# A Heterogeneous Cognitive Radio Network Enabling Dissimilar Cooperative Spectrum Sensing, Dynamic Spectrum Access, and Interoperability

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## 1. Introduction and System Overview

In this demonstration, the Center for Wireless Telecommunications (CWT) will build and operate a heterogeneous cognitive radio (CR) network which enables dissimilar cooperative spectrum sensing, dynamic spectrum access (DSA), and interoperability among legacy radios and a Wi-Fi network. Figure 1 shows the physical layout of our cognitive radio network.

First, we use five different sensors to build an ad-hoc sensor network for cooperative spectrum sensing. The first sensor employs broadband parallel RF sensing on a Lyrtech “Small Form Factor” (SFF) Software Defined Radio (SDR) board; this sensor’s algorithm primarily runs on the embedded FPGA and can cover signals up to 20MHz in bandwidth. The second sensor, with a USRP as the front end, implements a signal classification and synchronization system using frequency and time domain signal features; it is able to classify analog AM and FM, digital M-ary PSK, M-ary QAM, M-ary FSK, and OFDM signals. The third sensor is a matched filter using GNU Radio and a Universal Software Radio Peripheral (USRP); it uses SDR technology to dynamically reconfigure PHY/MAC parameters. The fourth sensor uses narrow band energy detection followed by a k-nearest neighbor (K-NN) algorithm classifying signal features on a laptop with a USRP as the RF front end; it is able to classify analog FM and AM, digital BPSK, QPSK, and 4FSK signals. The fifth sensor is a broadband energy detector based on Anritsu MS2781A Signature Signal Analyzer; this sensor can cover signals up to 20MHz bandwidth. We employ Wi-Fi adapter cards to connect these sensors into a sensor network. Such a sensor network can have several advantages: (1) overcoming multipath fading, shadowing, and the hidden terminal problem by distributing sensors over different geolocations, (2) boosting the overall spectrum sensing performance by complementing different sensors’ characteristics, (3) increasing frequency coverage by employing sensors with different frequency ranges.

Second, two CWT reconfigurable CR nodes communicate with each other using vacant channels obtained from a Dynamic Spectrum Access Broker. This DSA Broker is built on top of a Sensor Database that registers secondary channel request through a control channel. Furthermore, the DSA Broker provides an application programmable interface (API) which tells secondary user nodes to immediately switch to other vacant channels when the primary user’s signal shows up.

Third, the above two CR nodes apply cross-layer adaptation at the PHY, MAC, and application layers.

An audio/video stream is applied at the application layer.

Fourth, in the aforementioned CR nodes, CWT also developed three gateway functions based on GNU Radio and USRP to demonstrate interoperability in a heterogeneous network. These functions can: (1) bridge a Family Radio Service (FRS) radio to an E.F. Johnson hand-held radio (51SL ES), (2) bridge a P25 digital radio (RS-5300) to an analog police radio, and (3) bridge two radios through a WiFi network (radio-over-IP). In (2) and (3), the Wi-Fi network serves as a backhaul.

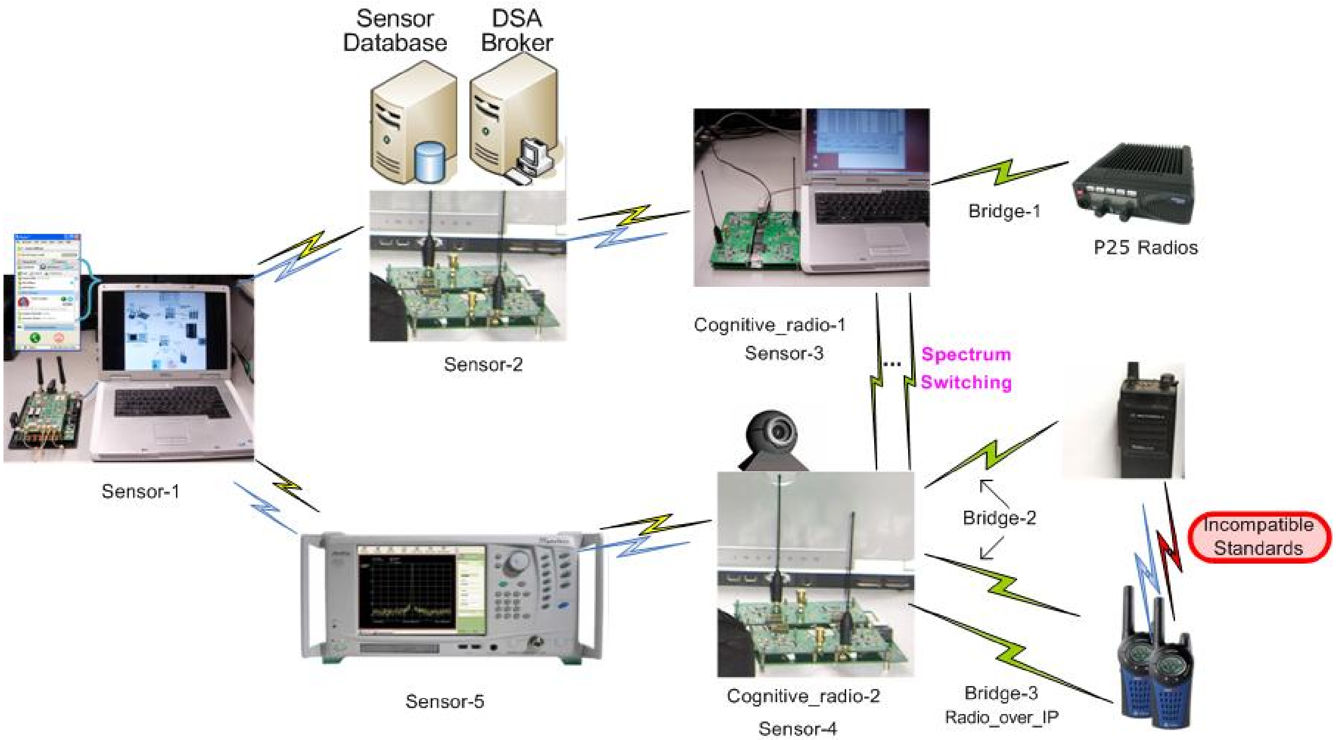


Figure 1 –CWT's Heterogeneous Cognitive Radio Network Enabling Dissimilar Cooperative Spectrum Sensing, Dynamic Spectrum Access, and Interoperability.

## 2. Demonstration Activity and Test Plan

### 2.1 Dissimilar Cooperative Spectrum Sensing

During the demo environment, there are many users working within the 400MHz (482MHz – 500MHz assigned by DySPAN 2008). Our five sensors cover the whole frequency range continuously and automatically updating the sensor database with detected signal features. The sensor database ("main sensor database") fuses all the results and displays them on a graphic user interface (GUI), as shown in Figure 2. This includes starting frequency ("F_min"), ending frequency ("F_max"), center frequency ("F_c"), power, modulation, the time being detected, and SNR of each signal. Currently the database indicates each signal's location by the name of the sensor that detects it. Once the user specifies both time and frequency range, the GUI can dynamically show a sequence of color bars with red ones representing currently active signals and green ones representing inactive signals. The GUI also indicates the spectrum utilization efficiency by using stored spectrum information.

### 2.2 Dynamic Spectrum Access

The DSA Broker automatically fetches all data from the sensor database, sorts them, and stores them in its own DSA table. Based on sensors' result and its own database of primary user signals, the DSA broker decides whether each channel is a primary signal or secondary user. For unknown signals, this field is shown as NULL. All the detected signals are stored in "DSA Broker Bandwidth Table" shown in Figure 2. Further, secondary users are required to register to the broker, here by specifying their IP, connection port number, center frequency, bandwidth, and modulation, as shown in Figure 2.

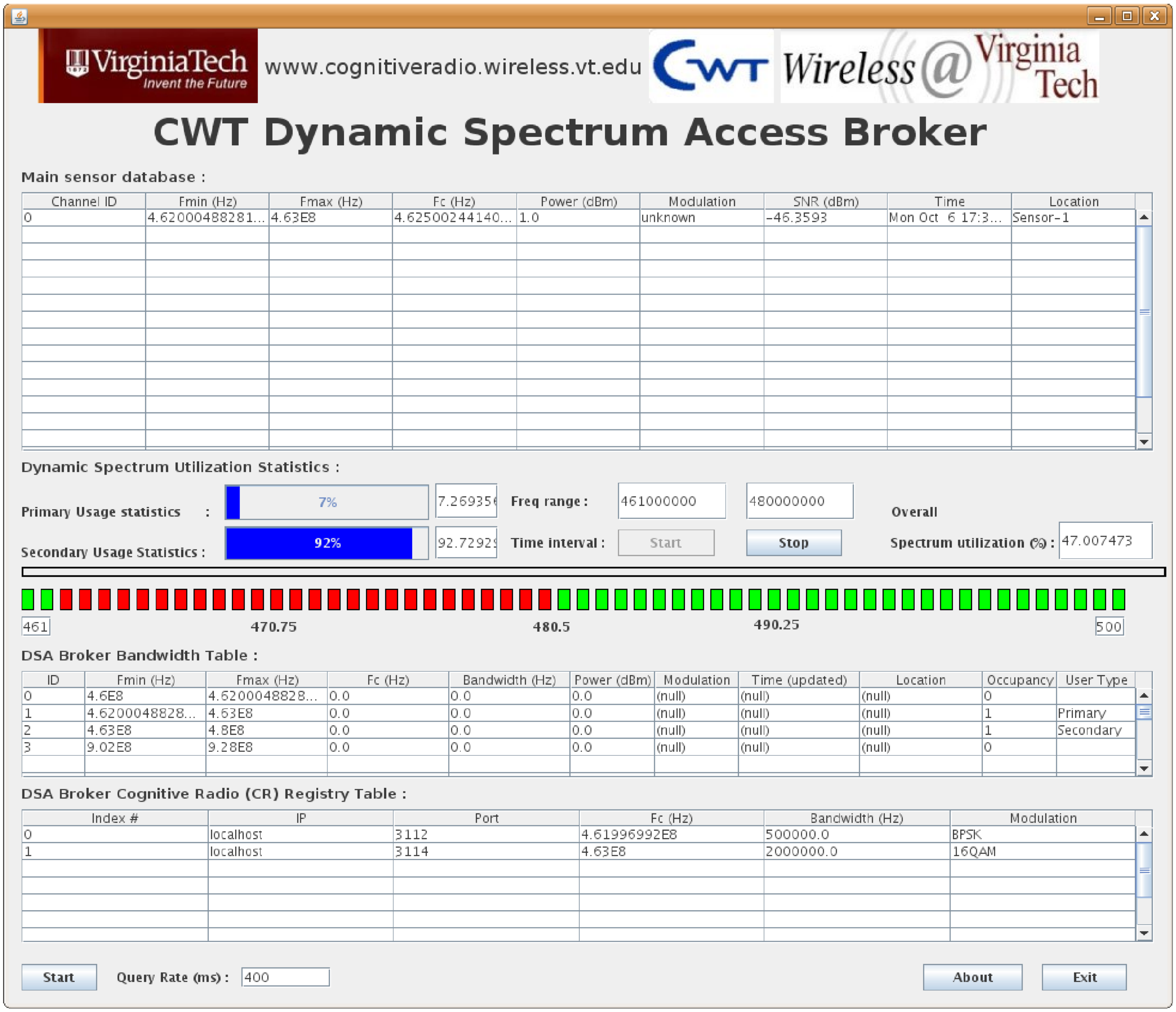


Figure 2 – CWT Dynamic Spectrum Access (DSA) Broker.

Upon communication between two CR nodes as shown in Figure 1, the transmitter node first queries the DSA Broker database and selects a vacant channel having the required bandwidth; it then notifies the receiver node by the WiFi control channel. At the same time, the transmitter node will also register its selected carrier frequency and bandwidth as well as both the transmitter's and the receiver's IP addresses with the broker database. Both CR nodes communicate with each other in the ISM band (902–928 MHz). Our sensor network will cover both this frequency range and the band from 482MHz to 500MHz.

To avoid interference with primary users, two CR nodes first rely on their own sensors which continuously detect in-band signals to determine whether primary users are present. Second, the DSA broker also regularly updates its database and it will notify both CR nodes to switch to other vacant channels upon primary users' presence. This way, two CR nodes will not cause interference even if they cannot detect any primary signal's presence because of propagation path loss, multipath fading, shadowing, and the hidden terminal problem.

## 2.3 Cross-layer Application

We will demonstrate that two CR nodes, with cross-layer design, adapt at the PHY, MAC, and application layer. The cognitive radio architecture is shown in Figure 3. It consists of 7 components: (1) A local database including possible regulatory policies, sensors related to data, and a learning knowledge base; (2) a visual sensor; (3) radio frequency (RF) sensors, etc.; (4) a Cognitive Engine (CE) which manages and coordinates components (1-3) and (6-7), adapts to environments and learns through experience; (5) A graphical user interface which enables a friendly interface to the CE and also includes users priorities for different applications; (6) A cross-layer controller which selects, reconfigures, and optimizes different network protocol stacks above the PHY layer according to the Cognitive Engines decision, users priority and applications, and network environments, etc. (7) A protocol stack sits on top of a reconfigurable SDR platform.

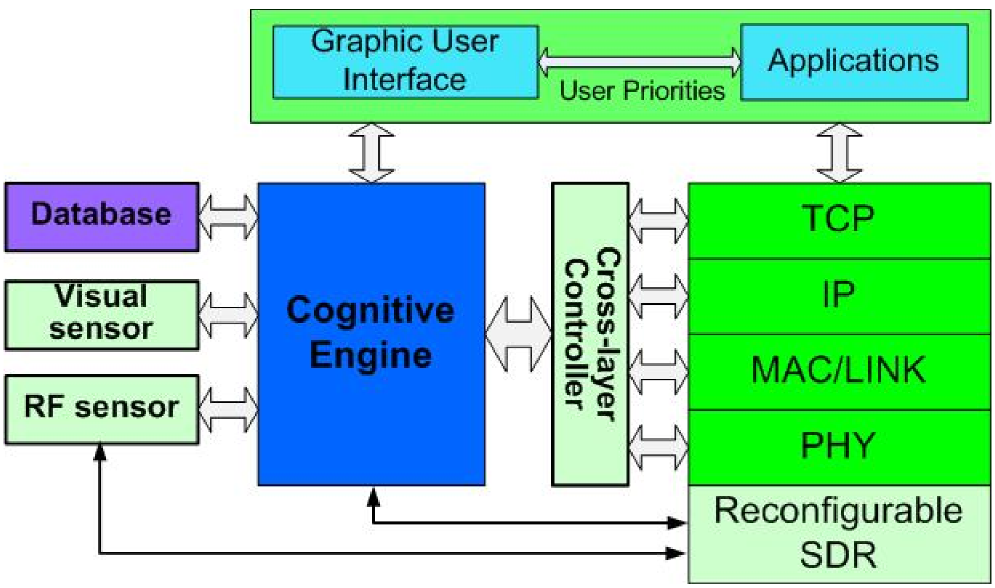


Figure 3 – The Cognitive Radio Architecture.

At the application layer, two CR nodes use VLC, an open source media player, to stream audio/video with each other. As user QoS requests vary for different application content, the cognitive controller, as shown in Figure 3, will send commands to VLC through a Unix socket and change VLC's frame rate and coding scheme; at the meanwhile, the controller will also inform the cross-layer controller to adapt the PHY/MAC layer settings. At the MAC layer, inter node protocols are applied to coordinate both CR nodes during reconfiguration transition between two nodes; at the PHY layer, the reconfiguration parameters are associated with the payload and include carrier frequency, modulation types, symbol rates, channel coding, power levels, pulse shaping, etc. The whole architecture certainly supports DSA application discussed in the previous section.

## 2.4 Interoperability

We will also demonstrate some functions in achieving interoperability among heterogeneous networks, as shown in Figure 4. First, we bridge a Cobra MicroTalk PR 100-2VP (22 Channels) 2-Way Radio and a EFJ hand-held FM radio. They have the same FM modulation, but with different channel filters and frequency range. Two radios talk to each other through a repeater supported by our cognitive radio.

Second, we bridge an EFJohson P25 radio (ES5300) to a FRS radio. One CR node works as a repeater between them. We use GNU Radio and two USRP daughter-boards as well as two Johnson Encryption Machine (JEMs) to achieve the repeater functions. An FRS radio will be able to talk to an EFJ P25 radio.

Third, we implement a Radio-over-IP link which bridges two radios through a WiFi network. We use two CR nodes to bridge two legacy radios to the WiFi network respectively. In the demo, two conventional radios will use different channels to talk to each other; our cognitive radios work as gateways and enable the communication link through a WiFi network.

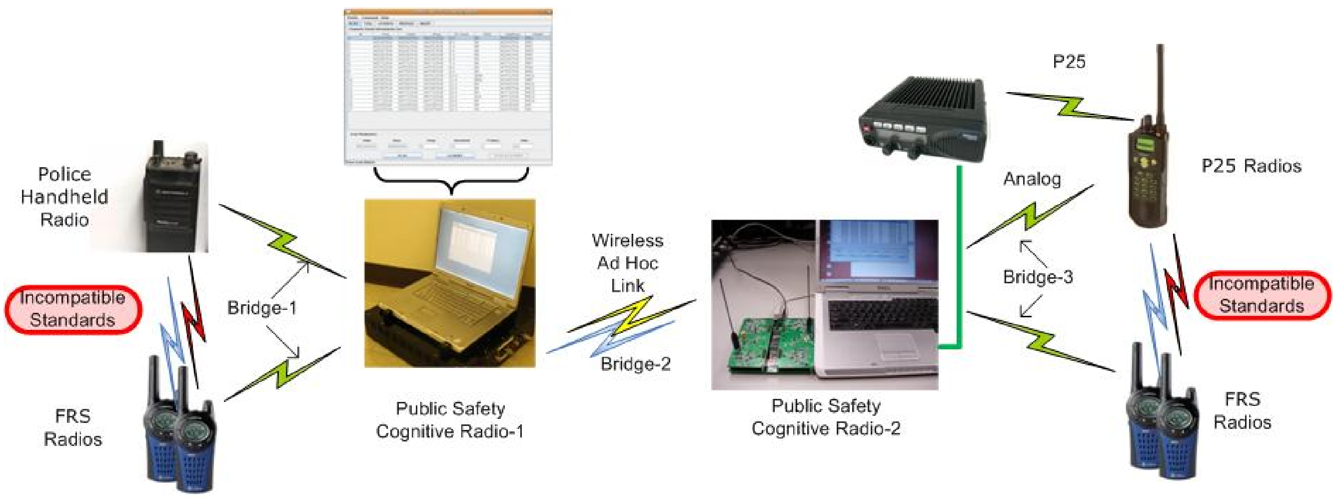


Figure 4 – Some Interoperability Functions Provide by CR.

## 3. Acknowledgments

This work was supported by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice under Award No. 2005-IJ-CX-K017, by the National Science Foundation under Grant No. CNS-0519959, and by DARPA under grant W31P4Q-07-C-0210,. The opinions, findings, and conclusions or recommendations expressed are those of the authors and do not necessarily reflect the views of these sponsors or the official policy or position of the DARPA, Department of Defense, or the U.S. Department of Justice or by the by the National Science Foundation.