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CorteXlab: A Large Scale Testbed for Physical Layer in Cognitive Radio Networks

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Abstract

With the profusion of low cost wireless platforms, such as the Ettus family of Software Defined Radios (SDR), experimentation in wireless research became a reality. Such platforms have allowed many ideas to become a reality, providing researchers a never before possible way to demonstrate the feasibility of their concepts. Nevertheless, such platforms are usually limited to a few at a time, since they become very hard to handle in larger quantities without a proper underlying infrastructure. This fact, unfortunately, limits the kind and scale of techniques that can be implemented and demonstrated. In this work we introduce the CorteXlab testbed, a large scale testbed comprised of heterogeneous platform nodes able to deal with distributed physical layer design and cognitive radio. We present its capabilities and limitations, and survey some target state-of-the-art techniques that can be implemented within.

1 Introduction

Physical layer radio research and design has until now been limited by the ability to test the designed techniques in *real* propagation environments. Until now, models have been refined to provide a good simulation representativity of propagation conditions. While this is still a valid design paradigm, providing extreme testing cases or stable conditions required for reproducibility, it still lacks in dynamic realism with respect to real propagation channels. Furthermore, all the characteristics inherent to the Radio Frequency (RF) chain itself bound to disturb the operation of a new design, are usually ignored in radio simulations.

The ability to test the designed techniques, once a privilege of big companies, is now in the hands of anyone, with the profusion of low cost wireless platforms, based on a highly reconfigurable digital part (known as Software Defined Radio platforms) such as the Ettus family of SDRs. Now, researchers can close the research and development loop, demonstrating the feasibility of their creations. SDR platforms are very tempting when it comes to testing new waveforms, codes or modulation schemes or any promising digital signal processing technique. However, to enable the test of advanced radio techniques such as wideband sensing, white space reuse, fractional bandwidth or multi-mode operations, the digital processing capabilities have to be associated to a flexible RF. Not all SDR platforms can tune the RF frequency in a wide range to cover a large set of existing or future standards. Moreover, an important issue to test enhanced wireless systems is the ability to dynamically (and quickly) reconfigure not only the central frequency, but also additional parameters such as channel bandwidth, emitted power and dynamic range.

Taking the experimentation capability provided by platforms to a larger scale, the so-called *testbeds* consist of multiple platforms grouped into a network. Testbeds allow the experimentation of systemic aspects of designed techniques, such as protocol stacks, resource management and network optimization. Nowadays testbeds are usually confined to Media Access Control (MAC) and above layers, such as [?] or [?], but Physical (PHY) layer testbeds are starting to arise, such as [?] and [?]. Considering the state of the art in SDR based testbeds, one key issue is the ability to consider large scale heterogeneous networks. Indeed, interoperability of radio access networks is on the forefront of the required techniques for future generation wireless systems.

The COgnitive Radio Testbed EXperimentation Lab (*CorteXlab*), part of the Future Internet of Things (FIT) project aims at deploying heterogeneous radio nodes to allow test and proof-of-concept of future wireless digital communications, software radio and inter-networking techniques. Such heterogeneous nodes open possibilities unavailable in currently deployed platforms, such as emulating heterogeneous, primary-secondary cognitive networks, coexistence techniques and cooperative networks. Last but not least, can also be used to perform single-system tests.

In this paper, we first summarize other existing testbeds in the community in Section **??**, and then we establish the link between CorteXlab and the FIT project in Section **??**. We then detail the ongoing process of designing the CorteXlab testbed, in Sections **??**, **??** and **??**, where the its specificities are emphasized (shielded room, heterogeneous nodes, highly flexible RF). Then we develop some examples of particular scenarios that we want to address with this new tool, for Ad-Hoc or structured networks in Section **??**. As this development is an ongoing work, in Section **??** we draw in conclusion the perspectives of this future open testbed.

2 Existing Testbeds Overview

Large-scale cognitive radio test-beds are mandatory to develop and evaluate the performance of upcoming PHY/MAC layers and future cognitive radio algorithms. Whereas numerous test-beds are available in the field of wireless communication, only a few large-scale test-beds have been developed in the SDR and CR field.

One has to distinguish fixed PHY layer wireless test-bed from cognitive radio test-beds. For instance, Europe's OneLab experimental facility, based at UPMC in Paris, has pioneered the federation of test-beds from both domains, allowing experiments that extend from edge devices in the NITOS wireless test-bed to PlanetLab Europe test-bed servers connected to the core wired Internet. Other important initiative are developed within the Global Environment for Network Innovations (GENI), which aims at building a unique virtual laboratory performing research on new possibilities of the future internet. These initiatives might mix wired and wireless communications, in which the wireless interfaces are immutable. An example of a well known of such platforms is Orbit test-bed at Rutgers' University Winlab [?] or Inria SensLab platform (`http://www.senslab.info/`) [?].

Cognitive radio experiments cannot be performed on these platforms because their wireless communication protocol PHY layers are fixed. Some attempts have been made to provide more advanced configurable radio possibilities such as the CREW (`http://www.crew-project.eu/`) or TRIAL (`http://www.tekes.fi/programmes/trial`) projects in Europe. The main target of the Cognitive Radio Experimentation World FP7 project (CREW) is to establish an open federated test platform, which facilitates experimentally-driven research on advanced spectrum sensing, cognitive radio and cognitive networking strategies in view of horizontal and vertical spectrum sharing in licensed and unlicensed bands. The CREW platform integrates five small individual wireless test-beds each with their own diverse wireless technology (heterogeneous ISM, heterogeneous licensed, cellular, wireless sensor, heterogeneous outdoor). At the time of writing, these platforms were only available for project members. The TRIAL Environment for Cognitive Radio and Networks program is a starting project aiming to develop a unique trial environment for cognitive radio and networks in Finland.

In the US, two important initiatives can be identified: CORNET platform from Virginia Tech [?] and the Wireless Networking Research Test-bed at University of California, Riverside (WRNT). The Virginia Tech CORNET test-bed is composed of 48 USRPs v.2 with custom RF front-ends which have been dispatched in the ceilings of a building, spanning 4 floors. Registered users can remotely program and run experiments on the USRPs. Nodes can be programmed using the OSSIE framework [?] also developed at Virginia Tech. The UCR Wireless Networking Research Test-bed was recently updated with 50 802.11a/b/g nodes, 8 802.11n nodes, 6 WARP boards and 15 USRPs, it supports Multiple-Input Multiple-Output (MIMO) communications [?]. Currently these test-beds are not deployed in an electromagnetic protected environment. Moreover, the programmability of the physical layer is not easy because the platforms have not been conceived with that objective. Detailed in the following section, the *CorteXlab* platform should provide features not available in these test-beds.

3 FIT and CorteXlab

FIT aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. It will provide this facility with a set of complementary components that enable experimentation on innovative services for academic and industrial users. The project will give french internet stakeholders a means to experiment on mobile wireless communications at the network and application layers thereby accelerating the design of advanced networking technologies for the future internet. FIT is one of 52 winning projects from the first wave of the French Ministry of Higher Education and Research's "Équipements d'Excellence" (Equipex) research grant programme.

FIT will be composed of four main parts: a Network Operations Center (NOC), a set of Embedded Communicating Object (ECO) testbeds, a set of wireless OneLab testbeds, and a cognitive radio testbed (CorteXlab). The NOC is a strategic component of FIT as it provides a means to aggregate all individual testbeds into a single shared resource as viewed by the user. It associates and manages activities such as the sign-up and maintenance of user accounts. The NOC also serves as a central point of coordination among testbed administrators. The ECO testbeds are based on the idea that the world is moving towards an "Internet of Things", in which most communication over networks will be between objects rather than people. The OneLab testbeds come from the fact that data communications take place in a combination of wired and wireless environments, and will continue to do so in the future.

Finally, CorteXlab (FITs Cognitive Radio component) will foster significant scientific progress by allowing users to design, benchmark, and tune their cognitive radio protocols. It will enable evaluation of different aspects of cognitive radio in a real environment. It will foster developing application-driven research aimed at validating some promising theoretical concepts. Compared to the other FITs testbeds and to other existing testbeds, CorteXlab will offer several particularities in order to address complex and evolved scenarios of next generation networks. The first point is that CorteXlab will be composed of a mix of radio nodes. Some simple Wireless Sensor Network (WSN) nodes with low capacity (SensLAB nodes), some Single-Input Single-Output (SISO) SDR nodes, and some MIMO SDR nodes will coexist in the same testbed.

Another important point is that all SDR nodes (SISO or MIMO) will present a high level of RF flexibility, enabling to easily tune the operating frequency, the channel bandwidth, the emitted power and of course the waveform used to communicate. Last but not least, the testbed will be installed in a large (see details in next subsection) shielded room (therefore isolated from any external interference) also partly covered with EM absorbing foams. Depending on the wide set of enabled frequencies, the design of the room will enable to control the radio channel characteristics (number of paths, delays, etc) and to ensure a high level of reproducibility of experimentations.

4 CorteXlab's Experimentation Room

CorteXlab will be composed of nodes uniformly distributed in a room of (approximately) 12 m by 19 m, isolated from outside interference by a layer of Electromagnetic (EM) isolation material and properly insulated against excessive reflexions. These nodes will be able to accept PHY layer implementations on both hardware, i.e. Field Programmable Gate Array (FPGA), and software and will be capable of outputing performance metrics, such as rates, Bit Error Rate (BER) and power consumption.

An overview of the room disposition can be seen in figure **??**. The SDR nodes will be disposed on a uniform grid, with an average same-node distance of about 2.4 m. The WSN nodes, on the other hand, will have an average same-node distance of about 1.7 m. The different kinds of nodes are placed in different positions to maximize signal diversity and minimize adjacent band and circuit coupling interference. The nodes are interconnected through a high speed ethernet link, in order to allow for cooperation and sharing of information. A unified server will also be available for starting, coordinating and collecting the results of experimentations. The experimentation themselves can be from PHY layer up, including the possibility of cross-layer interactions. Alongside these nodes, two equipments will be in the room: a configurable vector signal generator used to emulate legacy systems, and a vector spectrum analyzer to collect and analyze the signals in the room.

5 CorteXlab's Platforms

CorteXlab will support some target platform key features such as real-time communication using classical standards such as 802.11 and Zigbee, MIMO, wide band RF front-end and programmability of the PHY and MAC layers. According to these needs, the selected platform must possess some key features such as a General Purpose Processor (GPP) associated to a Digital Signal Processor (DSP) and/or a FPGA. A target platform structure is as seen in Fig. **??**, where we can identify a gateway, the digital processing part and an RF frontend. The Gateway is responsible for node management and experiment control defined by a middleware.

Example of candidate platforms are:

- Lyrtech Perseus 610x + Radio 420 FMC;
- Ettus USRP N210 with the SBX Daughterboard;
- Datasoft Thunder with the Monsoon RF;
- Rice Univ. WARP FPGA Board v2 with the WARP Radio Board;
- and the Eurecom OpenAir Interface, Express MIMO + Agile RF).

6 CorteXlab's Infrastructure

CorteXlab's infrastructure is the backbone of the testbed, and as such, has a direct impact on the testbed capabilities. Thus, its design will have to match several requirements set by research exploitation and federation with FIT. In order to narrow down these requirements, a great deal of effort has been put into testbed usage scenarios design.

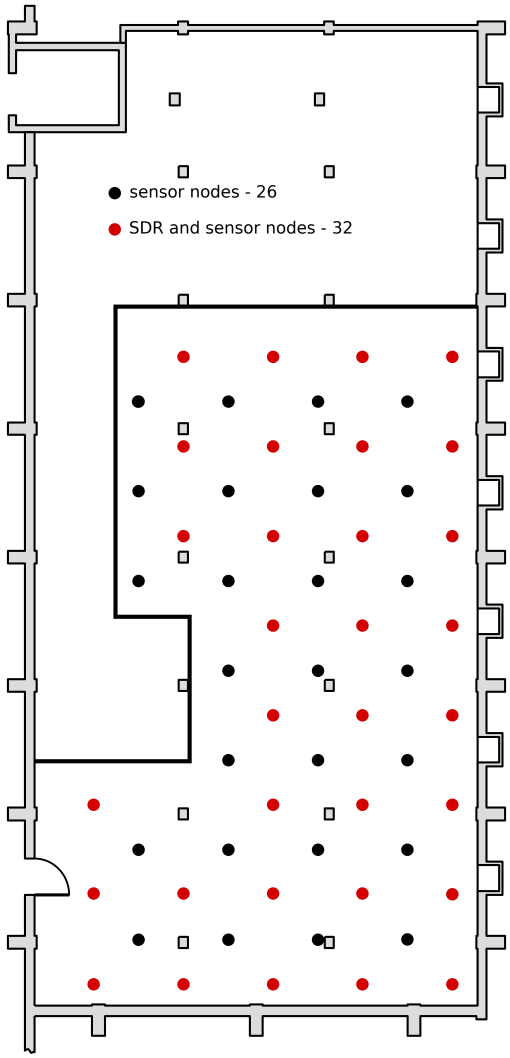


Figure 1: Experimentation room, with node locations.

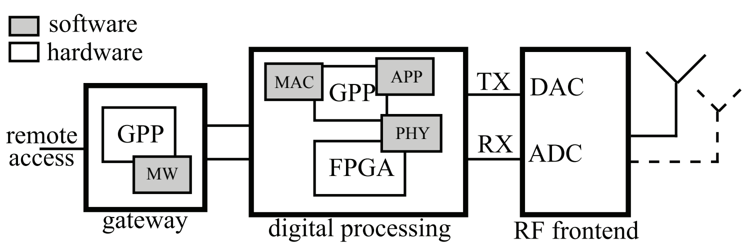


Figure 2: Experimentation room, with node locations.

Each SDR node will be provided with two independant 1Gbps ethernet links. This should offer the possibility of emulating a backbone network or running SON scenarios while controlling and feeding data to the nodes through the network. Moreover, the testbed network will be scaled to withstand such throughputs from many SDR and WSN nodes at the same time allowing large scale scenarios. For instance, the backbone of the testbed linking the servers to the experimentation room (i.e. the nodes) will be a dual 10Gbps optical fiber link.

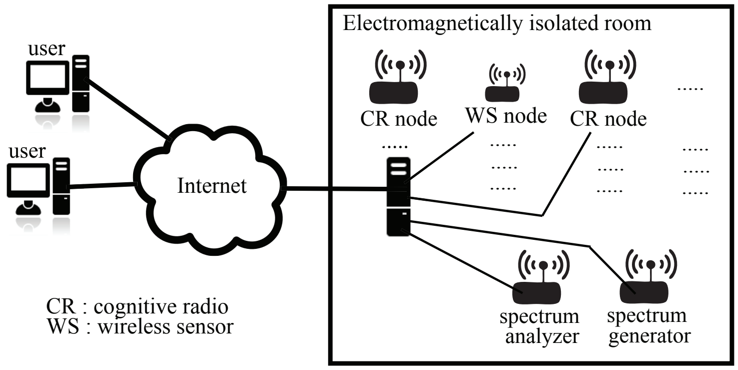


Figure 3: Experimentation room, with node locations.

Depending on the experimentation scenarios that will be implemented into the testbed, the network will have to convey different types of network streams. So far, experimentation scenarios chosen to be implemented in the testbed should not imply throughput needs higher than 4 Gbps at the network core, considering a node population of 50 to 60 elements in the experimentation room. However, meeting higher needs to run more demanding (though appealing) scenarios would be too expensive on the server side for now. Indeed, getting disk arrays for fast and reliable data throughputs is fairly expensive. Still, thanks to the network capacity margins left, higher demanding scenarios might be implemented in future versions of the testbed through simple server upgrades.

7 Envisioned Experimentation Scenarios

In CorteXlab, SDR and WSN nodes can be used together or separately to emulate the main architectures studied in the literature. The uniform disposition of nodes allows several different radio topologies to be deployed by simple selection of nodes and transmit power limitation. By means of a configuration interface, available to the user through a remote access web interface, such a disposition of nodes can be set to properly model several kinds of wireless system architectures as described in the following.

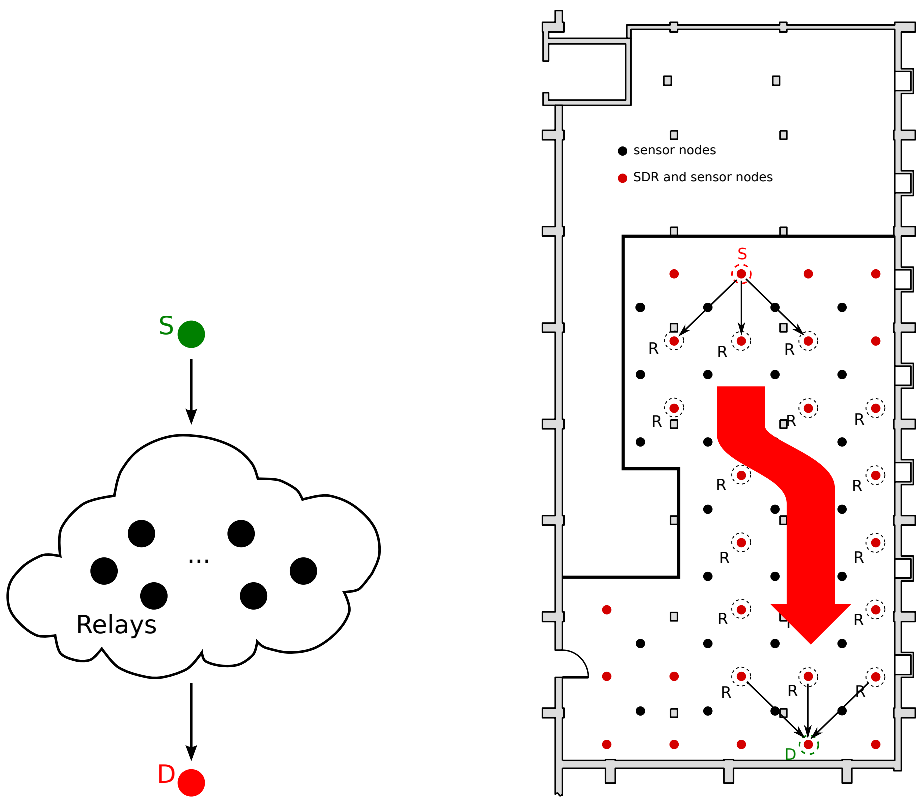
In this section we make a non-comprehensive selection of target scenarios which are particularly feasible with CorteXlab.

7.1 Ad-hoc Networks

The ad-hoc (or mesh) architecture does not rely on the use of existing fixed infrastructure, but rather on the nodes themselves to transmit, relay and route information. Works in ad-hoc networks traditionally focused in the MAC layer, but new concepts, such as network coding [?], bring interesting new study aspects to the PHY layer of these networks. CorteXlab will be able to address state-of-the-art techniques for ad-hoc networks, such as (but not limited to) PHY layer network coding and distributed computing for sensor networks.

To implement an ad-hoc structure, CorteXlab makes use of the uniform grid structure with reduced power transmissions, in order to limit their range to the desired amount of neighboring nodes. The idea is that a node can only broadcast to nodes in its vicinity, thereby motivating the need for relaying and/or routing mechanisms. The WSN or SDR nodes can be used to implement the ad-hoc nodes, depending on the kind of technique to be emulated. Any node (or even multiple nodes) in the testbed can be seen as the connection point to the internet, behaving as a source or sink of information to the testbed as a whole.

As an example of an ad-hoc network technique that can be addressed using CorteXlab, consider the PHY layer network coding, where a source S wants to transmit information to a destination D through a network of relays R, seen in Fig. **??** along with a candidate room deployment in Fig. **??**. In this tentative example, the nodes to be used are selected (highlighted by a dashed circle) while the remainder of the nodes are disabled. The candidate PHY layer techniques are uploaded via ethernet to the nodes a priori, and each node is configured as a source, destination or relay. Techniques such as Amplify and Forward (AF) [**?**], Decode (Compute) and Forward (DF) [**?**] can be therefore easily tested. Advanced PHY layer reconfigurability also allow to address issues common to this kind of networks, such as synchronization and power consumption. Note that the optimal way to address this kind of scenarios remains unknown in the academia, and is in the forefront of the research efforts.



(a) Ad-hoc PHY layer network coding

(b) Room deployment

Figure 4: Ad-hoc in CorteXlab.

7.2 Structured Networks

On structured networks, a prevalence of a hierarchical infrastructure devices are adopted, offloading important tasks such as routing and the overall organization of the network operation, from of the end-user nodes. Out of the many structured network state-of-the-art techniques that CorteXlab should be able to address are cognitive radio network techniques, Network MIMO and radio resource management.

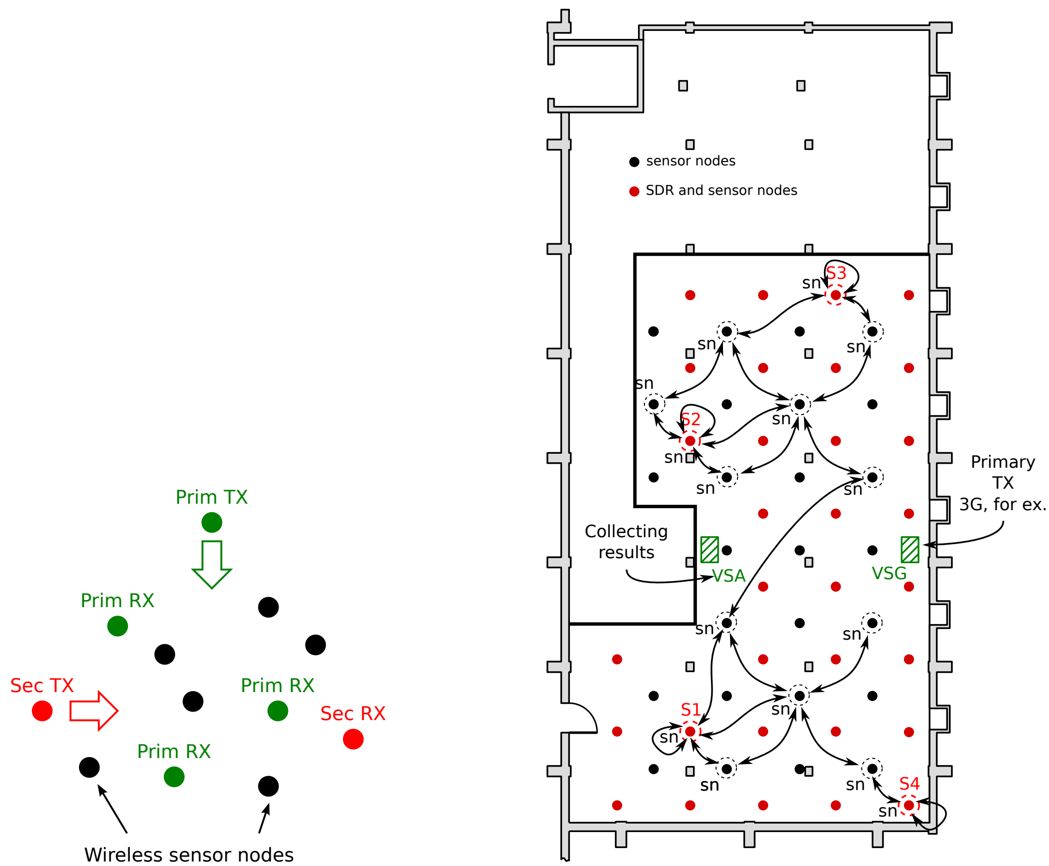
Similar to the ad-hoc networks case shown before, structured networks can be easily implemented with CorteXlab and its uniform grid structure. With structured networks, the transmit power will reflect the actual kind of scenario used, i.e., full power when the testbed aims at emulating a single cell or limited power to be able to cluster the whole testbed into several cells. The actual infrastructure can be emulated in several ways. A vector signal generator can be used to emulate, for example, a primary system in two tiered networks comprised of a legacy system and an opportunistic system, such as the ones target of CR, allowing the nodes to operate as part of a secondary system. If on the other hand, the infrastructure is based on SDR, the SDR nodes can be employed as base stations and nodes at the same time and the vector signal generator can be used as an interference source. The WSN nodes can also be used in structured mode to perform environment sensing to feed the SDR nodes with critical information. Finally, due to the diversity of available nodes, many kinds of systems can be implemented, including heterogeneous ones.

Since all nodes will be connected through a high-speed network, centralized and distributed algorithms are possible. For centralized schemes, a virtual machine will be made available to the end user, in which algorithms that perform control or supervision can be run. Nodes can also connect to themselves to achieve distributed cooperative operation.

As an example technique for structured networks in CorteXlab, let us select CR and Dynamic Spectrum Access (DSA) [**?**] and [**?**]. Spectrum sensing is an enabling technique for DSA. With spectrum sensing, a frequency band can be accessed without any special protection or power limitation only during the moments where no activity is seen at the primary system [**?**, **?**]. CorteXlab's capability to employ heterogeneous nodes allows to achieve simple or cooperative spectrum sensing in various ways. In the cooperative spectrum sensing, for example, spectrum sensing could be adopted by the WSN nodes co-located with SDR nodes. The WSN node decision would be reported to their respective SDR nodes to use the medium. One limitation might arise from the fact that to perform the energy, matched filter or cyclostationary feature detection, actual Base Band (BB) samples are required, limiting the range of choices of WSN node hardware that could be employed. The SDR nodes, on the other hand, can deal with all kinds of cooperative sensing techniques due to its inherent higher processing and BB capabilities. If fact, possessing dedicated processing capabilities such as DSP or FPGA would allow parts of the sensing procedure to be offloaded from the software defined core allowing more speed and flexibility in the sensing-to-action switch. Last but not least, due to the size of the testbed, clusters of nodes could be used to provide localized clustered sensing.

8 Conclusions and Perspectives

In this work we have introduced the CorteXlab testbed, that aims at providing a heterogeneous radio testbed to allow design and development of future wireless digital communications. CorteXlab will provide researchers all over the world with a up-to-date high quality PHY layer testing tool. Being part of the FIT project, CorteXlab will be accessible through an easy to use web portal, with possible future connection to the other testbeds integrating FIT. Since CorteXlab is not yet finished, we have presented some of the ongoing design processes where the main characteristics are emphasized. We have also developed some examples of particular scenarios target of this new tool. Ongoing work includes the development of a reference PHY design, based on PHY layer relay network techniques, the deployment of the middleware (heavily based on SensLab) that allows the management and remote activation of the nodes and the choice of the node platform itself.



(a) Spectrum sensing with helper sensing nodes

(b) Room deployment

Figure 5: CR and DSA in CorteXlab.