Entropic Analysis of Spectrum Sensing for Cognitive Radio

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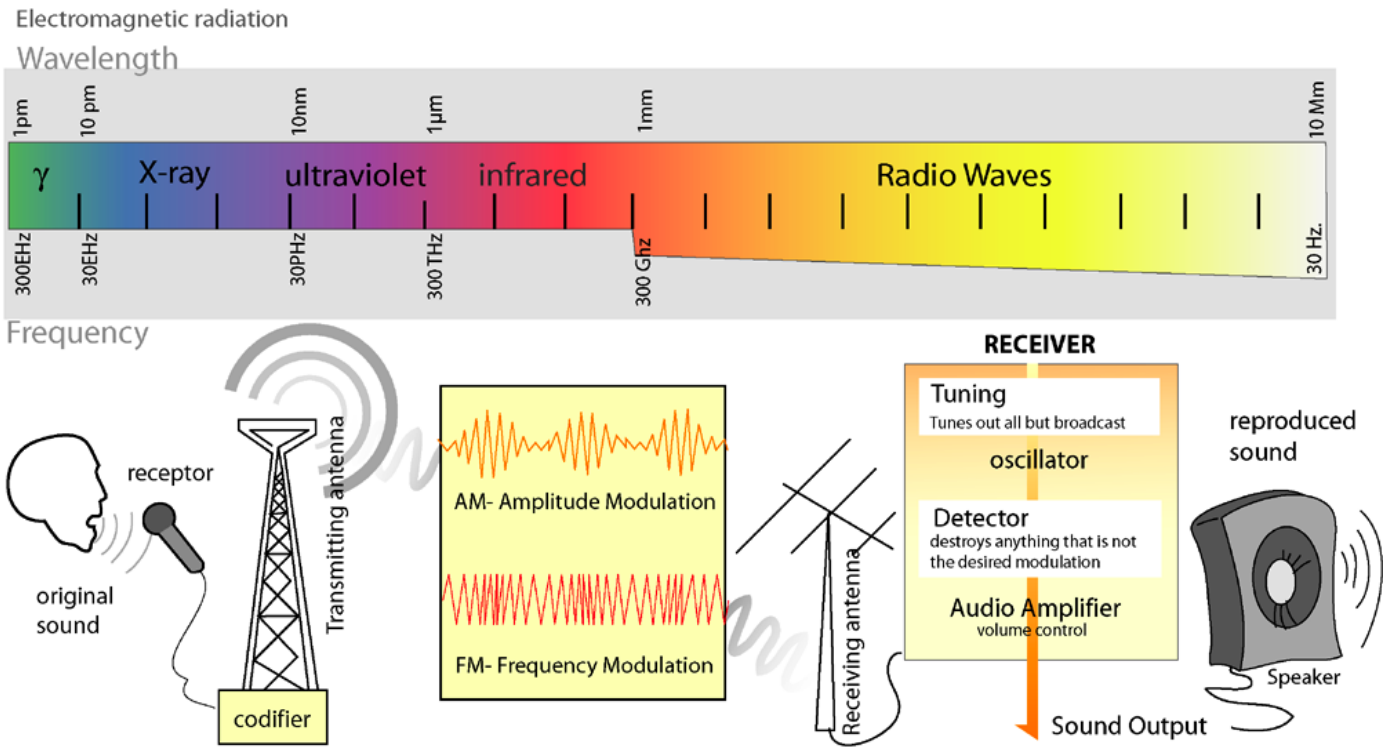
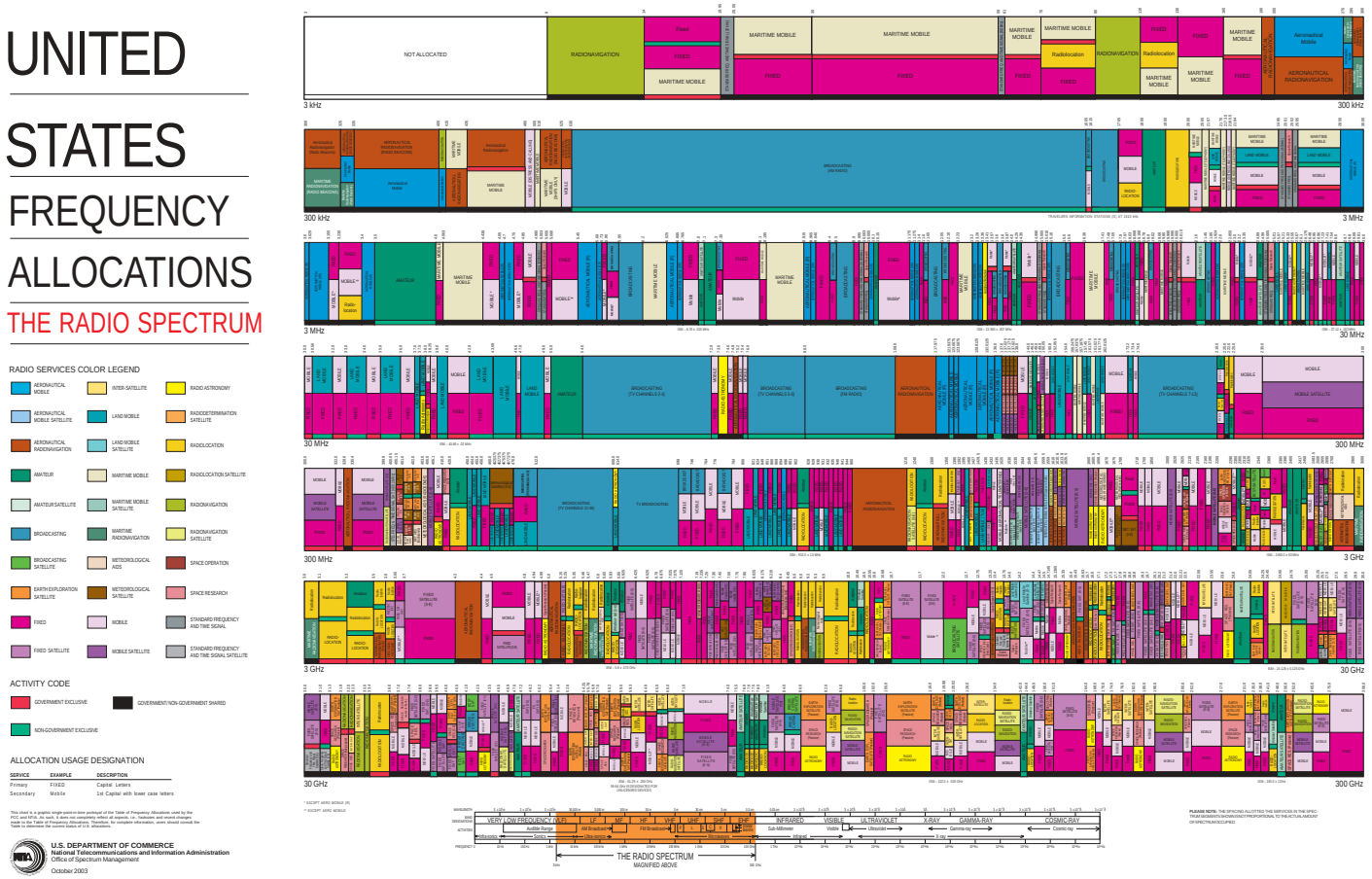
Undergraduate Research Symposium

Outline

Wireless Communications



FCC Frequency Allocation



Spatio-Temporal Variances In Spectrum Access

- FCC Study[1]: Utilization Varied From 15% To 85%
- Spatial Variances: Salt Lake City vs. Green River
- Temporal Variances: Business Hours vs. Late Evening
- If Only This Could Be Exploited. . .

[1] [FCC, 2003]

Fixed Spectrum Access

- Fixed Licensing Is Problematic
  - Crowded: No More Usuable Bands Available
  - Expensive: 90Mhz Recently Sold[2] For $13 Billion!
  - Under Utilized: Spatio-Temporal Variances
- We Need Something Better!

[2] [FCC, 2007]

Case Study: Public Safety Band Usage[3]

- Channels: 23
- Channel BW: 25KHz
- Total BW: 20MHz
- F_c: 856-869MHz

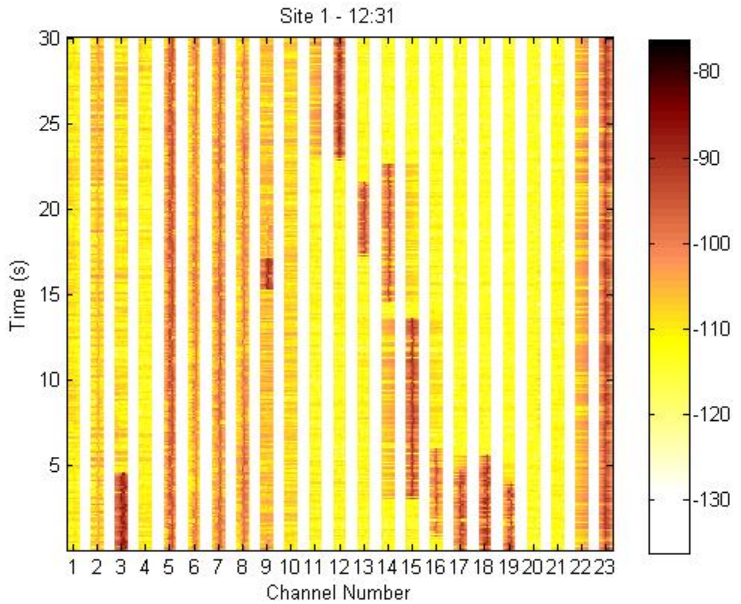


Figure: PSB Usage

[3][Jones, 2007]

Cognitive Radio

Definition [4]

A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

Adaptive Transmitter Parameters:

- Power Level
- Modulation Type
- Center Frequency

[4] [Haykin, 2002]

Hidden Terminal Problem

- Both Nodes Sense CR
- Can't Sense Each Other
- This Causes Interference

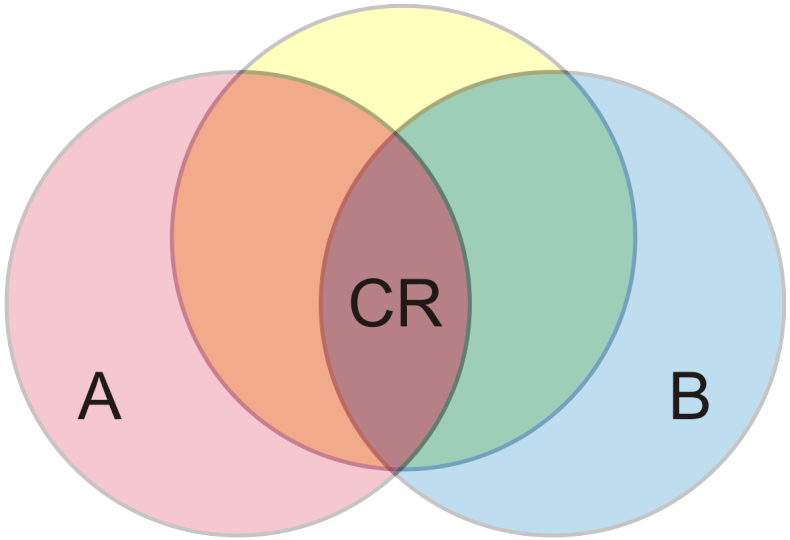


Figure: Hidden Terminals

Collaborative Spectrum Sensing

Pros

- Two Heads Are Better Than One!
  - i.e. More CR Nodes $\Longrightarrow$ More Accurate Detection [5]
- Solves Hidden Terminal Problem

Cons

- Some BW Wasted On Control Channel
- How Much?

[5] [Ghasemi, 2005]

Information Entropy [6]

Definition

The entropy of a discrete random variable X is a function of its PMF and is defined by

$$\mathrm{H}(X) = -\sum_{i=1}^{N} p_i \log p_i$$

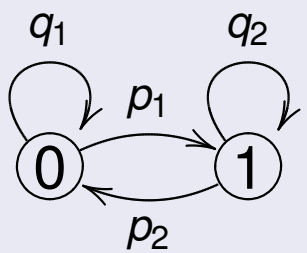
- The Number Of Bits Required By A Control Channel
- A Similiar Metric, Entropy *Rate*, Gives Bit Rate
- Need Only Know The PMF Of Primary User Activity

[6] [Shannon, 1948]

Widely Held Hypothesis

Hypothesis

Primary User Activity is a Markovian Process.



- PU Activity Depends Only On Previous State(s)
- This Is The PMF We Could Use To Measure BW Loss
- But Is This Hypothesis Correct?

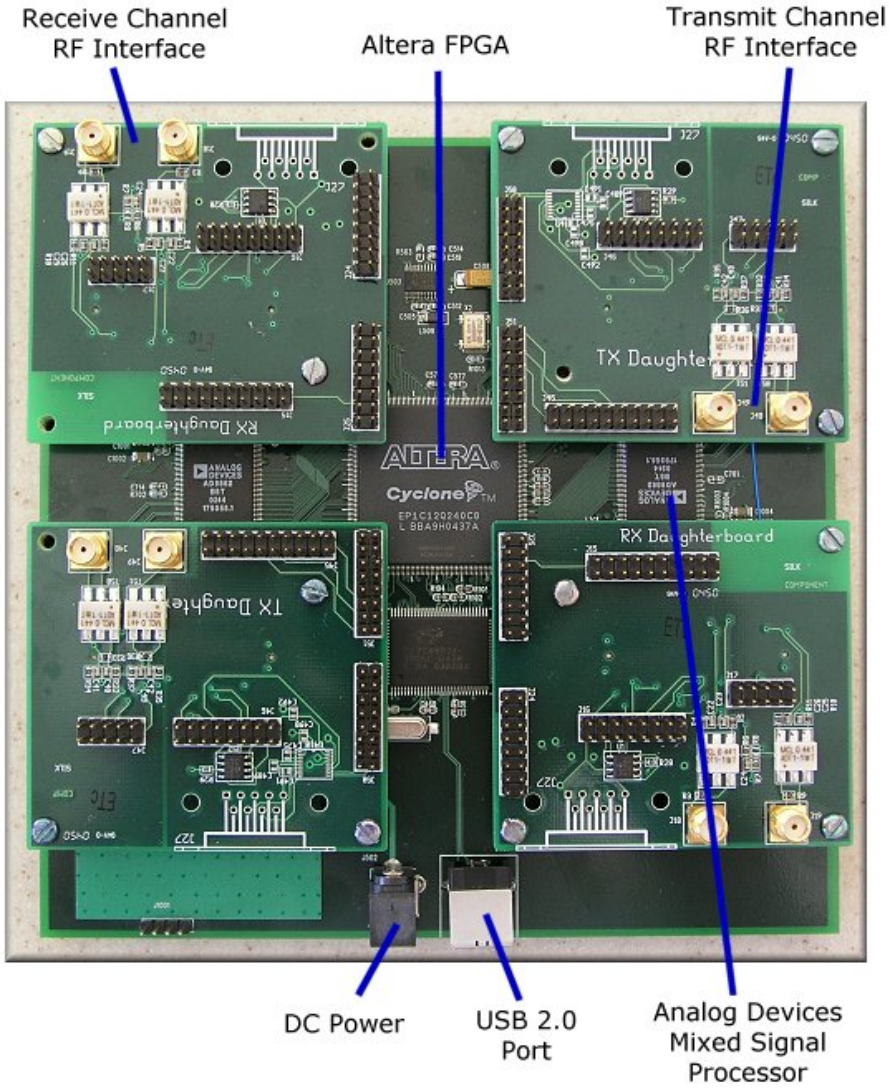
Problem Statement

Problem Statement

We Wish to Measure The Bandwidth Required of a Collaborative Sensing, Cognitive Radio Control Channel.

- Cognitive Radio Needs Collaborative Spectrum Sensing
- This Will Require a Control Channel
- Control Channel Wastes Some BW
- We Assume The Markovian Hypothesis (For Now)

Universal Software Radio Peripheral



GNU Radio

- GNU General Public License
- Python Wrapper For C++
- Object Orientated Approach
- Software Radios Defined In Terms Of Graphs
  1. Define Source (USRP)
  2. Define Signal Processing Unit (Spectrum Analyzer)
  3. Define Sink (File Format)
  4. Connect!

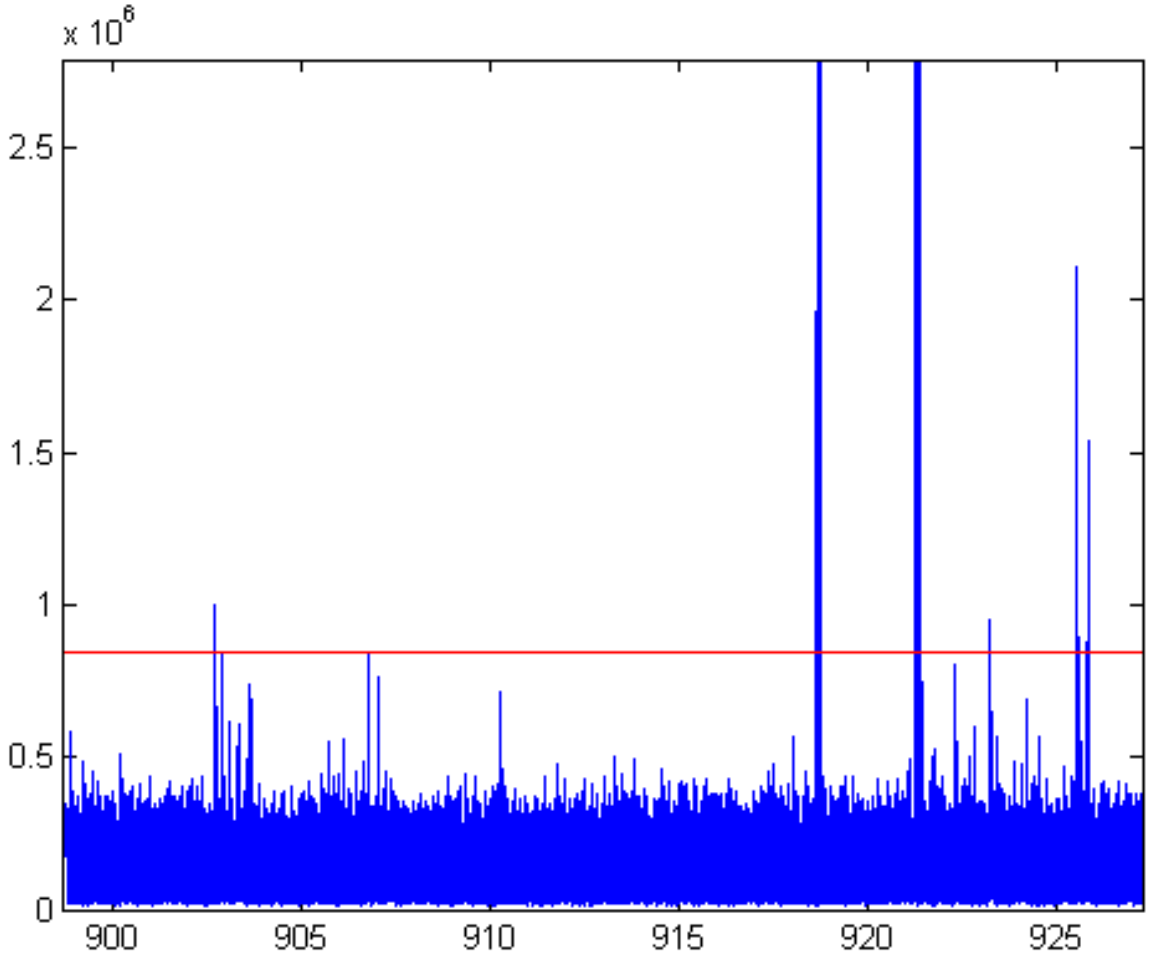
Class Definition

```
class my_graph(gr.flow_graph):
     def __init__(self, min_freq, max_freq):
         gr.flow_graph.__init__(self)
    self.u = usrp.source_c(...)

     s2v = gr.stream_to_vector(...)
    c2mag = gr.complex_to_mag_squared(...)
     stats = gr.bin_statistics_f(...)

    self.connect(self.u, s2v, c2mag, stats)
```

File Format

TimeDate Stamp	Frequency	Complex Samples
10/29/07 05:56 PM	898750000	56953 32489 ...
10/29/07 05:56 PM	900250000	322640 358258 ...
10/29/07 05:56 PM	901750000	284045 303849 ...
10/29/07 05:56 PM	903250000	46261 40136 ...

Sampled ISM Band



Public Safety Band Revisited[7]

- Count State Transitions
- Divide By Sample Count
- We Then Have Our PMF

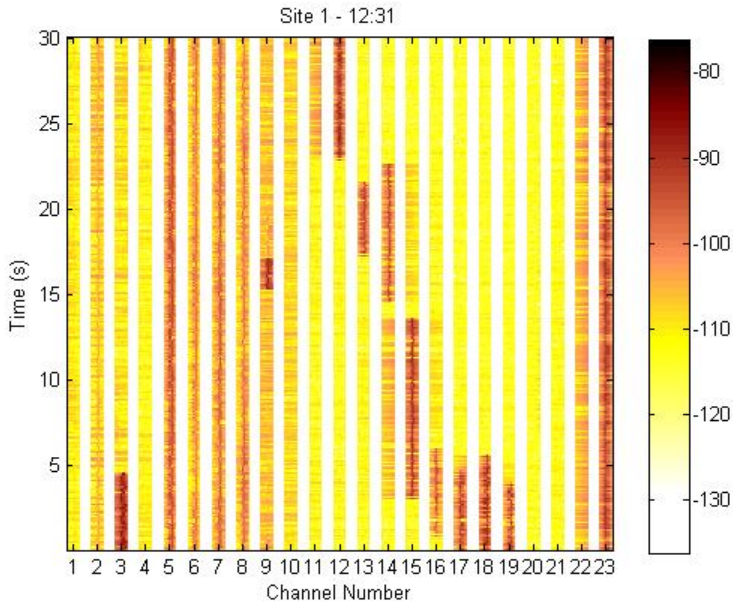


Figure: PSB Usage

[7] [Jones, 2007]

Challenges

A Lot to Learn

- DSP, Embedded Systems, Information Theory
- BASH, Python, Linux System Administration
- Deciphering Professor's Code!

A Lot of Obstacles

- Non-linear AGC and CIC Filters
- Calibrating USRP
- Minimal Documentation

Progress

- Software Defined ISM Band Spectrum Analyzer
- Matlab Scripts to Analyze Data
- BASH Scripts to Automate Data Collection
- Debian Domain Controller to Share USRP Access
- Custom File Format

Future Work

- Finish Statistical Analysis
- Mobile Spectrum Sensing
- Emulab Data Collection
- Online Database of Samples
- Investigate Cyclostationary Feature Detection

Questions?

- FCC, *ET Docket No 03-222, Notice Of Proposed Rule Making And Order*, Dec. 2003
- Committee on Energy and Commerce, House of Representatives, "Commercial Spectrum Enhancement Act", *Report to Congress on Agency Plans for Spectrum Relocation Funds*, Feb. 2007
- Jones, S., et. al., "Characterization of Spectrum Activities in the U.S. Public Safety Band for Opportunistic Spectrum Access", *New Frontiers in Dynamic Spectrum Access Networks*, 2007, pp.137-146
- Haykin, S., et. al., "Cognitive Radio: Brain-Empowered Wireless Communications", *Selected Areas in Communications*, Vol. 23, No.2, Feb. 2002
- Ghasemi, A., et. al., "Collaborative Spectrum Sensing for Opportunistic Access in Fading Environments," *Proc. Symposium on Dynamic Spectrum Access Networks*, Nov. 2005.
- Shannon, C., "A Mathematical Theory of Communication", *The Bell System Technical Journal*, Vol. 27, pp. 370-423, 623-656, July, Oct., 1948.