A DESIGN-AND-TEST METHODOLOGY FOR COGNITIVE RADIO

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ABSTRACT

Algorithm developers for spectrum sensing algorithms are faced with many challenges due to real-world environments that include multiple dynamic signals under dynamic fading conditions. This paper will explore a Cognitive Radio algorithm design and test methodology using simulation. The radio's spectral environment can be generated from live recordings, simulated signals, or a combination of the two. A sensing algorithm is then simulated to evaluate how well it can detect emitters and correctly identify usable spectrum. This combined simulation and test methodology enables algorithm developers to develop and evaluate their algorithms in simulation with recorded real-world signals, using the flexibility of simulation to explore radio spectral environment "what-if" scenarios.

Please note that this paper has been abstracted from an Agilent whitepaper publication. Please see reference [1] for further details.

1. INTRODUCTION

The term "Cognitive Radio" (CR) means different things to different people. However, most seem to agree that cognitive radios have, as a fundamental building block, the requirement to sense their environment. Specifically, spectrum sensing and location sensing.

For the purposes of this paper we will take a somewhat inclusive approach to the definition of cognitive radio, including even the simplest of forms dynamic spectrum sharing technologies, such as detect-and-avoid (DAA) and dynamic-frequency-selection (DFS). With this admittedly broad definition, a cognitive radio is a radio that can sense its environment, then, based on a set of rules (policy), and without operator intervention, modify its behavior.

The performance of a cognitive radio system depends on many factors. Some spectrum sensing algorithms are fast and low-complexity, while others provide high sensitivity and reliability but use more computational resources, and may require longer detection intervals. The cognition engine may be implemented with simple logic, or it may incorporate neural networks. CR performance generally increases when the radio has access to more relevant information. For example, cognitive radios might share information to enable cooperative spectrum sensing. They might also access external information from sources such as protected transmitter databases. As we increase the sophistication of cognitive radios we can perhaps evolve from simple DFS and DAA radio technology, to truly-cognitive radios that fabricate signals which fully utilize non-contiguous segments of underutilized spectrum in a predictive manner.

2. FILLING THE WHITESPACE

One motivation for cognitive radios is increased spectrum utilization in situations where it's not practical to have a centralized and all-knowing spectrum resource manager. In these situations, cognitive radios determine what spectrum resources are available and how best to use them. This is sometimes referred to as "filling the white space" as depicted in figure 1.

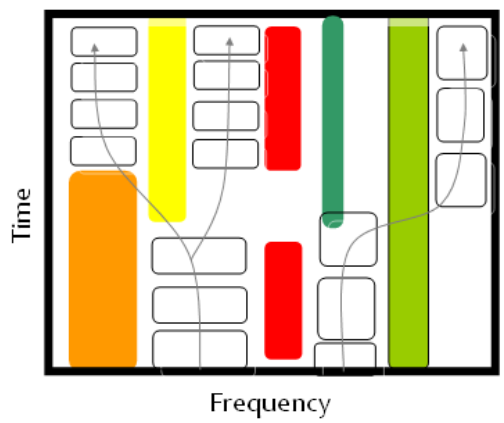


Figure 1- Filling the Whitespace

In this figure, one of the whitespace radios appears to simply change frequencies, while the other radio seems to anticipate the behavior of the protected signals and completely modify its signal's spectral shape to avoid interference, while filling the new spectrum holes.

OFDM technologies are particularly well suited to cognitive radio applications because of ease with which signals can be adapted to channel conditions and capacity requirements. This is evident in radio standards such as Mobile WiMAX™, and Long Term Evolution (LTE), both of which utilize a form of OFDM called OFDMA. For example, Mobile WiMAX can support 5, 7, 8.75, and 10 MHz channel bandwidths with FFT sizes of 512 or 1024. Similarly, LTE supports 1.4, 3, 5, 10, 15, and 20 MHz bandwidths. OFDM signals also have the potential to be modified on a subcarrier-by-subcarrier basis. By selectively disabling subcarriers, wideband signals can avoid interfering with narrow-band signals, even if the signals are located in the same main channel. While not specifically designed for cognitive radio or whitespace applications, we will use these standard signals to demonstrate key concepts.

3 CHALLENGES AND BARRIERS

Cognitive Radio (CR) development requirements represent a new paradigm for R&D engineers in challenging established design and test methodologies. In particular, CR development poses significant challenges and barriers to developing and testing CR whitespace algorithms:

- Real world spectral environments need to be used for algorithm development & testing. However, the use of live signals creates test conditions that cannot be replicated from one day to the next. Short field trials may not experience the full range of conditions and long field trials are expensive, and may be impractical.

- Conversely, Lab and R&D environments provide the design tools and equipment needed to develop and test algorithms, but it can be very difficult to emulate real-world CR spectral environments to adequately design and test CR algorithms
- Detect-and-avoid 'what-if' scenarios are difficult to evaluate in a lab environment, and are also difficult to test methodically in field environments.

- Metrology-grade test equipment is needed to test radio algorithms, but off-the-shelf test equipment typically does not support signal types that represent realistic CR environments that the radio would be exposed to.

- Algorithms need to be tested with real-world impairments such as intermodulation distortion and spurious signals (both internally and externally generated)

These challenges and barriers highlight the need to innovate new algorithm development and test methodologies which combine real-world CR spectral environments with the controlled, repeatable, and toolset-rich R&D/Lab environment to accelerate algorithm development and testing *before deploying the radio hardware to the field.*

4. A NEW COGNITIVE RADIO ALGORITHM DEVELOPMENT TESTBED

A new Cognitive Radio algorithm R&D testbed is presented which combines remote field sensing with the toolset-rich controlled lab environment so that CR algorithms can be developed and tested with real-world CR environment signals:

- Capture live signals at one or more locations for live testing, or record for later playback.
- Synthesize signals using simulated sources and channel models (to model transmitters and impairments)
- Combine captured and synthesized signals
- Test spectrum sensing algorithms (single or cooperative)
- Test cognition engine performance
- Test radio link performance

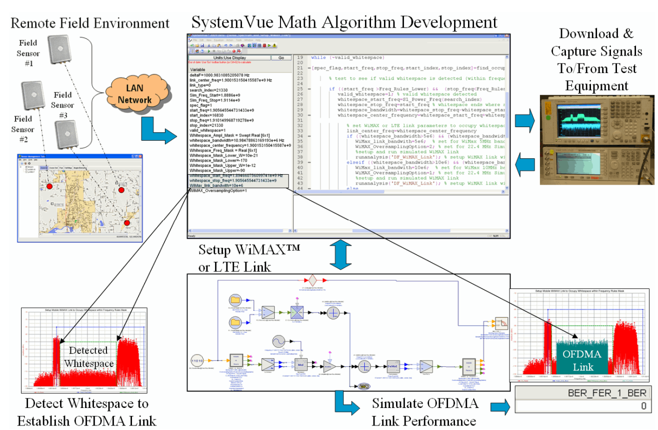


Figure 2- Cognitive Radio Algorithm Development Testbed

The remote field portion of the CR R&D testbed consists of one or more RF sensors installed at various geographic locations. The sensor locations are selected to gather data from different environments, or, to test cooperative sensing algorithms within an environment.

The lab environment portion of the CR R&D testbed utilizes system design simulation software to capture the CR environment data from the remote sensors, so that the system design software math language and math language debugger can be used to write and test CR whitespace algorithms with the remote field-captured signals.

OFDMA simulation models are then used to configure and evaluate OFDMA Mobile WiMAX and LTE link performance, using the math language to scale the OFDMA bandwidths and establish the transmission center frequencies within the detected CR whitespace to evaluate the coded OFDMA BER performance of the radio link. These simulation models can be customized for custom/proprietary OFDMA-based algorithms.

Simulation also provides the flexibility of evaluating "what-if" scenarios to determine the impact of swept interferers on OFDMA link coded BER/BLER performance for detect-and-avoid scenarios.

It can be useful to download and store remote field sensor data to metrology-grade test equipment for hardware DUT testing in the lab environment. Simulation provides the link between the remotely located field sensors and signal generators, so that the captured field sensor data can be downloaded to signal generator arbitrary waveform generators to re-create the field-captured signal in the lab environment. Once the waveform is downloaded to the signal generator arb, it can be stored in non-volatile memory. To facilitate DUT testing, DUT outputs can be captured and then read back into simulation to post-process signals in simulation. An example of this is testing the coded BER/BLER of a CR RF receiver, using simulation to provide the baseband post-processing required to support the coded BER/BLER measurement.

5. MOBILE WIMAX CASE STUDY

A Mobile WiMAX case study will now be examined, which involves capturing the CR spectral environment from the remote field location. The sensor is remotely located in western Washington State, and the simulation and test equipment setup is located in an office environment in eastern Washington State.

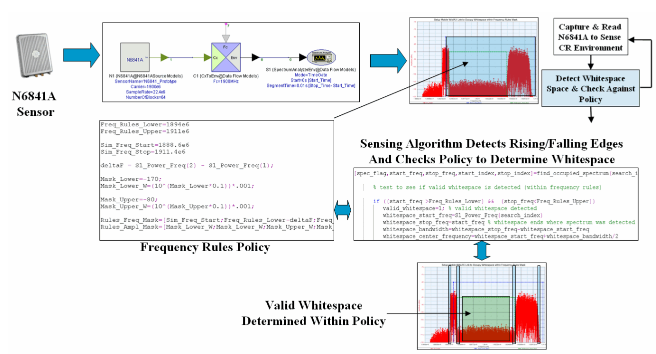
Custom math algorithms are then used to process the captured CR spectral environment to determine potential whitespace. The potential whitespace frequencies are evaluated against a policy to determine valid whitespace frequencies and available bandwidth to support an OFDMA Mobile WiMAX link. The math language algorithm then configures and scales the Mobile WiMAX center frequency and channel bandwidth to either 5 MHz or 10 MHz depending on the available whitespace it sensed and calculated. The coded BER of the configured Mobile WiMAX radio link is then evaluated to determine radio link performance.

The captured CR environment is also downloaded to a signal generator to re-create and analyze the CR environment. Lastly, the CR environment spectrum is de-modulated both in simulation and with test equipment using Vector Signal Analyzer (VSA) software to identify the CR environment.

The following sections will discuss each of these steps in more detail.

5.1. Whitespace Algorithm to Sense Spectrum and Determine Valid Whitespace

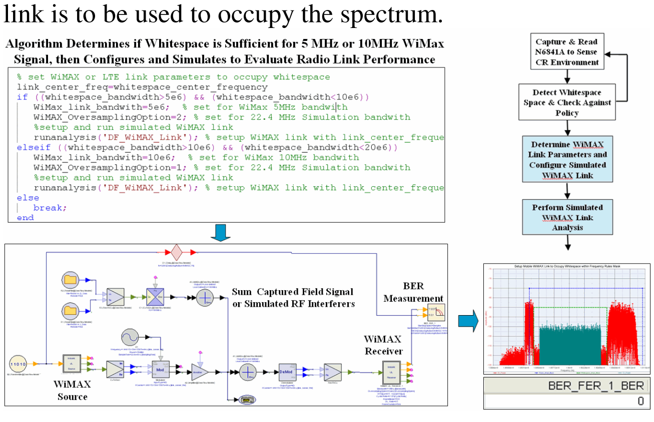
The first step in this case study is to capture the CR environment using a sensor remotely located in western Washington State. This is accomplished from the convenience of an office environment in eastern Washington State using a simulation tool link to the sensor.



The primary whitespace algorithm calls a secondary algorithm to detect rising and falling edges on the sensed CR environment spectrum. This secondary algorithm effectively integrates the spectral power within a user-defined resolution bandwidth, sweeps the frequency span, and compares the integrated power to user-defined power thresholds to detect rising and falling edges on the spectrum. The rising and falling edges are graphically illustrated as the vertical bars on the lower spectrum. These rising and falling edges are compared against a frequency rules policy to determine if the detected whitespace is valid. The valid transmission frequencies are displayed as the blue spectral mask on the upper spectrum. Once valid whitespace is determined it is displayed as the green spectral mask on the lower spectrum.

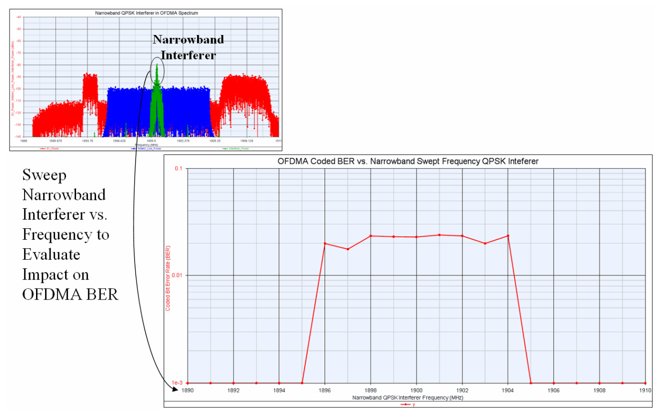
5.2. Establish OFDMA Link and Evaluate Performance

The rising and falling edges of the sensed CR spectrum are then compared to the frequency rules policy to determine the valid whitespace within the lower and upper frequencies defined in the policy. The policy frequency limits are being displayed by the blue rectangle in the spectrum below, and the valid whitepace that has been calculated is displayed as the green rectangle in the spectrum below. The CR algorithm then determines if the whitespace is sufficient to support a 5 MHz or 10 MHz OFDMA Mobile WiMAX or LTE link, and scales the OFDMA WiMAX or LTE channel bandwidth configuration accordingly to fill the available whitespace and centers the OFDMA spectrum within the valid whitespace. A user-defined preference is set in the algorithm to specify whether a Mobile WiMAX link or LTE link is to be used to occupy the spectrum.



The rectangular shaped spectrum (middle spectrum) on the spectrum plot shows the Mobile WiMAX spectrum which has been centered in the valid whitespace and scaled to occupy the available whitespace bandwidth. The two red spectrums on either side are the sensed CR environment detected with the sensor. The Mobile WiMAX schematic on the left is configured by the math algorithm and simulated to evaluate the coded BER performance of the Mobile WiMAX link.

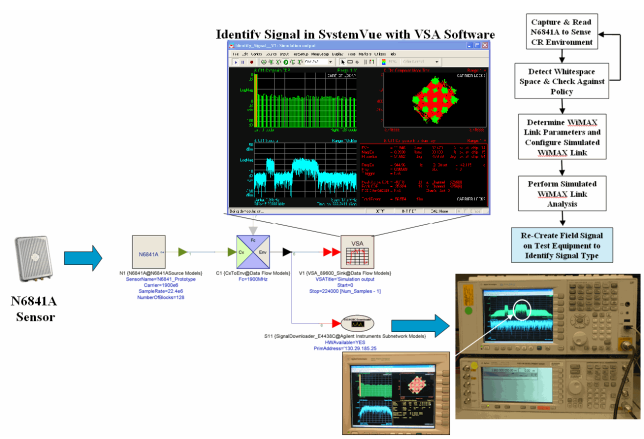
To evaluate detect-and-avoid scenarios, simulated interferers can be introduced into simulation and swept to evaluate the impact of the interferer on OFDMA link performance. The figure below shows a DQPSK narrowband interferer being swept across the CR frequency environment, and it's impact to the Mobile WiMAX OFDMA BER performance.



5.3. Identify CR Environment Signals

In the real world spectrum sensing, it's very likely that one will observe signals that raise questions about: their origin, and perhaps even their legitimacy.

Vector Signal Analyzer software can be utilized with simulation design software and test equipment to isolate and analyze CR environment signals in time, frequency, and modulation domains.



The first possibility is to identify the signal in simulation using the VSA software as shown in the upper-left corner of figure. The sensed spectrum from the remote sensor is read into the system design software and is then demodulated by the VSA software. The sensed spectrum shows two spectral peaks (spectrum traces on lower-left of VSA display). Setting the VSA's center frequency to center on one of the spectrums and trying different demodulation configurations pre-set on the VSA software identifies this signal type as a WCDMA downlink signal. The code domain is shown on the upper left, constellation on the upper right, and EVM on the lower right of the VSA display.

The second possibility is to download the captured signal from the remote sensor to a signal generator, as shown in the lower-right corner of figure . This is accomplished with a signal generator link in the system design software, which downloads the simulated I & Q to the signal generator's arbitrary waveform generator. This turns the simulated signal into a physical real-world test signal for DUT testing. In this example the captured signal from the remote sensor is downloaded to the arbitrary waveform generator in the signal source, and the RF output of the signal source is connected to an RF signal analyzer. The same VSA software used for the demodulation analysis in system design software is also used in the RF signal analyzer to demodulate the signal generator's RF output. Once the CR environment signal has been downloaded to the signal generator, it can be stored in non-volatile memory for further testing in the lab environment.

6. SUMMARY

This paper presents a novel R&D testbed for developing and testing Cognitive Radio whitespace algorithms. This new testbed combines simulation and test to enable sensor data to be captured at remote field locations, and used in the convenience of an office or lab environment to develop and test Cognitive Radio algorithms. This offers the benefit of using real-world environment signals (captured remotely) to develop and test algorithms in an R&D environment with a rich set of simulation tools and metrology-grade test equipment. Flexible simulation can be used to evaluate "what-if" interference scenarios for detect-and-avoid situations. Seamless integration between simulation and test equipment enables remotely detected signals to be identified in simulation, or on the testbench by downloading and analyzing signals with test equipment.

7. REFERENCES

[1] G. Jue, R. Cutler, Whitepaper: "Cognitive Radio Algorithm Development and Testing," *www.agilent.com/find/eesof-cognitive-whitepaper*