions promise to solve at least part of the spectrum scarcity problem. Many techniques have been and are being proposed to achieve such cognitive radio and networking operation, and they all claim to take advantage of the complex, dynamic and varying environment in a smarter, or more cognitive way. To allow for a thorough validation of these concepts, experimental validation of cognitive radio and networking techniques remains, however, important. Such experiments differ from traditional wireless networking solutions in the flexibility and configurability of the testbeds, and the dynamics and variability of the wireless environments. Through the federation of the CREW cognitive radio testbeds and components, each originating from existing European testbeds, the CREW project aims to enable advanced experimental research in the area of cognitive radios.

How to make use of the CREW federated testbed in order to achieve a meaningful experimental validation of cognitive radio and networking concepts is explained in this deliverable. As such, this deliverable can be used as a manual for the definition of CREW experiments, or at least it can be used to get an initial view on the different modes or ways to make use of the CREW federated testbed. Details about each of the individual testbeds, usage scenarios, cognitive components, the common data format and the benchmarking framework are not given here and can be found back in the deliverables of the respective workpackages.

We define the use of the CREW federation based on its three modes of operation.

- **Individual CREW testbed usage** enables access to each CREW testbed individually. This usage mode can leverage on the CREW federation high level objectives and tools, such as benchmarking framework or common data format.
- 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. This usage mode can leverage on the CREW federation high level objectives and tools.
- Multiple **sequential** CREW testbed usage involves the recording of **data/behaviours** from one CREW testbed to then be replayed in another. This usage mode can leverage on the CREW federation high level objectives and tools.

Examples are given for each of the CREW usage scenarios, explaining how to use the CREW federated testbed in each of the modes.

This deliverable then also details different ways to define a CREW experiment:

- Definition through an open call
- Definition for unfunded use of the infrastructure
- Definition of a self-sustained CREW experiment

It is explained what is meant by each of these approaches, and how to proceed in defining them.

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
BTS	Base Transceiver Station
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
CP	Cyclic Prefix
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	<i>Institute of Electrical and Electronics Engineers</i>
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: CREW: redefining the use of a federated testbed for the wireless domain

Cognitive radio and networking solutions promise to solve at least part of the spectrum scarcity problem. Many techniques have been and are being proposed to achieve such cognitive radio and networking operation, and they all claim to take advantage of the complex, dynamic and varying environment in a smarter, or more cognitive way. To allow for a thorough validation of these concepts, experimental validation of cognitive radio and networking techniques remains, however, important. Such experiments differ from traditional wireless networking solutions in the flexibility and configurability of the testbeds, and the dynamics and variability of the wireless environments. Through the federation of the CREW cognitive radio testbeds and components, each from existing European testbeds, the CREW project aims to enable advanced experimental research in the area of cognitive radios.

How to make use of the CREW federated testbed in order to achieve a meaningful experimental validation of cognitive radio and networking concepts is explained in this deliverable. As such, this deliverable can be used as a manual for the definition of CREW experiments, or at least can be used to get an initial view on the different modes or ways to make use of the CREW federated testbed. Details about each of the individual testbeds, usage scenarios, cognitive components, common data format and benchmarking framework are not given here and can be found back in the deliverables of the respective workpackages.

The remainder of this section is organised as follows. First, we define the use of the CREW federated testbed following three modes of operation. Then, the five usage scenarios are quickly revisited, but more information can be found in D2.1. Finally, in Section 1.3, a decision tree is introduced that can be used for each usage scenario, to select an appropriate mode of operation. In each mode of operation, it remains then still necessary to construct the experiment using cognitive components, common data formats and following the benchmarking framework, which are experiment ingredients that can be used in each usage mode. Examples are then given in Section 2 of this document.

1.1 Redefining the use of a wireless testbed: the CREW use

Federating a wireless testbed is because of the nature of wireless communication very specific. The CREW federated testbed consists of a set of experimentation islands that are very heterogeneous in terms of capabilities, size and environment. There are different ways in which this **heterogeneity can be exploited to enable cognitive radio and networking experimentation**:

- Heterogeneity is needed to **benchmark** a single cognitive radio or networking technique in **varying environments**, using the benchmarking framework in parallel with multiple **single testbed experiments**.
- The heterogeneity of the different testbeds is sometimes also **complementary**. In this case, the cognitive components of the different testbeds can be combined, into a **larger and more capable heterogeneous testbed**.
- The heterogeneity of different wireless signals and environments allows sometimes a **complementary sequential use**. In this case, information that is collected in one testbed is used to enrich the complex environment of another testbed. **Emulators** are used in the second testbed that emulate the behaviour, required to be repeated without actually physically relocating the first testbed. This is a special usage mode that requires the use of emulators and environment definitions, which can be re-played using those emulators.

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

- **Individual CREW testbed usage** enables access to each CREW testbed individually. This usage mode can leverage on the CREW federation high level objectives and tools to facilitate the use:

- Selection of the testbeds can happen through the CREW common **portal**. This is the most meaningful CREW federation tool for this usage mode.
- Comparisons of the results of different individual testbed experiments can happen through the **benchmarking framework**.
- **Common data format** can be used to store the results of the experiments for future reference.
- 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. This usage mode can leverage on the CREW federation high level objectives and tools to facilitate the use:
 - Selection of the testbeds and components to merge can happen through the CREW **common portal**.
 - Comparison of the enhanced cognitive experiment with earlier possibly more limited experiments can happen through the **benchmarking framework**.
 - **Common data format** can be used to store the results of the experiments for future reference.
- Multiple **sequential** CREW testbed usage involves the recording of **data/behaviours** from one CREW testbed to then be replayed in another. This usage mode can leverage on the CREW federation high level objectives and tools to facilitate the use:
 - Selection of the testbeds for sequential use can happen through the CREW common **portal**.
 - Comparisons of the results can happen through the **benchmarking framework**.
 - **Common data format** can be used to store the results of the experiments for future reference. This is the most meaningful CREW federation tool for this usage mode.

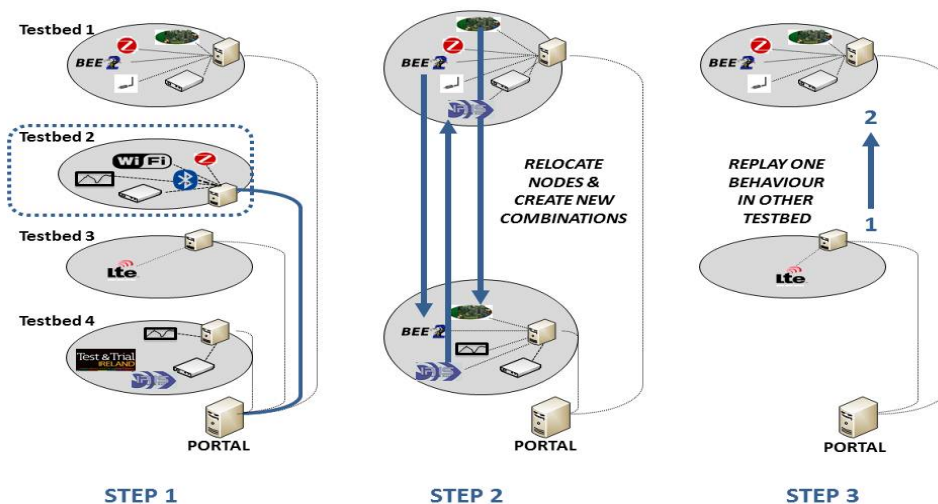


Figure 1: Federation modes of usage

1.2 Redefining cognitive experiments: the CREW usage scenarios

In Figure 2 an overview is given of the five CREW usage scenarios. We use these usage scenarios that were defined in D2.1, to structure the remainder of this document. Experimenters can use the example experiments worked out in this deliverable to define alternative usage scenarios, possibly filling the gaps in the usage matrix of Figure 2, or proposing alternative use cases for usage scenarios that are worked out within the CREW consortium.

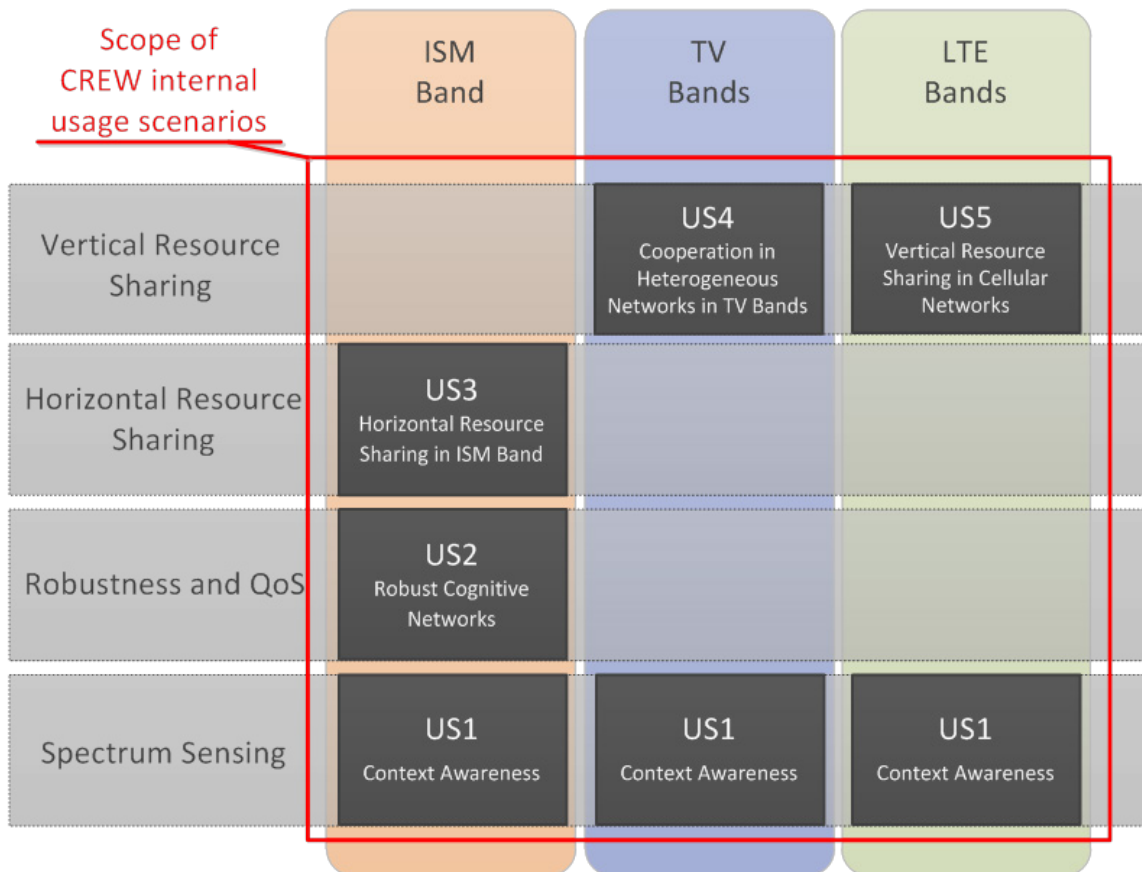


Figure 2: The Internal Usage Scenarios are used to structure this document. They are of exemplary nature and cover only a subset of many possible combinations of CR applications and frequency bands.

1.3 Structure of this document

In chapter 2 of this report, use cases will be described for the five CREW usage scenarios. For each use case, a possible mode of use of the CREW federated testbed is selected. These modes can be selected, following the decision tree detailed below. If a usage mode of the CREW federation is then selected, the experiment can be defined, possibly using some of the high level objectives or tools of the CREW federation. Example definitions are given in Section 2 of this document, for the five CREW usage scenarios.

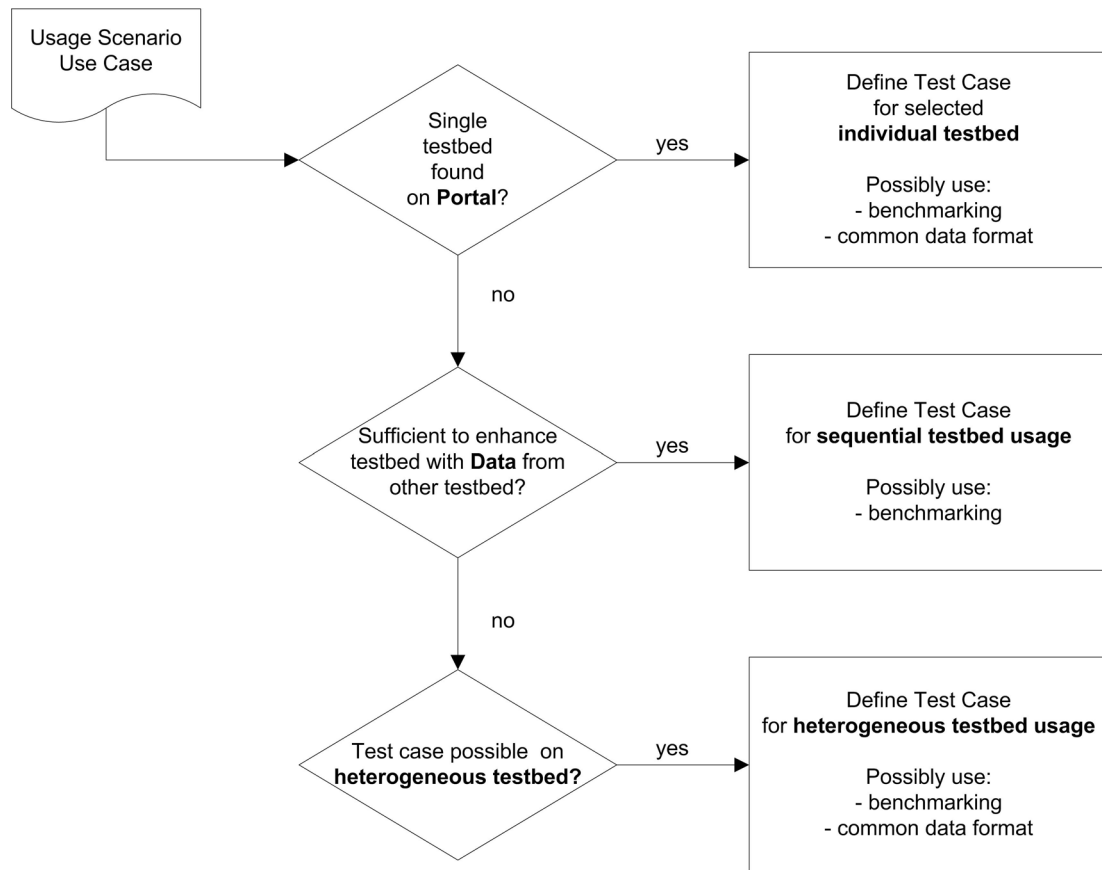


Figure 3: Selecting the use mode of the CREW federation for a given use case.

2 Use of the CREW federation

2.1 US1 – Context Awareness for Cognitive Networking

For this usage scenario, several use cases have been defined in D2.1.

A first use case focuses on comparing several solutions for spectrum sensing in the 2.4 GHz ISM band. Since this use case specifically aims at comparing the performance of the hardware and sensing algorithms of different testbeds, this use case has to be defined through a heterogeneous testbed use. The test case is defined in Section 2.1.2.

A second use case focuses on testing the sensitivity of sensing solutions for the TV bands. This use case aims at experimental validation of a single sensing solution and can hence be implemented by means of a single testbed usage, as illustrated in Section 2.1.1 for an example test case definition.

A third use case focuses on sensing of LTE signals. For that, it is sufficient to replay LTE signals in the TCF testbed, which is a sequential testbed usage, as defined in Section 2.1.3.

2.1.1 Individual testbed usage through the portal

2.1.1.1 Use case 1.2: Sensing performance of DVB-T algorithm

Context awareness in the TV White Spaces should be able to detect the presence of a primary user, or TV transmitter, with a very high reliability. Moreover, the required sensitivity should be low, up to -114 dBm or lower. As a result, a lot of research focuses on proposing algorithms for feature detection of TV signals that can detect the presence of these signals at very low SNR levels. A very relevant use case in the context of cognitive radio is hence the experimental validation of the performance of these classes of algorithms. Such experiments are possible within the CREW federated testbed.

2.1.1.2 Individual testbed usage

The imec testbed is equipped with a sensing agent that can tune to the DVB-T bands and can run algorithms to detect features of DVB-T signals. This testbed has also sufficient equipment to transmit DVB-T signals over the air or over a coaxial cable towards the sensing agent. As a result, when characterizing the performance of the implemented DVB-T feature detection algorithm, it is sufficient to use the imec testbed or sensing engine. This information can be found on the portal.

When presenting the sensing results, it is possible to use the common data format defined by CREW. For instance, for sensing results, ROC curves are used as the most appropriate way to represent sensing results. This allows for comparison with possible future solutions and experiments.

2.1.1.3 Heterogeneous CREW testbed usage

2.1.1.4 Use case 1.1: Comparison of sensing solutions in 2.4 GHz ISM band

Many different types of devices coexist in the 2.4 GHz ISM band. All these solutions rely on their own listen-before-talk etiquette. Also, hardware solutions of different cost and quality can be found in this frequency band. To better understand the coexistence problems in an ISM band, one can start by comparing the quality of the context awareness of all these different solutions. Such a use case can be implemented on the CREW federated testbed.

2.1.1.5 Heterogeneous testbed usage

Since the objective of the experiment is to compare the performance of various hardware solutions, it is possible to achieve a more thorough comparison or enhanced experiment by combining the hardware components found in the different testbeds. As a result, to implement a test case for this use case, one should rely on a heterogeneous testbed usage.

Once the different hardware components are brought together, one can then still decide to do a wireless or a cable measurement or test. This decision is part of the benchmarking framework, where repeatability is an important aspect. When repeatability is required, a cable experiment is most appropriate.

When comparing the performance of different solutions for context awareness in the ISM band, it is important to define a good common data format so that the experiments can be compared. Such a comparison was already presented in [1] [2], based on the ROC common data format that was selected for comparisons of sensing solutions,

2.1.2 Sequential CREW testbed usage

In this section, we first motivate the usage scenario and detail the use case, in addition to the information that was already given in D2.1. In this section, we are focusing on the “LTE metrology tool for network planning” case. This corresponds to the use case US13 “Reliable sensing of cellular systems”. The use of the CREW federation in a sequential mode is explained in section 2.1.3.3.

2.1.2.1 Use case 1.3: Reliable sensing of cellular systems

The multi-antenna sensing platform allows downlink interference analysis of LTE cellular wireless networks. Uplink interference analysis is not provided. Interference analysis consists in determining the list of the received signals on a LTE channel, with their physical characteristics and in identifying the stations which are transmitting these signals.

Interference analysis is based on the smart antenna technology, using an antenna array. When this antenna array receives several sources, emitted by different base stations, the multi-antenna processing consists in recombining the signals received by the different antennas in order to detect and demodulate each received source - the other received sources are considered as interference that the processing allows to reject.

The detection allows determining the LTE BTS characteristics such as Physical layer cell identity, Cyclic Prefix (CP) length, Duplex mode, BTS level and E_c/I_0 , Time channel impulse response and Frequency channel impulse response. The LTE sensing platform can be used by an operator to process all these information using GIS monitoring, either to optimize its network, or to complain to the regulator about interference, as described in Figure 4. Thanks to smart antenna technology and to high level functions, the multi-antenna LTE sensing is able to solve more accurately every intra-system interference situation. It is able to detect and identify interfering LTE base stations with E_c/I_0 as low as -20 dB, which allows to detect all interfering LTE base stations having a significant impact on the overall network performance.

Co-channel interference is due to frequency reuse and can never be completely avoided in cellular systems. In this context, the multi-antenna sensing platform can aid network operators in validating their LTE network planning and in analyzing the interference situation in areas where problems occur.

Several scenarios were simulated according to the location of the sensing device in the LTE network (close to a BTS, at the intersection of two cells, at the intersection of three cells) and the relative received power from the surrounding BTS. These scenarios and the obtained performance are described in details in D6.1.

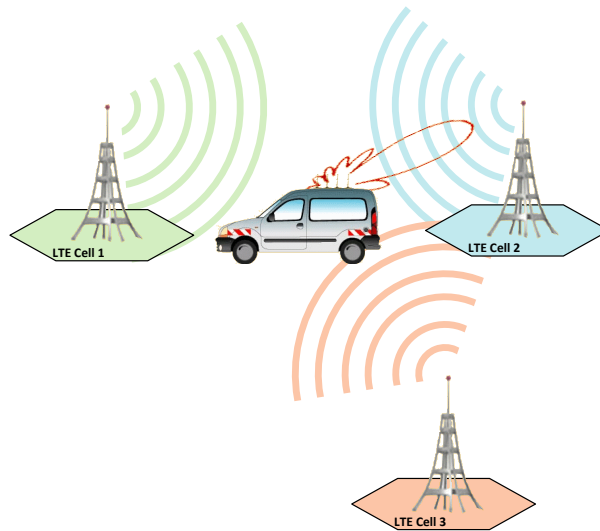


Figure 4 : Principle of interference analysis based on smart antennas processing

2.1.2.2 Sequential testbed usage

The “LTE test-bed reference signal generator” from TUD allows generating and storing LTE signals into data files. It also allows adjusting the parameters of the PHY layer, such as the bandwidth, the physical layer cell identity, the cyclic prefix length, the scrambling, etc.

During Dresden meeting, an LTE signals database was built using the TUD “LTE test-bed reference signal generator”. These signals are perfect (no noise, no propagation channel, no interference, no frequency offset). Their purpose is to check the good understanding of the LTE standard and to validate the algorithms in perfect environment.

These signal files were then used as inputs to the multi-antenna simulator as shown in Figure 5. Indeed, they correspond to the inputs of the TCF spatial propagation channel simulator described in D3.1. The characteristics of each spatial propagation channel can be adjusted (multi-path, fading, direction of arrival). Then, the signals are combined with relative power and white Gaussian noise is added. Finally, the signal is filtered by the reception filtered and ready to be processed for algorithm performance evaluation. The goal is to validate the detection algorithm in a more realistic, but known environment. The advantages of the multi-antenna approach are proven in simulation results in D6.1.

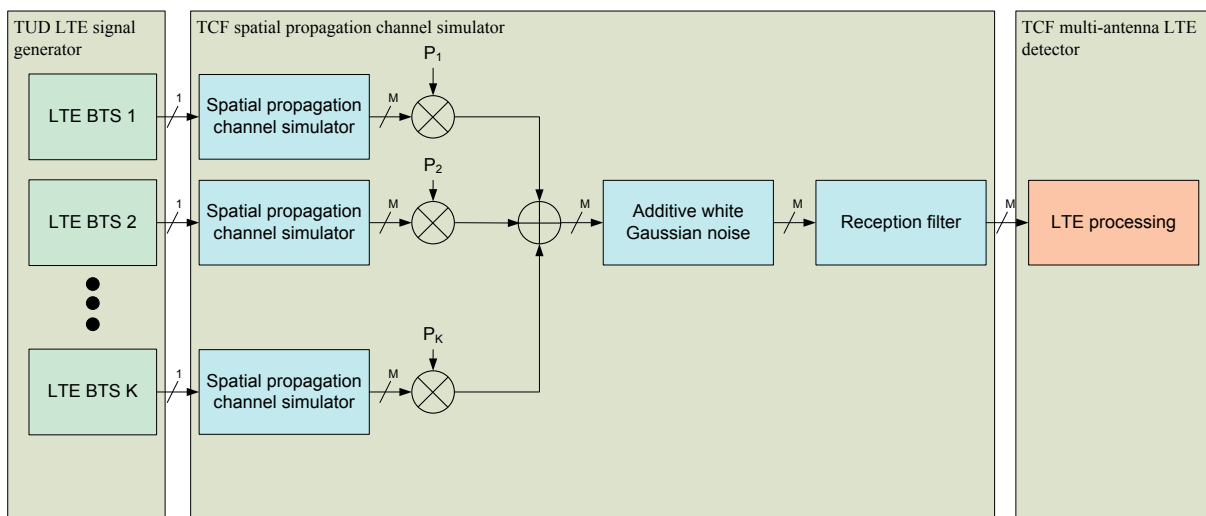


Figure 5 : Multi-antenna simulation environment

2.2 US2 – Robust Cognitive Networks

To illustrate the possibilities of the three different CREW usage modes for the robust cognitive networks usage scenario, we focus on the “Robust cognitive body area networks (CBAN)” use case as defined in D2.1. The goal of this use case is to make the CBAN communication robust by cognitively enabling the CBAN.

2.2.1 Individual testbed usage through the portal

Considered as an example is the CBAN setup, based on the shimmer nodes available in the TUB testbed. An experimenter can use this setup in conjunction with the TWIST testbed available at TUB (which can be either used as an infrastructure sensing network or as an interfering network or both). Additionally, low-cost WiSpy spectrum analyzers, a high precision Rhode & Schwarz spectrum analyser and a signal generator are available within the TUB testbed. All this information can be found on the CREW portal, which also points the experimenter to additional information on the individual components.

2.2.2 Heterogeneous CREW testbed usage

There are several ways how to extend the above example and how to make use of a heterogeneous CREW testbed. In this document, we exemplarily describe two possibilities. For both of them, the experimenter wishes to test its setup in different interference environments.

One solution to achieve this is to use devices from the other CREW testbeds and bring them to the TUB testbed for the experiments. The experimenter could use the iris devices from TCD to generate (additional) interference environments or could make use of the USRPs available in the IBBT testbed.

Another way of testing the CBAN setup in different interference environments is to move the CBAN setup to another testbed. The experimenter could, e.g. perform the same experiments in the IBBT testbed, which can generate various home / office environment interference scenarios.

2.2.3 Sequential CREW testbed usage

An example for sequential CREW testbed usage is for the case, that the experimenter is more interested in the protocols of the CBAN and not so much in the spectrum monitoring / detection of interference. For such a scenario, an experimenter could record some desired interference environments in an arbitrary testbed, e.g., the IBBT testbed. The recorded interference traces can then be used to emulate this interference environment in the CBAN network. Instead of using the sensing capabilities of the CBAN nodes, the experimenter would emulate the channel availability via a control channel using the information from the recorded traces. For such a scenario, it is important to minimize the (uncontrolled) interference during the experiment since it could significantly temper the results.

2.3 US3 – Horizontal Resource Sharing in ISM bands

2.3.1 Individual testbed usage through the portal

Suppose an experimenter is interested in developing a cognitive sensor networking solution in the 2.4 GHz ISM band. The sensor networking solution might, for example, organize sensor nodes in a multi-hop network using a specific frequency hopping technique that avoids interference caused by other devices in the environment, such as Wi-Fi devices.

While the experimenter is looking for an infrastructure on which to build his solutions, he stumbles upon the CREW portal. On the CREW portal, the user selects [Browse by name], to find an overview of the different components that are available in the CREW infrastructure together with a concise description. By using the filter functionality implemented on the portal (cf. Figure 6), the experimenter is able to narrow down the full list of components so that it e.g. only displays testbeds operating in the 2.4 GHz ISM band, with ZigBee interfaces.

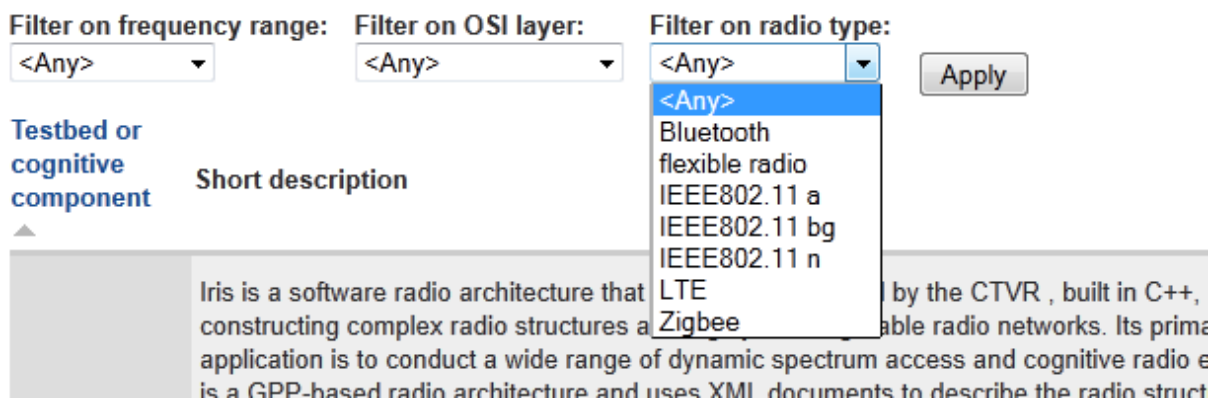


Figure 6 - detail of the page showing a list of testbeds on the portal. The full list of CREW testbeds and components can be narrowed down by using filtering functionality.

In the case of the above filtering operation, the experimenter will receive a shortlist of testbeds, limited to the TWIST (Berlin) and w-iLab.t (Ghent) testbeds. When adding another filter, requiring the presence of IEEE802.11 a/bg interfaces, the list is limited to the w-iLab.t. After reading through the concise description, the user decides to go for the w-iLab.t testbed and clicks through to the reference manual of the testbed, which is embedded in the portal (cf. Figure 7).

w-iLab.t documentation

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The sections contain an overview of all information needed to get you started using the w-iLab.t. If you are new to the testbed, the tutorials are a good place to start.

- [Introduction to w-iLab.t: overview of capabilities](#)
- ▶ [Getting started: tutorials](#)
- ▶ [Hardware and testbed lay-out](#)
- ▶ [Using the hardware: tools, interfaces, services](#)
- [Developer documentation](#)
- [FAQ](#)

[◀ System health monitoring](#)
up
[Introduction to w-iLab.t: overview of capabilities ▶](#)

Figure 7 - detail of the CREW portal, showing the index of the w-iLab.t reference manual

In this reference manual, the experimenter finds all information needed to execute his experiment, including how to get an account and how to access the network, reserve and program nodes in the testbed, collect, process and visualise results.

2.3.2 Heterogeneous CREW testbed usage

After his initial experiments, the experimenter from the above example might find that sensor nodes and Wi-Fi nodes alone are not enough for his experiment: suppose that the experimenter needs to have an accurate view on the 2.4 GHz ISM spectrum during his experiment, in order to quantify the impact of the developed coexistence protocol.

On the portal, the user dives deeper into the documentation of the w-iLab.t, and finds that multiple imec sensing agents are integrated in the w-iLab.t. For his initial experiments, the user uses the default settings of the imec sensing agent. As such, he is able to use the visualisation and logging

capabilities available in the w-iLab.t testbed without any need to reprogram the imec sensing engine, nor extend the functionality of the wireless testbed.

Some weeks later, the experimenter might want to adjust the behaviour of the imec sensing agent. Therefore, he again checks the portal and now consults the reference manual of the sensing agent. His changes to the configuration of the sensing engine will then be made on the devices that are embedded in the w-iLab.t since after all, the main target of this user is still to enhance the coexistence of devices in the ISM band.

2.3.3 Sequential CREW testbed usage

Consider again the user in the above example. After running a first selection of experiments in the w-iLab.t, while monitoring the spectrum usage with the imec sensing agent, the experimenter is interested to see how his now fully tested cognitive sensing solution behaves when deploying the sensor solution at another location.

Therefore, the user now deploys his sensor solution at the TWIST testbed in Berlin.

The user now generates a second set of experimentation results, gathered in a different environment. The results gathered at the different solution can easily be compared, since the experimenter logged his results according to the CREW common data format.

2.4 US4 – Cooperation in Heterogeneous Networks in Licensed Bands

2.4.1 Individual testbed usage through the portal

Within this usage scenario there are three ways in which experimentation and testing, using an individual testbed alone, can be performed. These are:

- Sensing only experiments. This is the testing of sensing hardware and algorithms to sense licensed band signals. This is also a strong constituent of US1 (Section 2.1).
- Testing within unlicensed bands of protocols/concepts designed/intended for use in licensed bands. The flexibility and reconfigurability of the Iris testbed makes testing of future licensed band protocols/concepts relatively accessible. This testing could include investigations into such concepts as transmission relaying, database-based environmental awareness implementations, and use of learning to predict future environment usage, among many others.
- Live network implementation testing within licensed bands involving both transmission and reception. Certain network implementations of this sort are made implementable through the use of a Test and Trial license, obtainable from the Iris communications regulator ComReg.

The CREW portal provides details of the required procedure for performing such experiments through use of the portal. Details on this usage scenario can be found within the portal either following links for either the Iris or LTE Advanced testbeds or through filtering for the desired frequency range.

2.4.2 Heterogeneous CREW testbed usage

In the case that the experimenter requires higher power or bandwidth than is provided by the URSP frontend, the use of the LTE Advanced platform in Dresden could provide the ideal transmission, allowing the experimenter to perform experiments such as the “detect and avoid” experiment (use case 4.3) on a larger scale.

Another example of heterogeneous testbed usage in the same use case (4.1), where the experimenter decides that the sensing capabilities afforded by the USRP are not sufficiently precise and then sees that it is possible to use the imec advanced sensing agent as it has been integrated with the Iris software radio in the form of a simple database that both platforms have access to. This then allows the experiment to employ much more advanced spectrum sensing techniques to achieve its goals.

At the moment, the integration of the imec and Iris platforms is at its preliminary stages, whereby the two platforms communicate through a mutually available database. To streamline this integration, there are plans to integrate the RF frontend of the imec platform with the Iris software in a similar way which iris was integrated with the USRP. This would allow the two platforms to perform integrated experiments in a more streamlined and comprehensive fashion.

2.4.3 Sequential CREW testbed usage

Sequential CREW testbed usage is enabled in the Iris testbed by both the Rohde and Schwarz FSVR Real-time spectrum analyser, as well as the Anritsu MG3700A vector signal generator. Together, these can be used to record wireless signals within the network, and transmit recordings from other testbeds, respectively. Additionally, the flexibility of Iris and USRP can enable the emulation of signals from certain technologies, which would be open for the external testbed user to implement if they so wished.

2.5 US5 – Cognitive Systems and Cellular Networks

2.5.1 Individual testbed usage through the portal

Suppose an experimenter is interested in cognitive PHY layer experiments with a cellular primary system present. The experimenter visits the CREW website and in the overview figure of the CREW facilities appears, he obtains the information that the Dresden testbed island offers LTE functionality. By further studying the information available on the portal, the user is provided with the information whom to contact for gaining access to the testbed. Next, the experimenter can read the complete documentation for a description of the available hardware, tools and a basic tutorial, and if the testbed satisfies the needs, correspondence via email is initiated. Further details regarding access can be discussed directly with the operator of the testbed.

Although individual use of the LTE Advanced testbed is feasible to study the behaviour of a primary cellular system, the strength of the facility lies in cognitive radio experiments that employ heterogeneous and sequential use.

2.5.2 Heterogeneous testbed usage

Multi-antenna LTE sensing: LTE detection performance can be highly increased by using antenna-array and antenna processing algorithms. In particular the interference rejection capabilities are of great interest for LTE incumbent user detection in a CR system. This corresponds to the use case US51 “Impact of cognitive networking on a cellular primary system”.

Use case description: LTE detection with interference rejection capabilities can be useful for sensing in CR as presented in Figure 8. This scenario can be described in three phases:

- Phase 1: A mobile opportunistic Rx is located in a white space. It finds the band B_0 free and uses it. It has to check periodically if an incumbent system does not want to use B_0 .
- Phase 2: The mobile opportunistic Rx has moved and is no longer in the white space. On B_0 , it now receives the signal from the incumbent LTE Tx. The opportunistic system is not aware of the presence of the incumbent Tx yet and is still communicating. For the opportunistic Rx, the signal coming from the incumbent Tx is seen as an interference
- Phase 3: The opportunistic Rx is performing sensing on B_0 . The goal of this phase is to detect the incumbent Tx. The signal coming from the incumbent LTE Tx is now the signal of interest (signal to be detected) and the signal from the opportunistic Tx, the interference (it is jamming the sensing process). Usually, in this kind of process quiet periods are allocated in the opportunistic system waveform, in order to perform sensing without being jammed by its own system. But sensing can also be performed at the same time than data transfer, which is called **parallel sensing**. If the opportunistic Rx has interference rejection capabilities thanks to the use of antenna-array and antenna processing, it can perform sensing even if the opportunistic

Tx is emitting, and it still is able to detect the incumbent Tx. As we will see in the following, this is true even if the received signal level from the opportunistic Tx is much higher than the one from the incumbent Tx.

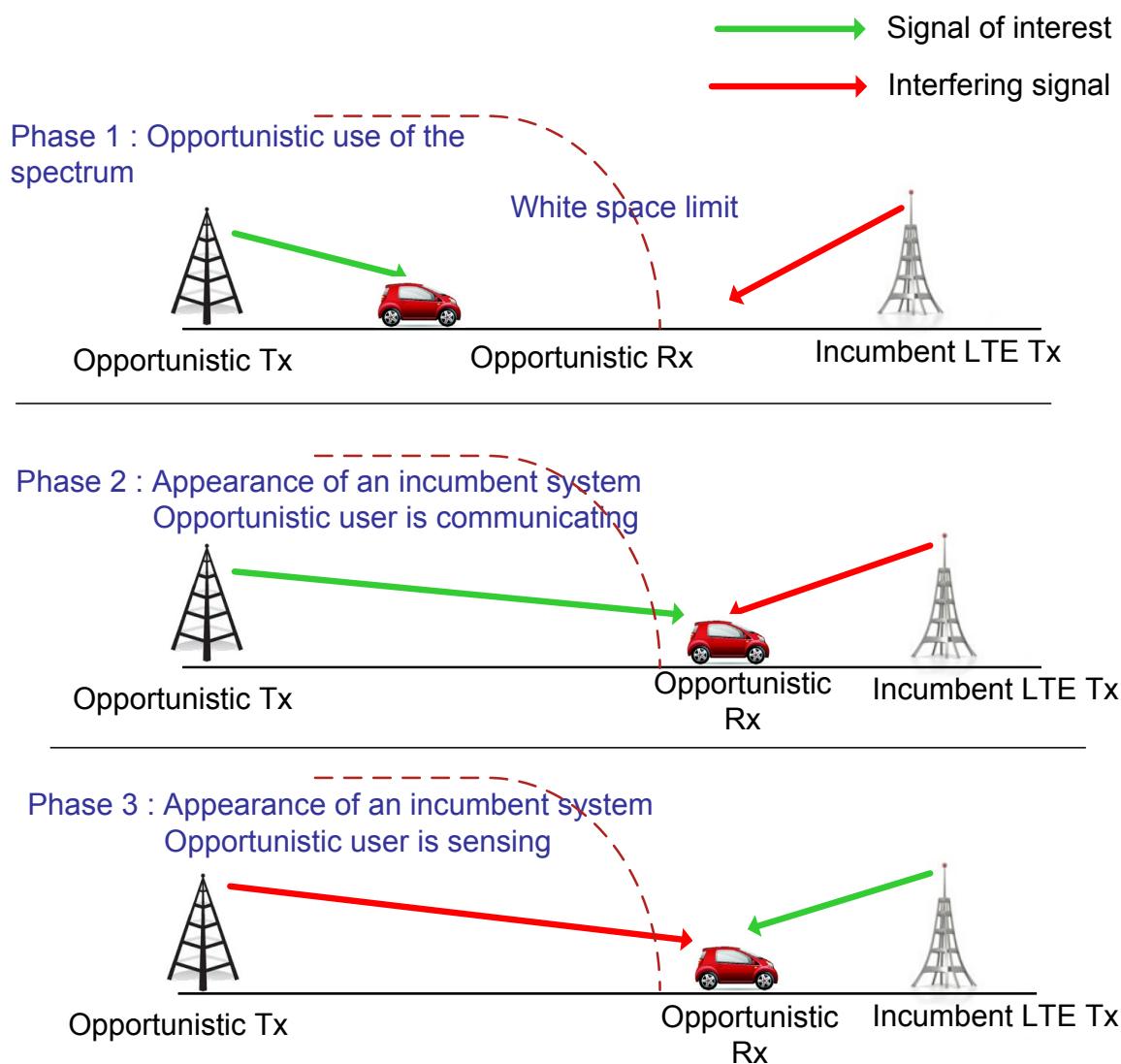


Figure 8 : Scenario for sensing with interference rejection in CR

CREW testbed usage: Both TUD LTE platform and TCF multi-antenna LTE sensing device can be very useful to validate and estimate the performance of such a use case. Indeed, they can be used for lab test as described in Figure 9. During these lab tests, the LTE BTS is used to generate real time downlink LTE signal. A wideband signal generator is used to generate an interfering signal. Using splitters, coupling modules and sets of cables with adapted lengths, the platform can simulate multi-sensor mono-path propagation channel with two different direction of arrival (one for the useful LTE BTS and the other one for the interfering signal).

Varying the level of both signal generators, one can deduce detection performance in terms of sensitivity and interference rejection capabilities.

At this time, these lab tests were not performed yet. They will be performed during year 2 of the project.

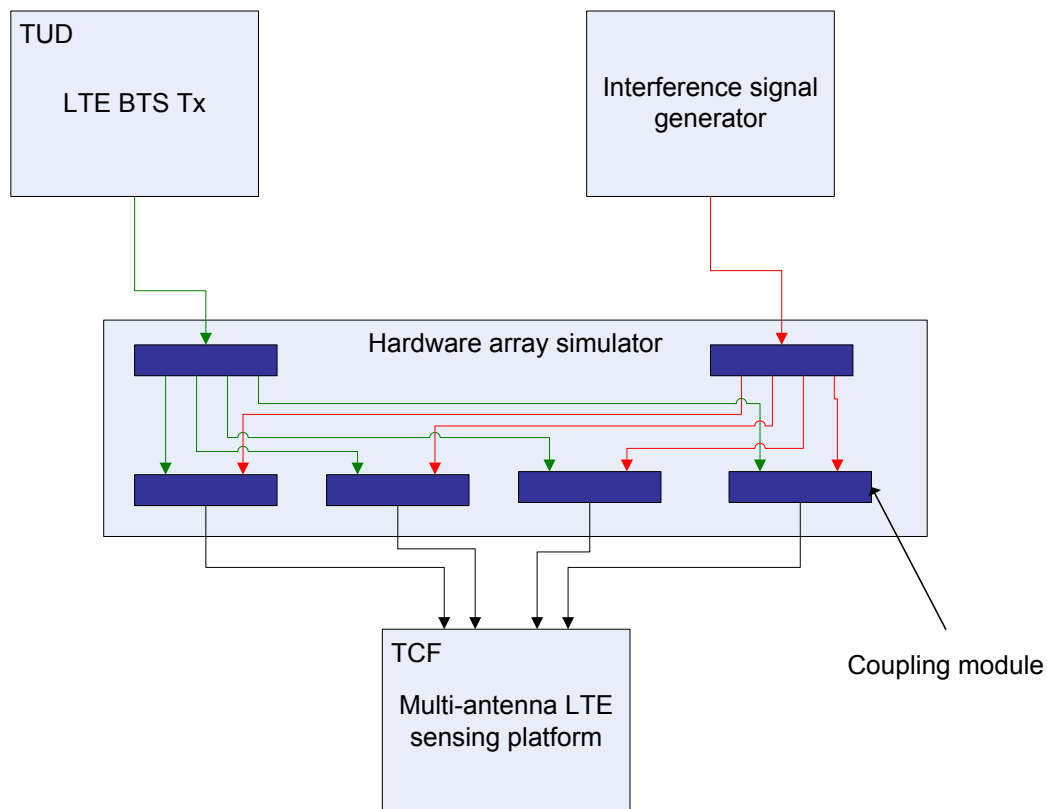


Figure 9 : Heterogeneous testbed usage for LTE sensing

2.5.3 Sequential testbed usage

Multi-antenna LTE sensing: A previously recorded LTE reference signal database, as well as testbed signal dumps obtained from real transmissions and stored in the common data format can be used as input to offline simulations as described in detail in section 2.1.2.2 and on Figure 5, without the need to physically relocate hardware.

It is important to underline that in this case, the interfering signal is a non-LTE signal that is therefore not generated by the LTE Advanced platform.

3 Defining a CREW experiment

There are fundamentally three options to define a CREW experiment. The first and most obvious is through the first and second open call. In this case, the open call guidelines should be followed. This is discussed in Section 3.1. A second option is the definition of an unfunded use of the infrastructure, which is possible for smaller experiments provided the testbed owner sees the clear benefit. This is discussed in Section 3.2. Finally, definition of a CREW experiment that is self-sustainable can be considered. This use of the federation is most relevant for the two final years of the project and will be defined in Section 3.3.

3.1 Definition through an open call

This option to define a CREW experiment is most relevant as an early use of the CREW platform. Since the CREW federation is still under development, initial experiments are promoted and funded via open calls. Experimenters receive funding for using the CREW federation and for giving feedback to further improve the CREW platform. Experimenters can also actively participate in extensions to the testbed (e.g. more advanced experimentation tools, novel cognitive components), as they become temporary partners of the CREW project. More information on how to define a CREW experiment for the first open call can be found on the CREW portal [3].

3.2 Definition for unfunded use of the infrastructure

Experimenters, not funded via CREW open call, have free access to the CREW platform and receive the necessary support from the CREW consortium. In return they provide feedback on the user experience. This option for defining a CREW experiment is more relevant for smaller experiments or exploratory use. It is not sustainable for the CREW partners to allow these kinds of experiments on a larger scale.

3.3 Definition of an self-sustained CREW experiment

A self-sustained CREW experiment is a CREW experiment performed by an academic institution, research center or industry that leverages on the investments made by the CREW consortium in setting up the federated testbed. Experimenters make use of the CREW facilities and pay for the use of the CREW infrastructure and necessary support. The budget for the use of the CREW facilities comes from external funding that is found by the external experimenter (e.g. FP7 projects, other European research projects, academic research projects, industrial collaborative projects, etc.). The price setting and policies for use of the CREW facilities will be defined in WP8 (Task 2). The use of the CREW federation should evolve from early use through the open calls to established and self-sustained use.

There are multiple possible ways to implement the use of the CREW federation and attract external funding to help sustaining the CREW federated testbed:

- A first option that one could imagine is that a company discusses a contract with the CREW consortium in order to develop, debug, or tune its cognitive solution on the CREW testbed. However, in the short time, it is not expected that many companies will pay for using the CREW facilities, since advanced cognitive radio solutions are not expected to conquer the markets tomorrow, but are still requiring some longer term research. In any case, the portal will provide interested companies with information on the available cognitive components and will direct them to contacts which can help them further in discussing the contracts.
- A second option, which is more likely in the short term, is that a company funds a bilateral project with one of the CREW partners or with the CREW consortium, to investigate a specific topic of interest together with the testbed and cognitive component owners.
- A third, and most likely option, is that the CREW consortium or partners of the CREW consortium are invited to join a research project by a different consortium of academic and

industrial partners. This way, the new project could become a user of the CREW project, thus paying for the use of the CREW facilities using external research budgets.

4 Conclusions

In this deliverable the use of the CREW federation is discussed. First, it is argued why a combination of heterogeneous wireless testbeds is needed to strengthen cognitive radio and networking experiments. Several modes to combine the testbeds are discussed: individual use with benchmarking, sequential use and heterogeneous use. Then, examples are given for meaningful CREW experiments that use these modes for each of the five CREW usage scenarios. Finally, it is detailed how CREW experiments can be set up: through one of the open calls, unfunded use for small experiments and self-sustained CREW experiments. This deliverable hence gives a first comprehensive overview of ways to use the CREW federation, and how to define experiments that make use of it. For more detailed information, we refer to the CREW portal ^[4].

5 References

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