IEEE 802 Tutorial
Spectrum Occupancy Sensing

Apurva N. Mody (WhiteSpace Alliance)
Anoop Gupta (Microsoft)
Chittabrata Ghosh (Nokia)
Sumit Roy (U. of Washington)
Chad Spooner, (NorthWest Research Associates)
Erik Luther (Ettus/ National Instruments)
Ivan Reede (AmeriSys)

IEEE 802 Plenary Meeting, July 14th, 2014, San Diego
Agenda

• Introduction of the Panelists and Overview of Spectrum Occupancy Sensing - Apurva N. Mody (Chairman, IEEE 802.22 WG) (5 minutes)

• Spectrum Observatory - Anoop Gupta (Microsoft) (15 minutes)

• Sensing to Complement Spectrum Management - Sumit Roy (U. of Washington) / Chittabrata Ghosh (Nokia) (15 minutes)

• Advances in Spectrum Sensing - Chad Spooner (NWRA) (15 minutes)

• Hardware Devices to enable Spectrum Occupancy Sensing - Erik Luther (Ettus/National Instruments) (15 minutes)

• Spectrum Sensing Implementation and Applications - Ivan Reede (AmeriSys) (15 minutes)

• Conclusions and Q&A (10 minutes)
Spectrum Sharing, A Digital Opportunity

- **Developed Countries**: More than 500 MHz of spectrum will be required before 2020 to support emerging wireless broadband services and applications.

- **Developing Countries**: Cost effective broadband access is still a challenge in rural areas and developing countries.

- **Spectrum sharing** can create tomorrow’s spectrum super-highways. It supports licensed, license-exempt and hierarchical access business models.

- **Technologies and Standards** supporting Cognitive Radios, Sensing and Database enabled spectrum access exist.
IEEE 802.22 WG on Cognitive Radio Based Spectrum Sharing and Wireless Regional Area Networks

IEEE 802.22 WG is the recipient of the IEEE SA Emerging Technology Award

IEEE 802.22 Standard – Wireless Regional Area Networks: Cognitive Radio based Access in TVWS

IEEE 802.22 Standard for Operation in Bands that Allow Spectrum Sharing

IEEE 802.22.1 – Std for Enhanced Interference Protection using beaconing

IEEE 802.22.1a – Advanced Beaconing

IEEE 802.22.2 – Std for Recommended Practice for Deployment of 802.22 Systems

NEW!! Spectrum Occupancy Sensing (SOS)

IEEE 802.22a – Enhanced Management Information Base and Management Plane Procedures

IEEE 802.22b Enhancement for Broadband Services and Monitoring Applications

Apurva N. Mody, Chairman, IEEE 802.22 Working, apurva.mody@ieee.org,
Chang-woo Pyo, Vice Chair, IEEE 802.22 WG, www.ieee802.org/22

IEEE SA awards ceremony
Spectrum Occupancy Sensing (SOS) Applications

- Quantification of the available spectrum through spectrum observatories
- On-demand spectrum survey and report
- Collaborative spectrum measurement and calibration
- Labeling of systems utilizing the spectrum
- Spectrum planning
- Spectrum mapping
- Coverage analysis for wireless deployment
- Terrain and topology - shadowing and fading analysis
- Complement the database access for spectrum sharing by adding in-situ awareness and faster decision making.
- Space-Time-Frequency spectrum hole identification and prediction where non-time-sensitive tasks can be performed at certain times and at certain locations, when the spectrum use is sparse or non-existent
- Identification and geo-location of interference sources.
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SOS for Spectrum Observatory

Anoop Gupta, Microsoft

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http://observatory.microsoftspectrum.com

Created to provide an intuitive presentation of the usage of the wireless spectrum. The project is sponsored by Microsoft's Technology Policy Group and the data is made freely available to the public. Data is recorded through monitoring stations and is stored and processed for visualization through the Microsoft Azure cloud.
Our Goals

A global spectrum-monitoring platform:
- Provides evidence (hard data) of the spectrum usage
- Aids in policy and regulation decisions
- Helps DSA systems

• Large Scale
  - Distributed to world-wide research orgs
• Low Cost
  - Suitable for large deployment
Adding New Stations

• Go to http://observatory.microsoftspectrum.com
• Sign in to the site (registration is required to register a new station)
• Click on the “Register New Station” button under where the sign in button was:

  • Hardware requirements, setup instructions, and links to monitoring software are displayed
  • Enter the information for the station (point of contact, location...)
  • Station will be approved by a Microsoft admin, and a station ID will be assigned
Openness and Collaboration

Working with university partners
- University of Washington
- MIT
- Rice
- UCSB

Released under Apache 2.0 OSS license on CodePlex:
https://spectrumobservatory.codeplex.com/

Full access to the all uploaded data available upon request. E-mail spectrum_obs@microsoft.com
System Overview

Radio Frontend

- **Outdoor Antenna**
- **Signal Splitter**
- **USRP1 (SBX)**
  - 400-4400MHz
- **USRP2 (WBX)**
  - 50-2200MHz
- Per USRP:
  - Sampling Rate: 50 MS/s
  - Instant BW: 40MHz

End User

- **Local Process & Control**
  - Feature Vector Extraction
  - Smart Scheduling / Scanning
  - Custom Device Support

Cloud & Storage

- **Data**
- **Control**
- **Processed Data**
- **Backwards Control**
- **Visualize**
- **Cmd**

Policy Makers

- **DSA Users**
- **Researchers**

Real-time/History Occupancy

- User Signal Feature
- Other Information...

End User

Tutorial on Spectrum Occupancy Sensing (SOS), IEEE 802 Plenary Meeting, July 14th 2014, San Diego
What can this be used for?

Which frequency band should I use?

- Occupancy information
- List of less occupied bands

What is the best timing for transmission?

- Existing users’ time pattern

What are the possible interferers?

- A list of existing users
- A signal pattern for each of the existing users
Real-time Database for DSA

- **Raw Power Spectrum**
- **Frequency bands**
- **Divide**
- **Per Band**
- **Legitimate User Other Users**
- **Learned Feature**
- **Occupancy History**
- **Per-user information**
- **User List**
Next Steps

• Onboard hundreds or thousands of new stations
• 3rd parties performing new analysis of data and going beyond basic presentation
• Uploading of much more granular data to the cloud
• Support for more RF Sensors
• Experiments for specific bands
• Support for mobile sensing stations
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Spectrum Sensing to Complement Spectrum Management

Chittabrata Ghosh (Nokia)
chittabrata.ghosh@nokia.com
Prof. Sumit Roy (Univ of Washington, Seattle)
roy@ee.washington.edu
TVWS Final Rules: Databases

- Device identifies its location and accesses a database that tells the device what spectrum is available.

- Database identifies protected services & locations: Full power TV, low power TV, wireless microphones…

- Model is transferrable to other spectrum bands.
Basic Challenges in Sensing

- **Better HW & SW** (reconfig HW, DSP, sensing, multi-band…)
  - Affordable, dynamic receivers that can move around in a wide band with high channel selectivity

- **Sensing versus GeoDB** – in a world of high protection ratios
  - “Dumb” detectors can't match performance of a matched filter
  - Broadcasters want protection below kTB, not practical, hence GeoDB
    - Incumbents demand high detection probability (Pd), which drives false alarm probability (Pfa) high - more sophisticated time-frequency signal processing (cyclostationary) improves the situation...but at what cost?

- **Proper operation** – ensuring the GeoDB system
  - Progress is being made, but focus required on coordination, validation, security…
    - Processes for detecting, identifying, locating, mitigating and reporting interference sources; building confidence that the applicable rules and regulations regarding such sharing will be enforced
UW Spectrum Observatory (SpecObs) Database

http://specobs.ee.washington.edu/
SpecObs Server Architecture

- Web Browser
- FCC CDBS
- Primary Parameters
  - Location
  - TVWS Info (Noise Floor, Capacity, WS channels)
- Propagation Engine
- Analysis Engine
- Geostatistics Engine
- Terrain Data
  - Elevation: 900 x 900 m, 90 x 90 m, 30 x 30 m
- Terrain Data
  - Primary Parameters, Protection Region
  - Antenna Pattern
  - Primary Parameters, Protection Region
- Terrain Data
  - Interpolated sample data for new location
- Web Server
  - Data Manager
    - Freq. and RSSI with location and time
- Primary Parameters
  - Primary Parameters
  - Sensing DB
  - Geostatistics DB
  - Antenna Pattern DB
- Analysis Engine
  - Sensing DB
  - Geostatistics DB
  - Interpolated sample data for new location
- Antenna Pattern DB
  - Interpolated sample data for new location
SpecObs Functions

- Displays TV coverage with Longley-Rice model for various TV types
- Secondary Network Planning
  - Show coverage of secondary networks
  - Coverage defined in the FCC ruling
Query data by various options

Show TV White Space Data
(Example Data for latitude: 40.3832, longitude: -96.0511)

Protection region of each TV channel
Scenario 1: FCC Defined Coverage Area for Single TV Channel

- Geographic area within the TV station’s noise-limited contour
  → Defined with F-Curve and Field Strength Threshold

Input Parameters
- Distance (TX and RX)
- Channel
- Propagation Curve
- ERP
- TX HAAT

CalcFieldStrength()

Output Parameters
- Field Strength (dBuV/m)

Coverage Area computed by F-Curve (KIRO-TV in Seattle)

<table>
<thead>
<tr>
<th>TV Type</th>
<th>Channel 2-6</th>
<th>Channel 7-13</th>
<th>Channel 14-51</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog</td>
<td>47</td>
<td>56</td>
<td>64</td>
</tr>
<tr>
<td>Digital</td>
<td>28</td>
<td>36</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 1. Field Strength (dBuV/m) Threshold to define TV coverage
Longley-Rice Model

- L-R P2P mode
  - Input – All elevation value (every 100 m) and distance between TX and RX
  - Output – Field Strength (dBuV/m)
  - Takes account for LOS, diffraction, scatter effect with terrain data
  - The below figures show L-R P2P mode is sensitive to terrain elevation
SpecObs Coverage using L-R P2P

- Method using classification algorithm
  - Calculate field strength at all dense points around transmitters with L-R P2P mode
  - Run K-NN algorithm to classify points as WS or service regions

Estimation of L-R field strength (KIRO-TV)

Comparison of coverage (KIRO-TV)
L-R P2P Vs F-Curve
Scenario 2: Two Co-channel TV stations

- Two nearby DTV stations operating co-channel (channel 39)
  - coverage regions partially overlap per F-curve
- High possibility of co-channel interference

Coverage area for WMYT-TV and WKTC (F-Curve)

Undesired Station
Channel: 39
Call sign: WKTC
Service type: DT
ERP: 500.0 kW
HAAT: 391.0 m
Antenna Type: DA
Coordinate: 34.11611,-80.76417

Desired Station
Channel: 39
Call sign: WMYT-TV
Service type: DT
ERP: 225.0 kW
HAAT: 571.0 m
Antenna Type: ND
Coordinate: 35.36222,-81.15528
SpecObs Results

- Result of TV Coverage (WMYT-TV)
  - Calculates SNR-based coverage and SINR-based coverage
  - Run KNN algorithm to compute a closed-loop coverage
  - SINR-based coverage are lost some service regions of WMYT-TV due to interference from WKTC

WMYT-TV service region and coverage based on SNR threshold (16 dB) and $K = 250$

Total error rate = 15.376 %
Type 1 (8.218 %) + Type 2 (7.158 %)

WMYT-TV service region and coverage based on SINR threshold (15.16 dB) and $K = 250$

Total error rate = 13.916 %
Type 1 (6.491 %) + Type 2 (7.425 %)
SpecObs Results Comparison

- Comparison of TV Coverage
  - SINR-based coverage of two stations are distinct
  - Our approach shows better estimation of coverage
TV White Space Capacity

- Need to go beyond just WS listing, need to answer
  "How much white space *capacity* is available to secondary users at a location?"
  -> max rate a *single* secondary user may reliably transmit at a point
# Channel Availability Statistics

<table>
<thead>
<tr>
<th>Device Type</th>
<th>LVHF (2:6)</th>
<th>HVHF (7:13)</th>
<th>LUHF (14:51)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Available</td>
<td>2.36</td>
<td>2.59</td>
<td>21.77</td>
<td>26.73</td>
</tr>
<tr>
<td>Fixed Devices</td>
<td>2.36</td>
<td>2.59</td>
<td>15.2</td>
<td>20.17</td>
</tr>
<tr>
<td>Portable/Personal</td>
<td>0</td>
<td>0</td>
<td>18.79</td>
<td>18.79</td>
</tr>
<tr>
<td>Microphone Reserved</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Busy Channels by TV</td>
<td>0.45</td>
<td>2.22</td>
<td>10.43</td>
<td>13.11</td>
</tr>
<tr>
<td>Unused Channels</td>
<td>2.18</td>
<td>2.19</td>
<td>4.67</td>
<td>9.05</td>
</tr>
<tr>
<td>Channel Utilization Factor</td>
<td>%56</td>
<td>%68</td>
<td>%89</td>
<td>%81.5</td>
</tr>
</tbody>
</table>
Modeling: Validation of Beta Distribution in Spectrum Occupancy

Beta Distribution with estimated $\alpha$ and $\beta$ over expected channel availabilities between 3:00 - 4:00 pm (left) and between 7:00 to 8:00 am (below)

Table 1: Observed and Expected Frequencies of Spectrum Occupancy

<table>
<thead>
<tr>
<th>Time of the day</th>
<th>Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0-0.2</td>
</tr>
<tr>
<td>Observed(7 – 8am)</td>
<td>21</td>
</tr>
<tr>
<td>Expected(7 – 8am)</td>
<td>22.27</td>
</tr>
<tr>
<td>Observed(12 – 1pm)</td>
<td>23</td>
</tr>
<tr>
<td>Expected(12 – 1pm)</td>
<td>23.3</td>
</tr>
<tr>
<td>Observed(3 – 4pm)</td>
<td>16</td>
</tr>
<tr>
<td>Expected(3 – 4pm)</td>
<td>16.86</td>
</tr>
<tr>
<td>Observed(11p – 12a)</td>
<td>15</td>
</tr>
<tr>
<td>Expected(11p – 12a)</td>
<td>15.6</td>
</tr>
</tbody>
</table>
Advantage of Combining SOS with Current Database Architecture

Shows available sum capacity over the U.S graphically.
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Advances in Spectrum Sensing: Applying Cyclostationary Signal Processing to Cognitive Radio Problems

Chad M. Spooner, PhD
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Outline of Presentation

• The problem of interest
  – Spectrum sensing: detection, classification, characterization

• An attractive solution and its difficulties
  – Energy detection

• An alternate family of solutions
  – Cyclostationary signal processing (CSP)

• Spectrum sensing with CSP
  – Multiple-Signal Scene Analyzer
  – Narrowband processing for wideband signals
  – Radio-frequency environment map (RFEM) estimation for CR

• Future direction
The Problem of Interest: Primary and Secondary User Signal Detection; White-Space Detection

Complications:

• Time-variant noise floor

• Colored noise floor

• Weak signals due to propagation effects

• Interference

Detect Occupied Bands

Verify Empty Bands are Truly Empty
Energy Detection (ED): Inexpensive Spectrum Sensing

- Measure energy in any band of frequencies
  - Sum the squares of the complex samples, or
  - Integrate subband of PSD estimate
- Compare to energy expected due to known noise PSD
  - Requires knowledge of $N_0$
- Noise uncertainty and/or variability causes poor performance for weak signals (“SNR Wall”)
- Limited ability to discriminate between different signals
- Limited ability to tolerate cochannel interference
- Can use inexpensive ED to cheaply find obviously occupied channels
- Then use more complex methods to verify unoccupied bands are truly unoccupied
- Multi-resolution spectrum estimators can be used to handle RF scenes with high dynamic ranges in signal power and signal bandwidths [1]

- Need noise- and interference-tolerant detectors for weak signals

Beyond Energy Detection:
Cyclostationary Signal Processing (CSP)

- The cycle frequencies (CFs) $\alpha$ are key [2]
- For nonlinearities like $x(t + d)x^*(t)$, the CFs are called non-conjugate:
  - Symbol, bit, chip, and hop rates and harmonics
- For nonlinearities like $x(t + d)x(t)$, the CFs are called conjugate:
  - Doubled carrier frequencies
  - Doubled carriers +/- non-conjugate CFs
- The preferred higher-order nonlinearities are the cyclic cumulants [2]

The Power of CSP: Noise Tolerance

DSSS QPSK in moderate noise (left) and strong noise (right).
DSSS QPSK in moderate noise and interference with simplified cycle frequencies for easier feature viewing.
Applied CSP: The Multiple-Signal Scene Analyzer (MSSA) [3]

- Single-sensor processing

- Goal is to automatically recognize and characterize very wide variety of communication signals

- Spectral correlation and cyclic cumulants lead to interference tolerance and feature generality

- Multiple copies and hosting hardware in use in USG labs

Applied CSP: Spectrum Sensing with the COTS Components System

- The system integrates the MSSA with COTS hardware to form acquisition and processing capability
- Development ongoing
Applied CSP: Wideband Signal Detection Using A Few Narrowband Subchannels

Note many strong small CFs

Implies that signal can be detected without processing full 10 MHz BW [5]

Applied CSP: Radio-Frequency Environment Map (RFEM) Estimation

- Multiple independent CRNs vie for limited number of spectral bands

- External sensor network used to automatically and blindly estimate the RF environment [6]
  - Emitter locations
  - Modulation types
  - Tx power levels
  - Path-loss exponents

- RFEM used by spectrum access manager to maximize number of granted network-access requests

Future Directions: Algorithmic Cost Reduction

- Blind
- Non-Blind

<table>
<thead>
<tr>
<th>Increasing Mathematical Complexity</th>
<th>Increasing Computational Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time/Freq/Phase Histograms</td>
<td>Cumulant Classifier</td>
</tr>
<tr>
<td>Constellation Analyzer</td>
<td>Energy Detector</td>
</tr>
<tr>
<td>Spectral Correlation Analyzer</td>
<td>Multi-Cycle Detector</td>
</tr>
<tr>
<td>Cyclic Cumulant Analyzer</td>
<td>Multiple-Signal Multi-Cycle Detector</td>
</tr>
<tr>
<td>Multiple-Signal Cyclic Cumulant Analyzer</td>
<td></td>
</tr>
</tbody>
</table>

Desired Operating Region

Increasing Tolerance to Noise and Co-Channel Interference
Increasing Classification–Decision Resolution
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Software Defined Radio (SDR) for Spectrum Sensing

Erik Luther (Ettus Research / National Instruments)

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Common SDR Architecture
Candidates for Shared Spectrum

- ISM
- TV Bands
- PCAST

Discrete RF Solutions

Common RFIC Solutions

Discrete RF

RFIC
RFIC Enables Smaller Form Factors

Mobile phone sized package
- 70 MHz - 6 GHz
- Embedded Linux
- Embedded Ethernet
- Internal GPS
- USB Host connections

Size: 120x90x50 mm
SDR Processor Example

- FPGA = widest bandwidth, lowest latency
- GPP = convenient and easily programmable
- GPU = offloading intensive parallelizable algorithms & visualization
GNU Radio Design Flow Example

DSP Block – C++ Work Function

```c
int gr_add_ff::work(int noutput_items,
                     gr_vector_const_void_star &input_items,
                     gr_vector_void_star &output_items)
{
    float *out = (float *) output_items[0];
    int noi = d_vlen*noutput_items;
    memcpy(out, input_items[0], noi*sizeof(float));
    volk_32f_x2_add_32f_a(out, out, (const float*)input_items[i], noi);
    return noutput_items;
}
```

• Blocks
  • Large library of existing IP -> Mod/demod, filters, USRP I/O, GUI features, etc.
  • Write custom blocks – C++ or Python
• GNU Radio Companion (optional)
  • Import blocks
  • Connect blocks
  • Generate python source code for flowgraph
• Python Flow-Graph
  • Generate from GRC and/or hand-write
  • Simplifies block connectivity

Python Flow-Graph

```python
tb = gr.top_block()
src1 = gr.sig_source_f(32000, gr.GR_SIN_WAVE, 350, .5, 0)
src2 = gr.sig_source_f(32000, gr.GR_SIN_WAVE, 440, .5, 0)
adder = gr.add_ff()
sink = audio.sink(32000)
tb.connect(src1, (adder, 0))
tb.connect(src2, (adder, 1))
tb.connect(adder, sink)
tb.run()
```
GNU Radio spectrum visualization example
Combining Models of Computation

- Describe the algorithm graphically
- Combine models of computation
- Seamlessly integrate I/O
Cognitive Radio & WhiteSpace Implementation

Spectrum Monitoring Testbed
- Spectral sensing with blind detection
- GPS geographic localization
- Active database management
- Adaptive spectrum utilization
SOS Software Defined Radio Examples

- Software Designed Instrumentation
- High Performance SDR Prototyping
- Desktop SDR
- Host Based SDR Prototyping
- Deployable SDR
- 2 MHz BW SDR (USB 2.0)
Summary

• Software defined radio is ideal for spectrum sensing

• Spectrum sensing considerations
  – Bandwidth
  – RF performance
  – Deploy-ability

• Multiple software design to deploy approaches
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Spectrum Sensing Implementations and Applications

Ivan Reede (AmeriSys)
Spectrum Sensing Implementations

- Various implementations exist
- From high end, lab grade test equipment
- To low end, mass market/consumer grade devices
Spectrum Sensing Implementation
Two main kinds of devices

• Test equipment

• SOS Internet of Things (SOS-IoT)
Spectrum Sensing Implementation
Test Equipment

• Usually have a direct interface to an operator

• Are not primarily designed to fit in the typical client-server model
Spectrum Sensing Implementation of SOS-IoT

- Are designed to fit in a client-server network model
- Need to be part of a network to achieve their full potential
- Communicate via UDP/IP or TCP/IP such as ssh or http or https
- Servers usually are coupled to an SDR and appropriate software
  - They communicate with one or more clients
- Clients often perform post-processing jobs such as
  - Correlate the output of many servers into area map
  - Presenting results to operators
  - In turn, take the role of servers to other clients in a processing chain
Spectrum Sensing Implementation and Applications

- SOS-IoT devices deserve immediate IEEE802 standardization attention
  - Basic functionality needs to be standardized
  - Client-Server communications need to be standardized

- Such standardization has the power to transform
  - Current SDR devices
  - Into low cost, widespread consumer products
Example of SOS-IoT

Spectrum sensing can fit in a USB dongle

- USB3 I/Q
- 2.5Ms/s A/D
- Tuner
- 6/7/8 MHz BW
- 24-1766 MHz
- Antenna Port
Spectrum Sensing Implementation
Why standards are needed

• Current market is a jungle of implementations

• This is mainly due to
  • market is developing faster than standards
  • in a vacuum of standards
  • inconsistent performance amongst manufacturers rules

• Every manufacturer goes their way, making their own devices
Spectrum Sensing Implementation

Broad Market potential – currently, we have a jungle of SOS SDR candidates & tools

The current maverick expansion scenario in a standards vacuum

- Microsoft
- PDW
- DStar
- HDSDR
- NRF905 Decoder
- Redhawk
- SoftFM
- GNU Radio
- GR-AIS
- PowerSDR
- RTL-SDR
- GR-Phosphor
- GQRX
- DREAM
- SDR_Lab
- Trunk88
- Sdrangelove
- AmeriSys
- ShipPlotter
- Acarsdec
- WebRadio
- LTE-Scanner
- PlanePlotter
- Radio Receiver for Chrome
- rtalamr
- QtRadio
- Orbitron
- Studio1
- SDR-J
- AISMon
- OpenCPN
- Virtual Radar Server
- Multimode
- GR-Elster
- DAB_Player
- ViewRF
- ShinySDR
- GNSS
- coca1090
- adsbSCOPE
- gr-air-modes
- Ettus
- dl-fldigi
- Panorama
- NRF24-BTLE Decode
- Wavesink Plus
- Wavesink Plus
- SondeMonitor
- NRF905 Decoder
- NRF24-BTLE Decode
- RTL_433
- RDS_Spy
- ADSB
- GD-31 Deco
Spectrum Sensing Implementation
What standards need to do

- Standards are needed to define classes of devices by specifying
  - the PHY layer abilities for each class of device
  - the client-server communication protocols

- For the best results, servers standards should specify vendor independent
  - basic behaviours for each class of device
  - means to communicate abilities, limitations and observation results
Spectrum Sensing Implementation

Hardware requirements – TV band specific challenges

- The dynamic range of signals that need to be handled is challenging.
  - We will illustrate this by an example:
    - Assume Goliath is a 1 MegaWatt transmitter, (+90dBm)
    - A receiver close to Goliath receives its signal at +8 dBm (max TV receiver spec)
    - Simultaneously, to be sensitive down to the 6MHz BW noise floor at -103 dBm
    - A receiver needs to have a dynamic range of 111 dB
    - RF front end and down converters need exceptional linearity
    - Good high speed A/D samplers today give 14 bits resolution, or 84 dB dynamic range
    - In such a case, 27 dB of RF AGC is required to increase the receiver's dynamic range
    - This means that close to Goliath (+8dBm) anything less than -76 dBm is invisible
    - With DSP filtering alone, this is true, even if Goliath is on a channel quite far away channel from the observation channel
      - We call the zone around Goliath a “radio black hole” due to the receiver limitations
Spectrum Sensing Implementation

Hardware requirements – TV band specific challenge example

Signal strength

+8
+2
+4
+6
+8
+10
+12
+14
+16
+18
+20
+22
+24
+26
+28
+30
+32
+34
+36
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+70
+72
+74
+76
+78
+80
+82
+84
+86
+88
+90
+92
+94
+96
+98
+100
+102
+104
+106

Conclusion – DSP filtering alone is insufficient and requires analog filter assistance before A/D conversion to reject adjacent channel transmitters. This may also be true for RF chain, down converter and demodulator. If AGC is used, processor must know exact AGC attenuation and compensate.

At these levels signals are invisible

6 MHz BW noise floor

Full Gain
No AGC
AGC On
Can’t detect to Noise Floor
+8 dBm TV tuner acceptance spec
Spectrum Sensing Implementation
Conclusions

• SOS sensors will have hardware performance limitations
  • Far adjacent channel interference limitations
  • RF stage performance and limitations
  • A/D precision performance and limitations
  • Filtering performance and limitations
  • Demodulation performance and limitations
  • etc...
SOS observed Spectrum Occupation vs coverage area

- **Blue** – dashed line: Coverage based on No terrain information

- **Shaded**: Coverage based on SOS and terrain combination
Spectrum Sensing Implementation

Conclusions

• Standards are needed
  • to get consistent results
  • allowing correlation of result amongst many devices
  • which ultimately will be the strength of SOS
  • allowing the vast amount of fallow spectrum
  • to become available for opportunistic use
  • and allow everyone to view, in quasi real time
  • Store vast amount of data in a standardized format

• the actual spectrum use and the fallow spectrum that can be shared by other users
**Agenda**

- **Introduction of the Panelists and Overview of Spectrum Occupancy Sensing** - Apurva N. Mody (Chairman, IEEE 802.22 WG) (5 minutes)

- **Spectrum Observatory** - Anoop Gupta (Microsoft) (15 minutes)

- **Sensing to Complement Spectrum Management** - Sumit Roy (U. of Washington) / Chittabrata Ghosh (Nokia) (15 minutes)

- **Advances in Spectrum Sensing** - Chad Spooner (NWRA) (15 minutes)

- **Hardware Devices to enable Spectrum Occupancy Sensing** - Erik Luther (Ettus/National Instruments) (15 minutes)

- **Spectrum Sensing Implementation and Applications** - Ivan Reede (AmeriSys) (15 minutes)

- **Conclusions and Q&A** (10 minutes)
2.1 Title: Part 22.3: Standard Specifying Spectrum Occupancy Sensing (SOS) Measurement Devices and Means that Enable Coalescing the Results from Multiple Such Devices

5.2 Scope: The Spectrum Occupancy Sensing (SOS) Project creates a stand-alone system specifying measurement devices and means that enable coalescing the results from multiple such devices. The aim is to use messaging structures, interfaces and primitives that are derived from IEEE Std. 802.22-2011, and to use any on-line transport mechanism to achieve the control and management of the SOS system. This standard initially specifies a device operating in the bands below 1 GHz and a second device operating from 2.7 GHz to 3.7 GHz. This standard may specify interfaces and primitives to provide value added sensing information to various spectrum sharing database services.
5.4 **Purpose**: The purpose is to specify operating characteristics of the spectrum sensing devices.

5.5 **Need for the Project**: The project will enable creation of low cost sensors for improved spectrum utilization and other shared spectrum applications.
**Conclusions**

- Spectrum sharing can benefit *developed and developing countries*
- Spectrum sharing will create tomorrow’s spectrum super highways
- Current approach of using Database to enable Dynamic Spectrum Access in TV Band White Spaces has been implemented and tested
- Advanced spectrum sensing techniques have already been implemented in hardware
- Devices are becoming more sophisticated
- Spectrum Occupancy Sensing (SOS) systems can be used for spectrum management and also to complement database enabled spectrum access
References
