

# A GNU Radio Based Cognitive Signal Identification and Classification Platform

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**Abstract--**In the US the commercial dawn of unlicensed wireless products based on cognitive radio technology is anticipated to begin in 2008 when the Federal Communications Commission (FCC) will issue rules and regulations for low power operation in the UHF TV Spectrum. Viable products will undergo a rigorous regime of testing to demonstrate their ability to coexist on a non-interfering basis with existing over-the-air (OTA) Digital, Analog TV and non-TV services. High reliability algorithmic processes for incumbent signal identification and classification are core to an effective and dynamic local area spectrum utilization plan. In this paper the authors will describe their experience in developing, implementing, and field testing a GNU radio based cognitive radio platform recently presented to the FCC for testing the viability of reliably detecting and identifying low level North American 8VSB DTV and wireless microphone signals.

**Index Terms--**Cognitive radio, incumbent, sensing, spectrum agility, IEEE 802.00, coexistence

## I. INTRODUCTION

Wireless communications devices that forage and hunt for operating spectrum in existing commercial and military bands will be commercially marketed within a year. Initial applications are expected to provide transport infrastructure for a wide range of business and residential network based devices. The concept of scanning, evaluating and automatically selecting an operating frequency plan or regime is not new. An antecedent to cognitive radio is the adaptive radio concept in use by radio amateurs and governments alike to establish high reliability High Frequency (HF) links. Automatic Link Establishment (ALE) (<http://hfink.com/automaticlinkestablishment/>) stations have the capability to make contact, or initiate a circuit, between itself and another specified radio station(s), without human intervention and usually under processor control within a predetermined band using a well defined protocol. Nominally, ALE techniques

include automatic signaling, selective calling and automatic handshaking. Other automatic techniques that are related to ALE are channel scanning and selection, Link Quality Analysis (LQA), polling, channel sounding, message store-and-forward, address protection, and anti-spoofing.

## II. COGNITIVE RADIO CONCEPT

The purpose of a cognitive radio based communication system is to provide point-to-point and/or multi-point communication networks utilizing locally clear spectrum – where, in simple terms, this process is defined by set of metrics set by regulatory, radio engineering and economic and market factors.

Operating spectrum and rules are set by national or international agencies. In the US, the FCC has jurisdiction over commercial entities that market wireless transmission and receiving devices. In the UK, this agency is Ofcom. Each of these national agencies are undertaking processes that will free-up spectrum in their respective UHF TV bands due to the scheduled change over from analog-to-digital television transmissions. In the US the transition from analog to digital TV transmissions is scheduled for February 2009, in the UK the transition is scheduled for 2012.

In the US, the FCC is considering allowing cognitive radio operation, on a non-interfering shared basis with on-the-air Digital TV transmissions from UHF TV Channels 21 (512 MHz) to 51(698 MHz).

The UK's approach, as shown in Figure 1 is to define spectrum into two categories, Clear and Interleaved. Clear spectrum, 112 MHz, is proposed to be allocated to a wide variety of services including, cognitive radio, emergency services, etc.

Interleaved spectrum, 256 MHz, is proposed to be occupied by Digital Terrestrial Television (DTT) services, DTV transmitters, relays, etc. The free space between incumbent users is termed White Space.

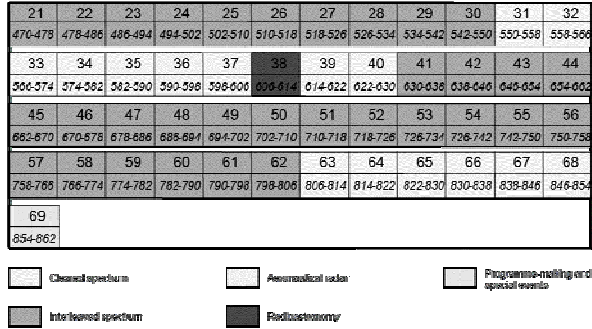


Figure 1. Channel Numbers and Frequencies for UK TV bands IV and V.

Lastly, FCC rules will require that when transmitting the cognitive radio transmitter minimize the potential of interference to DTV receivers by monitoring for incumbent occupancy prior to transmitting.

A Basic Cognitive Radio consists of the following components

1. A fast scanning sub-system that scans, analyzes and categorizes spectrum to allow dynamically selected candidate operating frequency channels in a changing spectral space.
2. A transmitter/receiver suite capable of dynamically adapting channeling, modulation, coding and power to maximize information transfer using the results of the scanning sub-system. It is expected that some these techniques would include:
  - a. Dynamically agile contiguous and non-contiguous modulation frequency plans.
  - b. Code morphing techniques to balance power and application information requirements.
  - c. Rule based modulation shifting techniques, much like the 802.11xx devices which dynamically adapt to varying spectrum environments and signal processing  $E_b/N_0$  requirements.

3. An effective wide-band high-dynamic range low-noise antenna system. A practical cognitive radio will need to operate with a dynamic range of over 134 dB. In the US, the maximum received DTV signal can be as high as + 10 dBm, where the lowest signal level required is nominally -124 dBm to meet incumbent signal detection requirements.
4. A forward and reverse channel command and control system to interchange link establishment and frequency roving requirements.
5. Supporting these processes, an embedded processor and operating system capable of high throughput multi-thread operation.

### III. PROTOTYPE WHITE SPACE COGNITIVE RADIO DEVICE

The purpose of Metric Systems Corporation’s Prototype White Space Cognitive Radio Device was to serve as a demonstration platform for the FCC in evaluations on the practicality of cognitive radio operation in the UHF TV band. The FCC is currently undertaking a series of strenuous lab and field tests. (<http://www.fcc.gov/oet/projects/tvbanddevice/>)

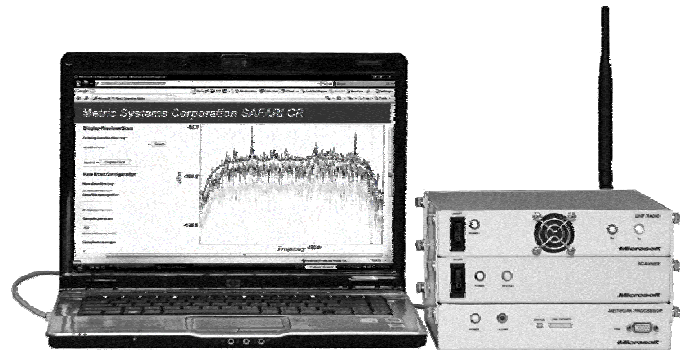


Figure 2. The GNU radio based White Space Device Submitted to the FCC for testing.

The WSD device submitted to the FCC consists of three Physical modules and several software modules:

- A. *Hardware*
  - An x86 based processor module running Linux version 2.6.19.1.

- A Scanner Platform based on the Universal Software Radio Peripheral, or USRP from Ettus Research LLC (<http://www.ettus.com/>)
- A 2.4 GHz to UHF Translator board to create a -10 to + 20 dBm narrow-band OFDM signal was designed and built.

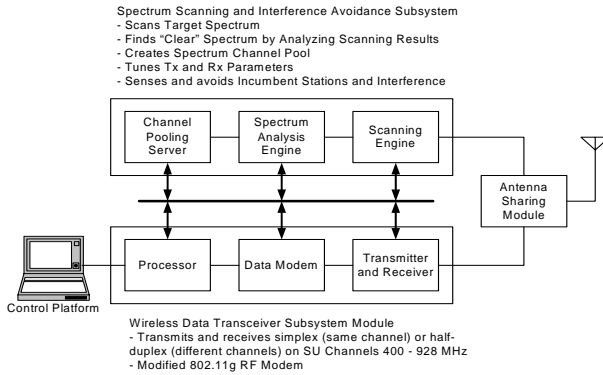


Figure 3. WSD Functional Block Diagram

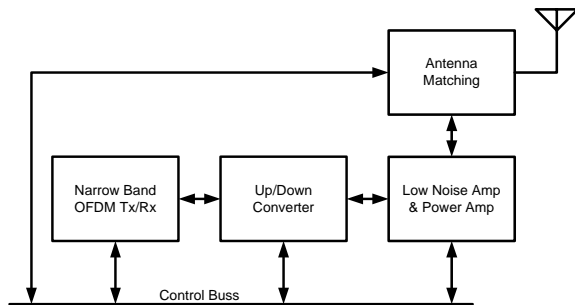


Figure 4. 2.4 GHz to UHF Up/Down Functional Block diagram

### B. Software and Firmware

- Open Source GNU embedded software together with in-house developed code to provide the software radio functions for scanning, signal feature detection and decision making.
- An integrated HTML and Python module to present a visual output of the scanning function.

### C. Scanner Platform

The choice of hardware for the scanner platform was primarily based on building or buying the simplest thing that would consistently meet the expected FCC signal detection requirements. After researching the market, we chose the Universal Software Radio Peripheral or USRP (from Ettus Research LLC, <http://www.ettus.com/index.html>). The USRP is a device which allows one to create a software radio using any computer with a USB 2 port

The choice of the USRP was sufficient to act as a hardware core for the basic WSD scanning platform and along with the GNU Radio software library of DSP signal processing blocks.

The purpose of the White Space Detector is to analyze the frequency spectrum associated with the US UHF television channels 21 through 51. This corresponds to frequencies 512 to 698 MHz with each channel being 6 MHz wide. The result of the analysis should answer the simple question, "Is the channel occupied with the presence of a target signal, or not?" The signals that were expected to be found in this range are NTSC analog television broadcasts, ATSC DTV signals and FM Wireless microphones.

The device detects and analyzes signals from an on-air ATSC DTV source down to -125 dBm which parametrically indicates channel power at -114 dBm. This is 40 dB lower than the minimum signal level required for a standard receiver. Figure 5 below shows typical power spectrums for a DTV-ATSC and Analog NTSC signal.

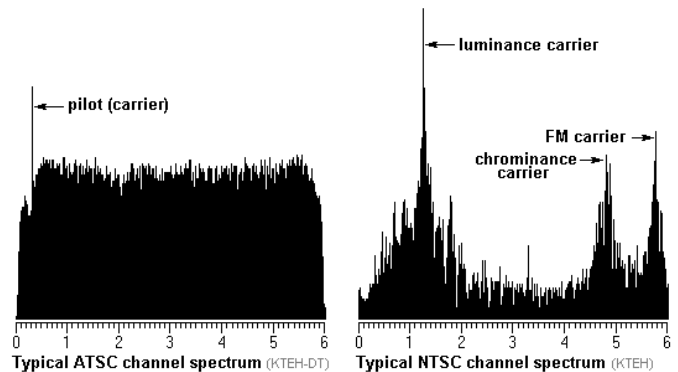


Figure 5. Typical Power Spectrums for DTV-ATSC and Analog NTSC Signals.

To maintain a non-interfering DTV transmission protocol, the spectrum band would be declared clear or available if the aggregate power over the DTV transmission bandwidth of 6 MHz was -114 dBm or less. In addition, a high probability detection of professional wireless microphones was required. Although the strict regulatory requirements for meeting DTV, analog and wireless microphone detection do not necessarily indicate that a channel is clear for transmission. Additional measurement tests for noise level and other potential interferers to the cognitive radio must be located and classified.

#### IV. SIGNAL DETECTION METHOD

The GNU DSP implementation is based on multiple signal feature extractors, which analyze the on-air power spectrum. A number of methods were empirically tried to reliably detect the signals at the specified levels.

Examining a large number of test equipment generated and over the air captures, the decision was made, that for reliable (> 99%) detection of ATSC, NTSC, and Wireless microphones waveforms, a peak above some local average in the power spectrum approach would be implemented. The challenge remained on how to process the data such that the peak features were consistently revealed in the noise of the low signal level sufficient enough for detection. A robust generalized Peak Detection algorithm was developed for the target suited signals. Parameters variable could be adjusted to produce an indication of presence of the feature(s) in a given FFT sample. Over a fixed period of time a number of FFT samples were taken, processed and the Peak Detection feature presence (or absence) recorded, along with power magnitude and bin location. The prototype algorithm was then evaluated against numerous on-air target signals and a wide variety of equipment generated pathological signals representing typical and extreme signal waveforms. Figures 6 and 7 below show two typical over-the-air signals that the WSD is expected to detect.

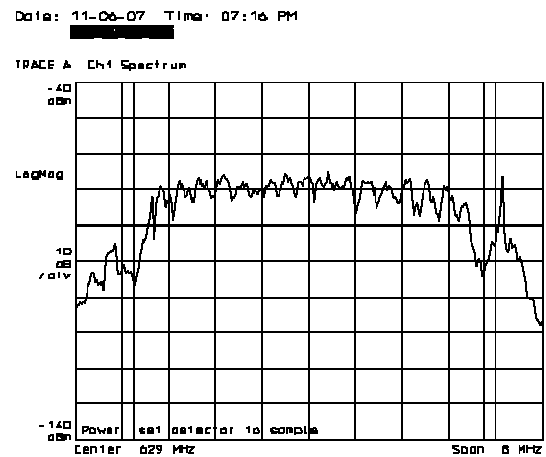


Figure 6. DTV Signal with Weak or Non-Existent Pilot Tone.

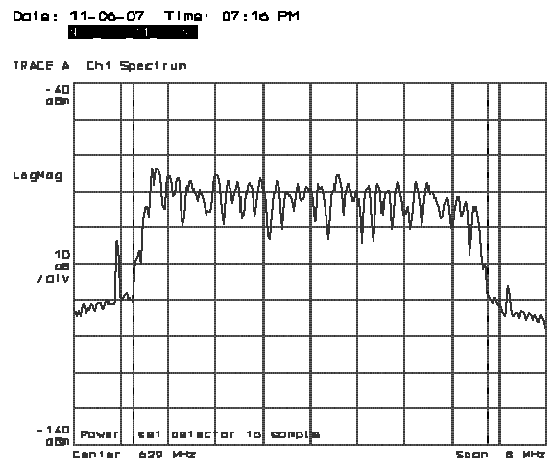


Figure 7. High Multipath DTV Signal.

Once a record of peaks for a series of scans is determined, an empirically derived scoring procedure is employed, where for example if a target feature per bin count rose above a threshold a 'peak' was confirmed as 'detected'. This allowed time varying signals to be detected, even though the spectrum had been averaged. By using the bin location information, an empirical determination of the type of signal could be made.

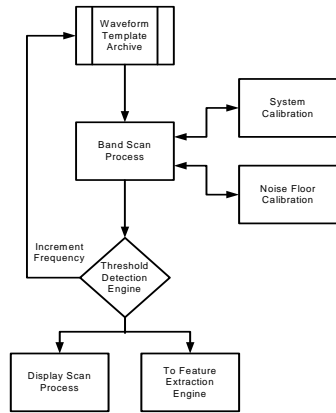


Figure 8. Functional Overview of Band Scan Detection Process

### V. WSD GRAPHICAL INTERFACES

Graphical interfaces for GNU Radio applications are built in Python. Interfaces may be built using almost any toolkit you can access from Python; we recommend wxPython to maximize cross-platform portability. GNU Radio provides blocks that use interprocess communication to transfer chunks of data from the real-time C++ flow graph to Python-land.

The system was designed to be usable in a variety of ways. The system could be commanded to display the spectrum of a given channel or a range of channels. With the use of detection processing, the system could be also commanded to take a number of FFT samples, perform analysis and provide detailed detection results. The results of the detection and the FFT samples for a given run could be saved as an Excel file. See Figure 12 for further processing and algorithm development.

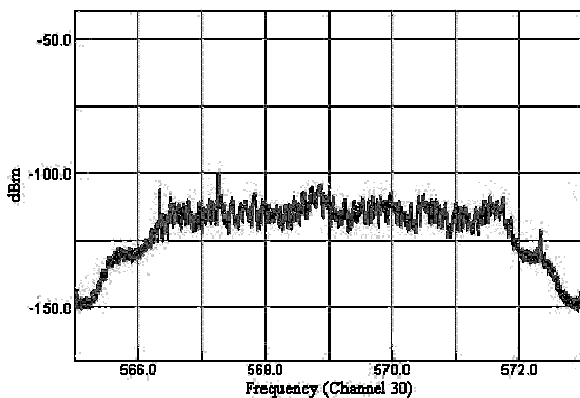


Figure 9. WSD Python scan of DTV signal with NTSC signal co-channel.

While not as accessible as the User Interface, the WSD detection parameters were placed in a set of Python files, and could be changed to observe differences in setting various thresholds in detection capability. Parameters such as number of FFT samples to average, peak magnitudes, and thresholds covering number of features needed to make a determination allowed the user to change sensitivity of the detector to signal levels, as well as noise in the signal.

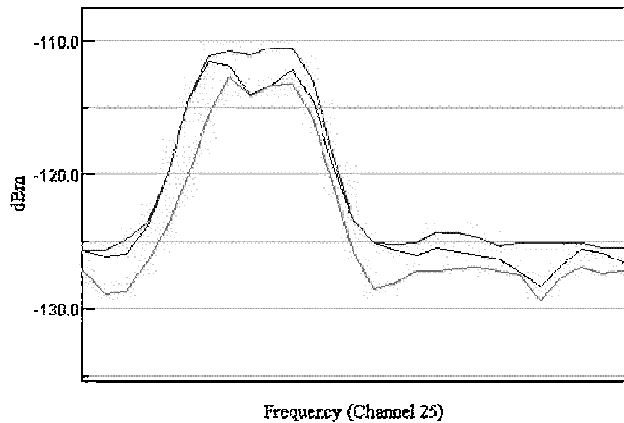


Figure 10. Expanded view of DTV Pilot Tone.

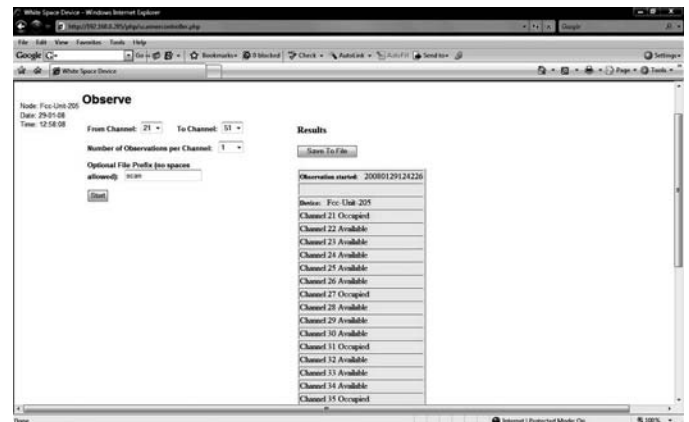


Figure 11. HTML User Interface Scan Results

Time Stamp	Description	Channel	Channel Status	DTV Detect Counts	Pilot Peak Power	Channel Power	NTSC Detect Counts	FMW Detect Counts/Peak Position	UnkSig Peak Power
20080129131849	scan	21	Occupied	0	0	-102.22783	0	258	-109.338
20080129131849	scan	22	Available	0	0	-102.33383	0	0	0
20080129131849	scan	23	Available	0	0	-101.7682	1	0	0
20080129131849	scan	24	Available	0	0	-101.46953	0	0	0
20080129131849	scan	25	Available	0	0	-101.37267	0	0	0
20080129131849	scan	26	Available	0	0	-101.41559	0	0	0
20080129131849	scan	27	Occupied	0	0	-101.22413	0	1044	-110.784
20080129131849	scan	28	Available	0	0	-101.33753	0	0	0
20080129131849	scan	29	Available	0	0	-101.14767	0	0	0
20080129131849	scan	30	Available	0	0	-100.88655	0	0	0
20080129131849	scan	31	Occupied	0	0	-100.47311	0	1282	-109.715
20080129131849	scan	32	Available	0	0	-100.59884	0	0	0
20080129131849	scan	33	Available	0	0	-100.77374	0	0	0
20080129131849	scan	34	Available	0	0	-101.1159	0	0	0
20080129131849	scan	35	Occupied	0	0	-101.6297	0	1581	-114.313

Figure 12. Processed Detection Results Excel file out put.

## VI. SUMMARY

The WSD represents the how a useful and beneficial development tool can be made using basic but powerful tools from the collective intellect and works of dedicated individuals. The advent of cognitive wireless devices will provide increasingly more bandwidth opportunities which will in turn spread communications into more and more areas and applications.

We will continue to evolve the utility and capability of this first generation WSD device based on the GNU model and contribute to solving the myriad suite of practical challenges by actively contributing experimental code and applications to the GNU Radio organization.

## ACKNOWLEDGEMENTS

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