700MHz BAND SPECTRUM-USAGE MEASUREMENTS FROM DENVER TO WASHINGTON DC DURING NOVEMBER 2007 AND THEIR VALUE IN HELPING SOFTWARE-DEFINED RADIO ENTER THE MAINSTREAM

Keith E. Nolan Centre for Telecommunications Value-Chain Research (CTVR) at Trinity College Dublin (keithnolan@mee.tcd.ie), Thomas W. Rondeau, CTVR at Trinity College Dublin (trondeau@mee.tcd.ie), Paul D. Sutton, CTVR at Trinity College Dublin (suttonpd@tcd.ie)

CTVR, Room 1.17, Lloyd Institute, Trinity College Dublin, Dublin 2, Rep. of Ireland
Telephone: +353-1-8968443 Fax: +353-6772203

ABSTRACT

This paper presents key outcomes from mobile spectrum measurements research covering in excess of 4500km along a route from Denver, CO to Washington DC during November 2007. The main focus was on the 698MHz – 806MHz band covering a variety of busy urban and quiet rural areas along the chosen route. This paper describes how the spectrum measurement data are being used for offline prototype wireless communications research by CTVR. This database is being made available for other academic and industrial research work worldwide in a bid to narrow the gap between simulation and real-world tests, significantly reduce the time to market and costs of conducting field tests and accelerate the development of SDR-based dynamic spectrum access systems.

1. INTRODUCTION

Following the 2007 Software-Defined Radio Forum conference in Denver, the authors conducted mobile spectrum-usage measurements in the 698MHz to 806MHz range from Denver, to Washington DC; the location of the 2008 Software-Defined Radio Forum conference [1]. This frequency band is currently occupied by mainly TV and public-safety communications system. The purpose of these spectrum measurements was to evaluate actual spectrum usage in this '700MHz' band which has been the subject of the recently concluded FCC auction 73 [2]. The 700MHz band is considered 'sweet-spot spectrum'; striking a balance between sufficient bandwidth to support high-quality media and the ability to penetrate buildings and operate over non line-of-sight links. This auction, which raised almost $19.6 billion from 1090 winning bids [2], has strongly highlighted the critical need for more effective use of frequency spectrum. Given the significant costs associated with licensing and spectrum 'ownership', service providers are under significant pressure to extract as much value from their investment by way of supporting more services, reducing the time that a spectrum segment remains unoccupied, and exploiting the ability to support multiple co-channel users over a wide geographical area. In an era where the emphasis is on more efficient use of spectrum, the authors' objective was to capture spectrum-usage measurements and location information for use by researchers developing new and more effective methods of wireless communications using software-defined and cognitive radio.

As software-defined radio enters the mainstream, and the direction of technology-development is becoming more influenced by market requirements instead of technical development, the importance of relevant, timely, and real-world measurement information is increasing dramatically. The value in being able to increase the probability of a robust and successful SDR and dynamic spectrum access-based solution and to reduce the time to market is incredibly high.

This paper presents the authors' tactics to establish a credible source of measurement information from a large cross-section of the United States, example outcomes from their mobile spectrum measurements work, and details of how this information and tools required to access and manipulate this valuable information has been made freely available for use by researchers worldwide.

A key benefit of carrying out detailed spectrum measurements is the availability of stored "real-world" data for experimentation. In the context of dynamic spectrum access, this data can be used as test input for a number of essential algorithms including white-space detection, signal detection and signal classification. Most importantly, the use of such stored data permits like-with-like comparisons of alternative algorithms to be carried out. This experimental repeatability permits the key advantages and drawbacks of different approaches to be examined.

2. MOBILE SPECTRUM MEASUREMENTS

The mobile spectrum measurements lab consisted of an Anritsu MS2721B 9kHz–7.1GHz battery operated handheld spectrum analyzer [3] connected to a laptop PC using an Ethernet connection and housed in a rental car. The analyzer was connected to a monopole wideband receive antenna attached to a magnetic mount on the roof of the car. The MS2721B handheld spectrum analyzer features an inbuilt preamplifier and GPS receiver. Spectrum traces and current GPS location and time information were captured every three seconds using a Python-based capture application operating on the laptop. Communication between the laptop PC and the spectrum analyzer over Ethernet was conducted using standard commands for programmable instrumentation (SCPI). Spectrum activity was observed for one second and averaged over four traces during that interval in order to reduce the negative effect of any impulsive noise or *sparkle* caused by the motion of the vehicle and contents on the trace data.

Figure 1 illustrates the route taken by the authors. Two map markers are located on the west of this map corresponding to the venue for the 2007 SDR Forum Technical Conference in Denver and the University of Colorado, Boulder. The authors proceeded to Boulder, CO, following the 2007 SDR Forum conference before making their way eastwards toward Washington DC. The GPS track begins east of Denver, CO.

3. DATA MANIPULATION AND VISUALISATION

Each measurement comprises 551 points or bins, and each of these bins represents the power-spectral density of a 196 kHz segment of the 698MHz-806MHz observation bandwidth. The range power spectral density measurements range was from a minimum of approximately -120dBm to a maximum of -20dBm; a 100dB dynamic range. The GPS information comprised latitude, longitude, and timestamp for each measurement. The combined information set was stored in a MySQL database. The raw trace files and database versions can be easily accessed by Matlab and Python-based tools to produce graphical representations of the spectrum usage patterns in addition to using the information as part of reconfigurable software-defined radio dynamic spectrum access system prototypes.

Figure 2 shows part of the route taken by the authors as they moved from Kansas towards Chicago. The route overlay on this map was derived from the GPS location data contained in the trace files. Figure 3 is a three-dimensional plot of the spectrum usage as the authors moved north east towards Schaumburg, IL. The spectral activity increased as the trip progressed towards the Chicago area in terms of both absolute received signal power and spectrum occupancy.

Figure 4 illustrates another section of the route undertaken by the authors as they moved from Charleston, West Virginia towards Blacksburg, Virginia. A three-dimensional plot of the spectrum occupancy measurements captured during this route is illustrated in Figure 5. Spectrum occupancy and measured power levels illustrated in Figure 5 are distinctly different than the spectrum occupancy measurement data illustrated in Figure 3 due to the absence of detected TV and public safety transmissions for most of this route.

4. USE WITHIN A RECONFIGURABLE COMMUNICATIONS PLATFORM

In addition to using this information to gauge the level of activity in the 700MHz band, this source of information can, and has been used to aid the prototyping and testing of dynamic spectrum access-based systems. CTVR at Trinity College Dublin has a mature reconfigurable software-defined radio platform called Implementing Radio in Software (IRIS) [4]. This platform enables developers to rapidly prototype a myriad of software-defined radio-based applications using a suite of modular and dynamically reconfigurable software modules. As part of this measurement work, the authors have developed a module designed to interrogate and extract information from the database of spectrum measurements for use within software-defined radio applications. Using this, CTVR can demonstrate new wireless communications applications that make use of real-life, time-varying, and geographically-varying spectrum-usage measurements. This module has enabled developers to prototype dynamic-spectrum access-based systems using more realistic test cases than what conventional simulation platforms can offer. The value of this module is that it has accelerated the development process and increases the confidence in expected outcomes before real-world trials are conducted.

The spectrum database module enables the developer to query and extract spectrum measurement data based on location, time, and received power levels. As part of a signal-processing chain in a dynamic spectrum access system, this source of information can be injected directly into the transceiver chain or used within an external control logic system facilitating pseudo ‘real world’ tests prior to actual field test deployments.

5. CASE STUDIES

Figure 5 is an example of a three-dimensional power spectral density plot of the 700MHz band while travelling eastwards through the Topeka, Kansas region. In this figure, the dominant spectrum user is a MediaFLO orthogonal frequency division multiplexing (OFDM) service designed to stream audio/video/data to mobile devices [5]. Figure 6 is a spectrogram alternative view of this band where the power of the intercepted signal is denoted by a range of colors from blue (low or no received signal) to red (strong intercepted signal power).

The spectrum database component acts as a signal source, reading measurement data from the database and providing the results of the query as an input to the transceiver process. Time can be simulated by advancing or retarding the rate at which spectrum data are extracted from the database and provided to the system under test.

An example of usage includes a white-space detector implemented within the IRIS framework requiring tests using real-world spectrum occupancy measurements before field tests are conducted. Using the same measurement data, alternative detector designs and decision metrics can be rapidly prototyped and compared before a final design is chosen for field testing and deployment.

Using the spectrum occupancy information displayed in Figure 5 and Figure 6, the spectrum database component facilitates testing of an energy detection based dynamic spectrum access system built using IRIS. In this case, a simulated 6.3MHz bandwidth secondary-user dynamic spectrum access OFDM transmission is centered on 716.8MHz. When the received power from the MediaFLO transmission centered within the bandwidth of the simulated secondary user transmission exceeds -96dBM, the secondary-user signal changes frequency. The dynamic spectrum access system moves the transmission frequency to 726.6MHz where no other primary or secondary user transmission has been detected. The combined spectrum measurements information and injection of the simulated secondary-user transmission are illustrated in Figure 7. In order to highlight simulated injection of the secondary user transmission, Figure 8 is a three-dimensional spectrum occupancy plot of the difference between the combined spectrum usage plot shown in Figure 7 and the original spectrum measurement data illustrated in Figure 6. In this example scenario, detection thresholds and guard spacing between primary users and opportunistic secondary users may be varied in order to evaluate the risk of interference to existing users in the band of interest before attempting to conduct real-life licensed tests. It is important to note that no live secondary user transmissions were initiated during these tests.

5. CHALLENGES

The technical challenges faced by the authors during the mobile spectrum measurements work included maintaining continuous operation of the spectrum analyzer and laptop within the confines of the vehicle. At one stage during the journey, the maximum recorded internal temperature of the analyzer was 54 degrees Celsius due to a temporarily obstructed air vent. Occasional anomalous measurements were noted due to this reason and also from continuous operation of the analyzer and capturing system for ten hours or more per day. These erroneous measurements were identified by uncharacteristically uniform spectral density measurements across the observation band that significantly exceeded the range of expected received power levels. The number of these trace captures was considerably low; in the order of one in two thousand, which were identified by the reported power levels outside of the expected received power range and then filtered from the database.

It was not possible to maintain a continuous speed for the entire duration of the route. This affected the distance between measurement points; as the pace increased, the distance between measurement points increased and vice versa. The maximum recorded distance between measurement points was approximately 800m.

The spectrum analyzer analogue to digital conversion stage was overloaded at one stage during the route. This occurred when the authors' vehicle passed very close to the MediaFLO OFDM transmission site near Topeka, Kansas. The received power level near the transmission site was in excess of -15dBm.

Challenges also arise regarding the use of the spectrum measurement data set for system prototyping and testing. These include the inability to emulate channel effects beyond additive interference i.e. intermodulation and spurious emissions due to the introduction of an artificially generated waveform in the simulated spectrum environment, and the effects of transmitter local oscillator leakage and nonlinearity in the transmission power amplification stages. The reasons for this are that the tests do not involve live transmission, i.e. they are carried out in a simulation environment and that the spectrum measurement data represent absolute power measurement data and not time-domain in-phase and quadrature signal components. Interference that may be experienced by existing primary users within the band of interest cannot be determined exactly without live transmissions and quality of service information derived from a set of receiver nodes within the geographical test area. However, the availability of actual absolute power measurements provides a critical function in enabling legacy user detection, avoidance, spectrum assignment and information fusion schemes (i.e. using two or more sources of information as part of the decision process) to be tested.

The spectrum measurements set and software tools are available at http://www.ctvr.ie/en.

6. CONCLUSIONS

This paper has presented some key outcomes from mobile spectrum measurements in the 698MHz-806MHz band covering in excess of 4500km along a route from Denver, CO to Washington DC during November 2007. An outline of how the collected spectrum measurement data are being used for offline prototype dynamic spectrum access-based system development by CTVR has been presented. This database is being made available for other academic and industrial research work worldwide in a bid to narrow the gap between simulation and real-world tests, significantly reduce the time to market and costs of conducting field tests and accelerate the development of SDR-based dynamic spectrum access systems. Further information regarding this work is available at http://www.ctvr.ie/en/blog

7. REFERENCES

[1] Software Defined Radio Forum http://www.sdrforum.org

[2] http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73

[3] Anritsu MS2721B Spectrum Master. Information available at: http://www.anritsu.com

[4] Doyle, L.E., Nolan, K.E. et al., A Platform for Dynamic Spectrum Experimentation ", under review for the First International Workshop on Technology and Policy for Accessing Spectrum (TAPAS), Boston, August 1-5 2006.

[5] http://www.mediaflo.com

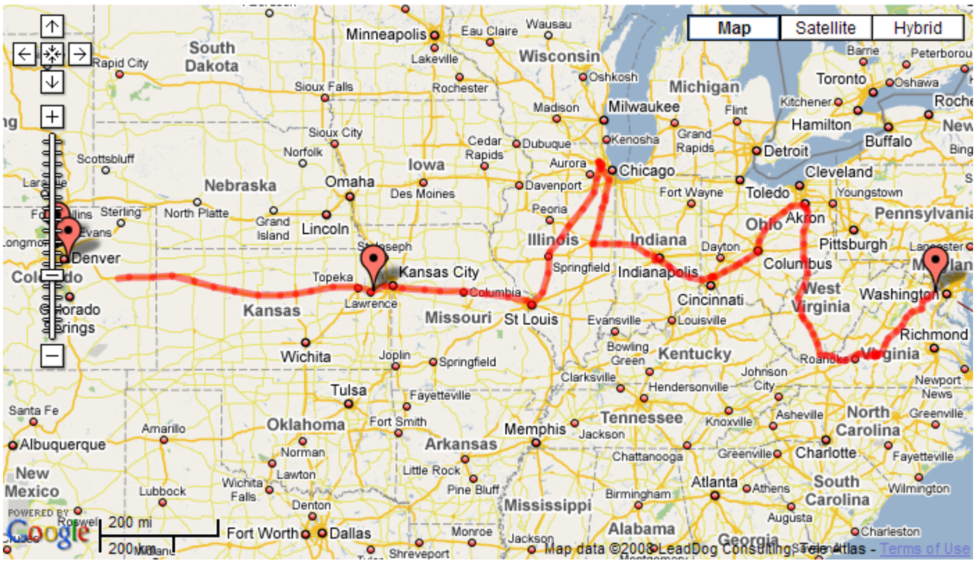

Figure 1. The route taken by the authors from Denver, CO, towards Washington DC. The GPS track begins east of Denver, Colorado.

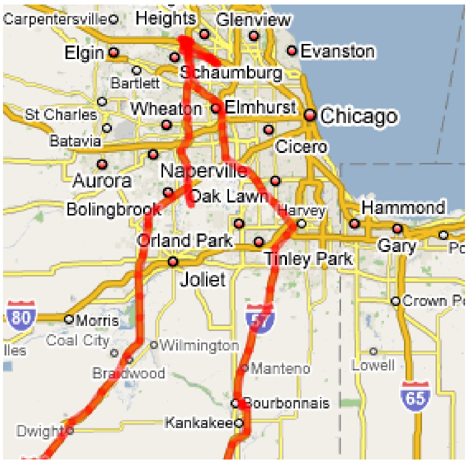

Figure 2. A section of the route taken by the authors as they travelled from Kansas to Schaumberg, IL., and then onwards to Cincinnatti, OH.

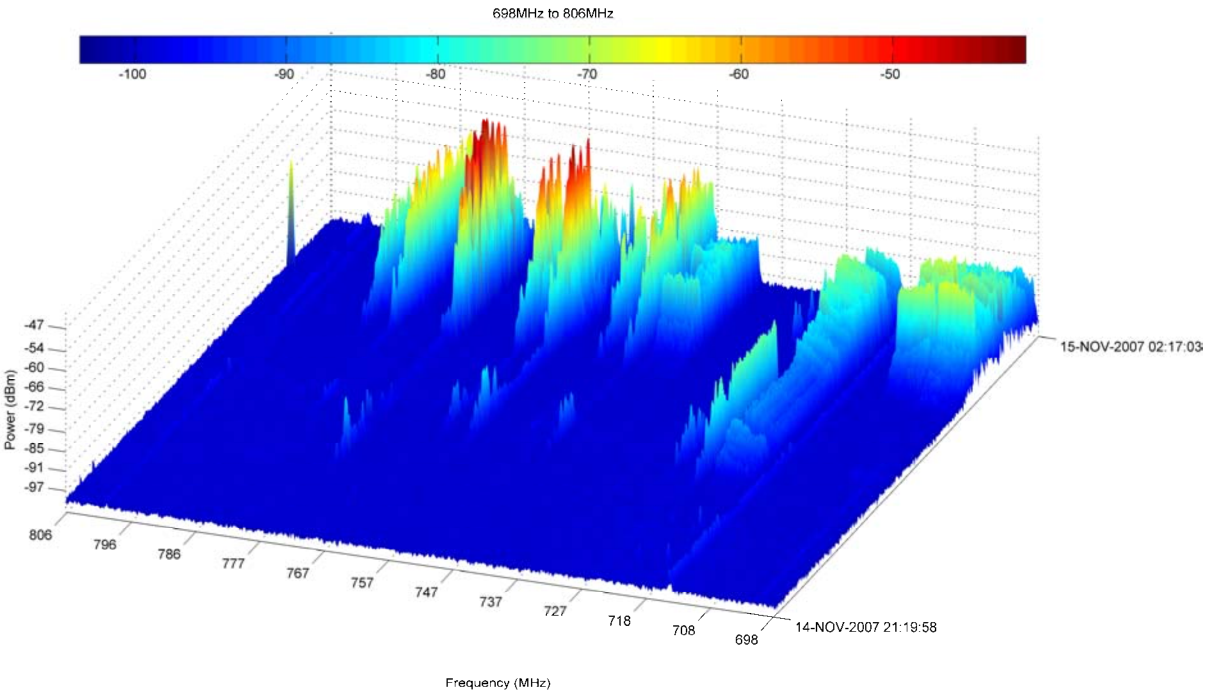

Figure 3. A plot of the spectrum occupancy for the route shown in Figure 2. Frequency is shown on the X-axis, time and date are represented on the Y-axis and the received power levels in dBm are displayed on the Z-axis.

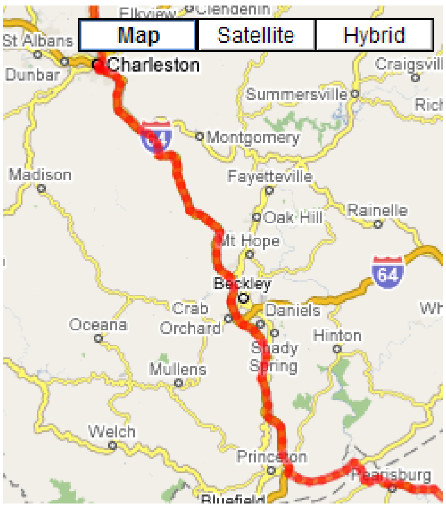

Figure 4. A GPS track showing the route taken by the authors from Charleston, West Virginia to Blacksburg, Virginia.

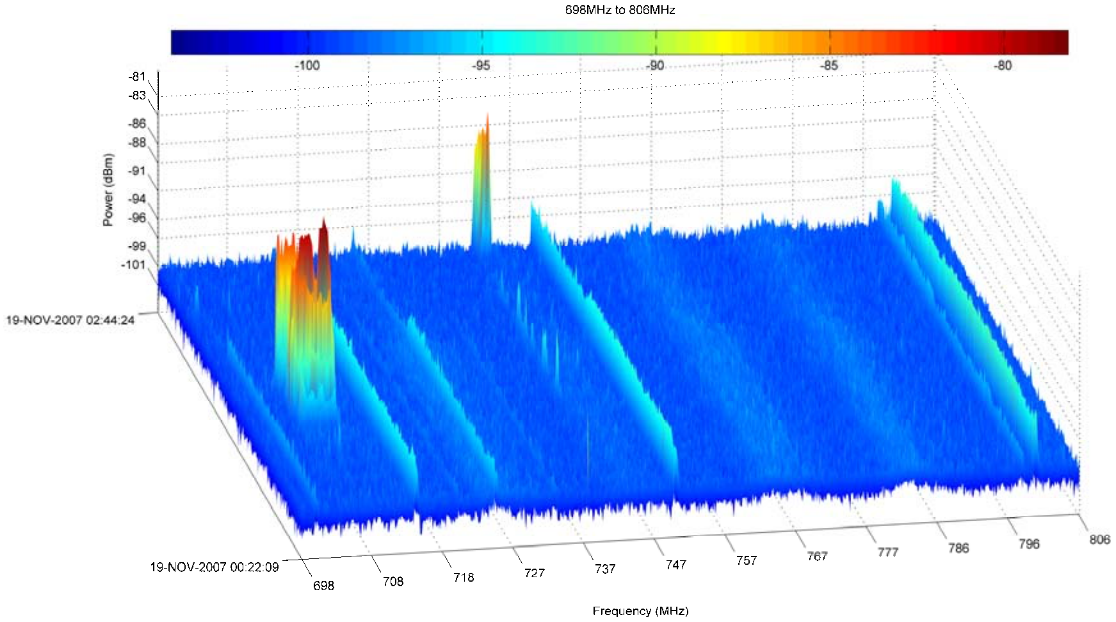

Figure 5. A three-dimensional spectral-occupancy plot for the route shown in Figure 4. Frequency is displayed on the X-axis, time and date information on the Y-axis and received power levels in dBm on the Z-axis.

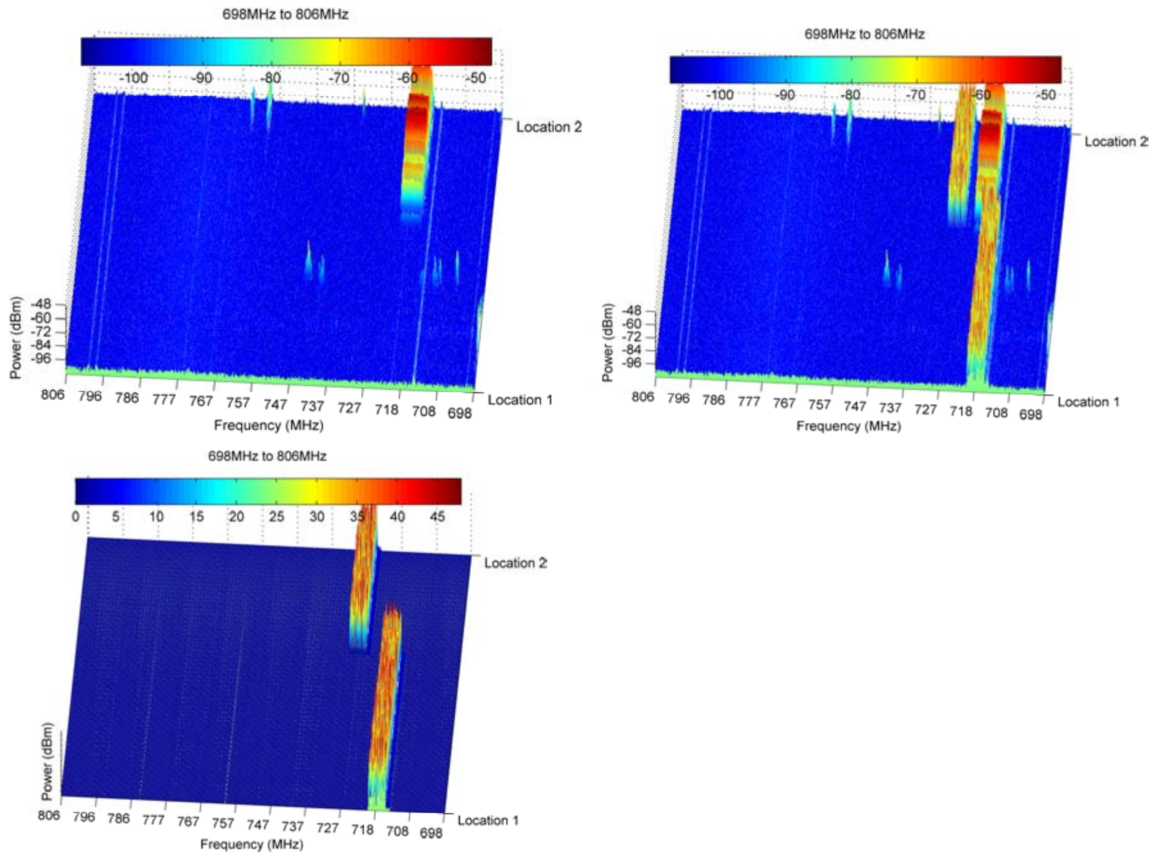

Figure 6,7,8 (clockwise from the top). A plot of spectrum usage in the Topeka, Kansas region. The main visible received signal is a MediaFLO service centered at 719MHz. The plot on the top right is the same spectrum usage plot with the simulated injected OFDM-based dynamic spectrum access secondary user transmission. The plot on the bottom left shows the isolated injected OFDM secondary-user transmission.