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

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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)

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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

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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

- **802.22.1 – Std for Enhanced Interference Protection using beaconing**
  - **802.22.1a – Advanced Beaconing**
- **802.22.2 – Std for Recommended Practice for Deployment of 802.22 Systems**
  - **NEW!! Spectrum Occupancy Sensing (SOS)**
- **802.22a – Enhanced Management Information Base and Management Plane Procedures**
- **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

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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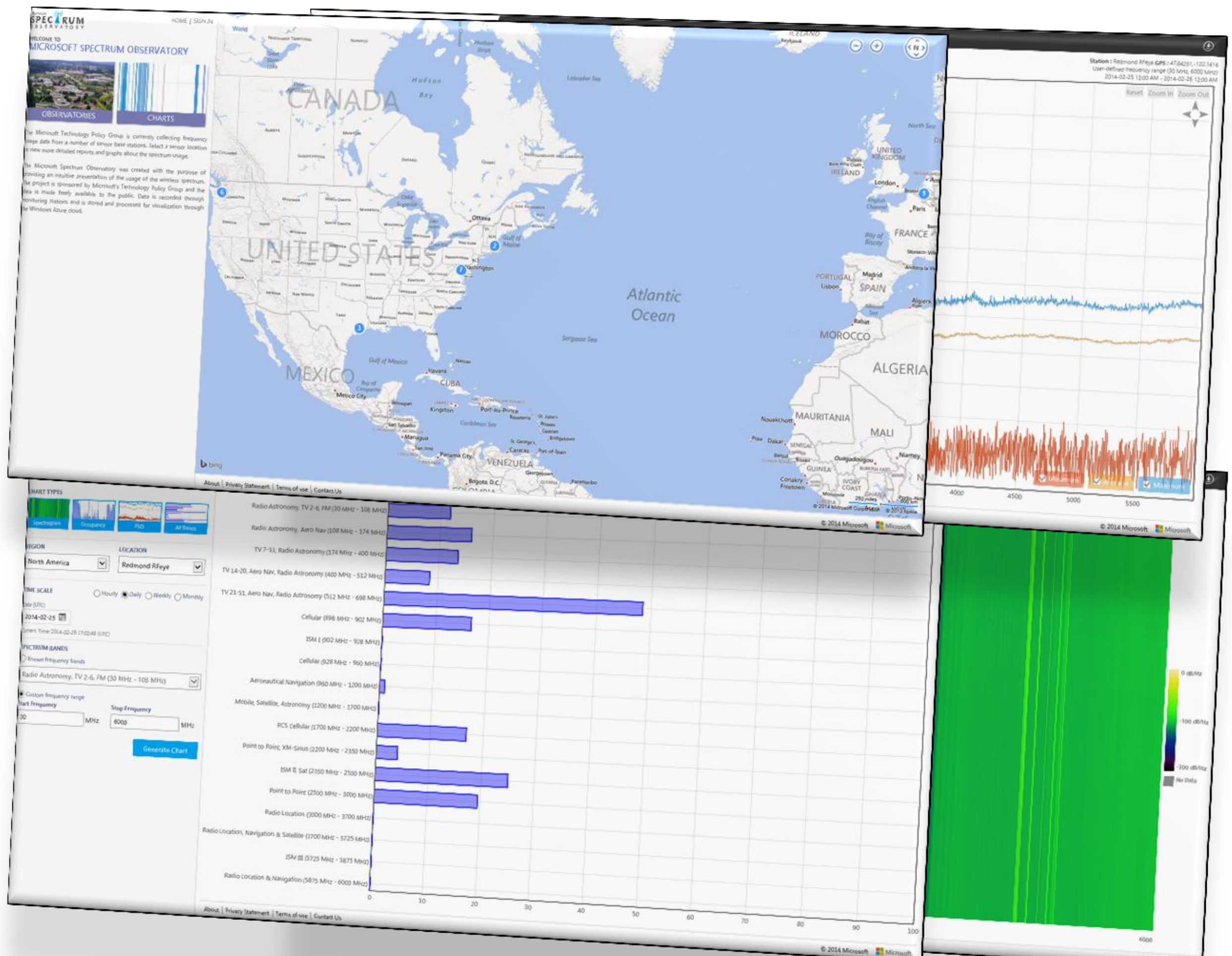
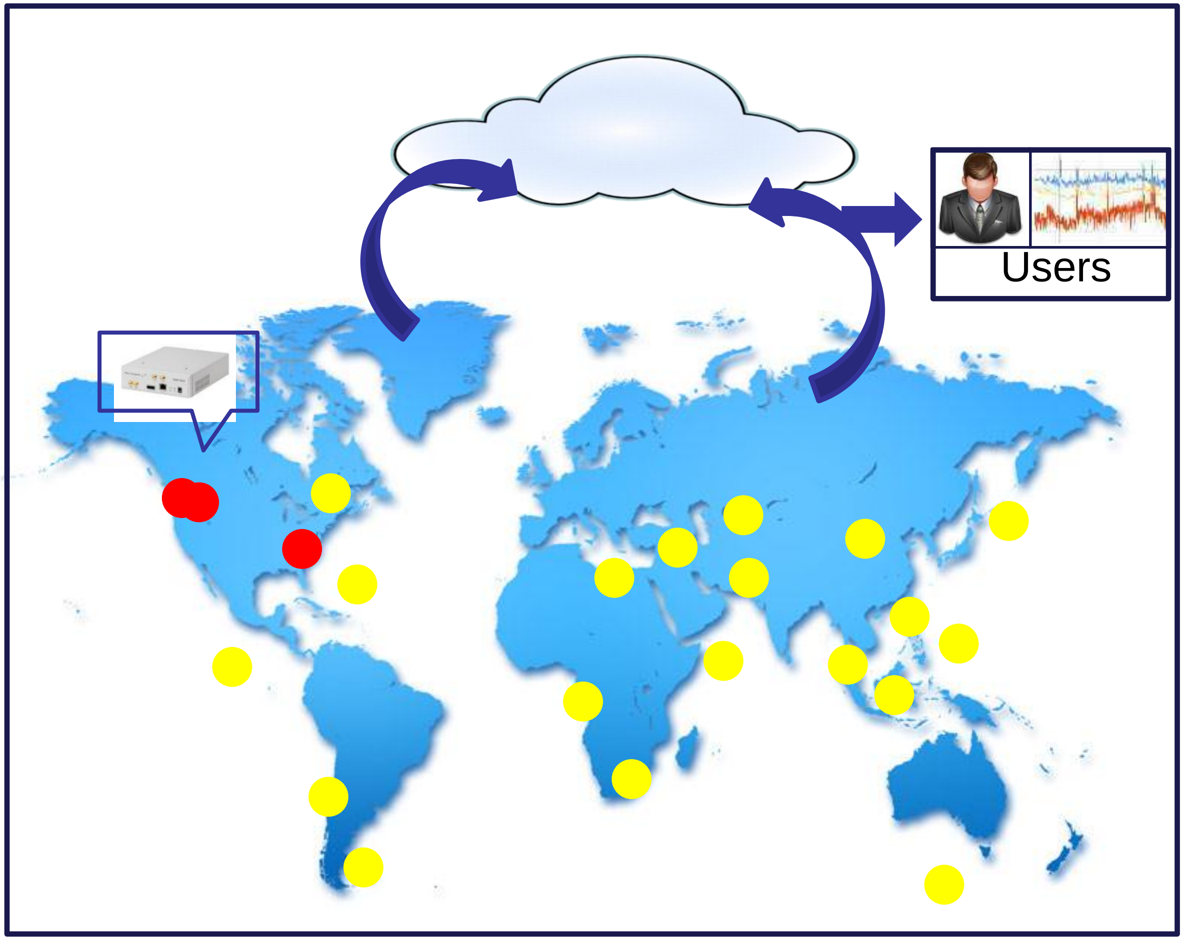
Microsoft Spectrum Observatory

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

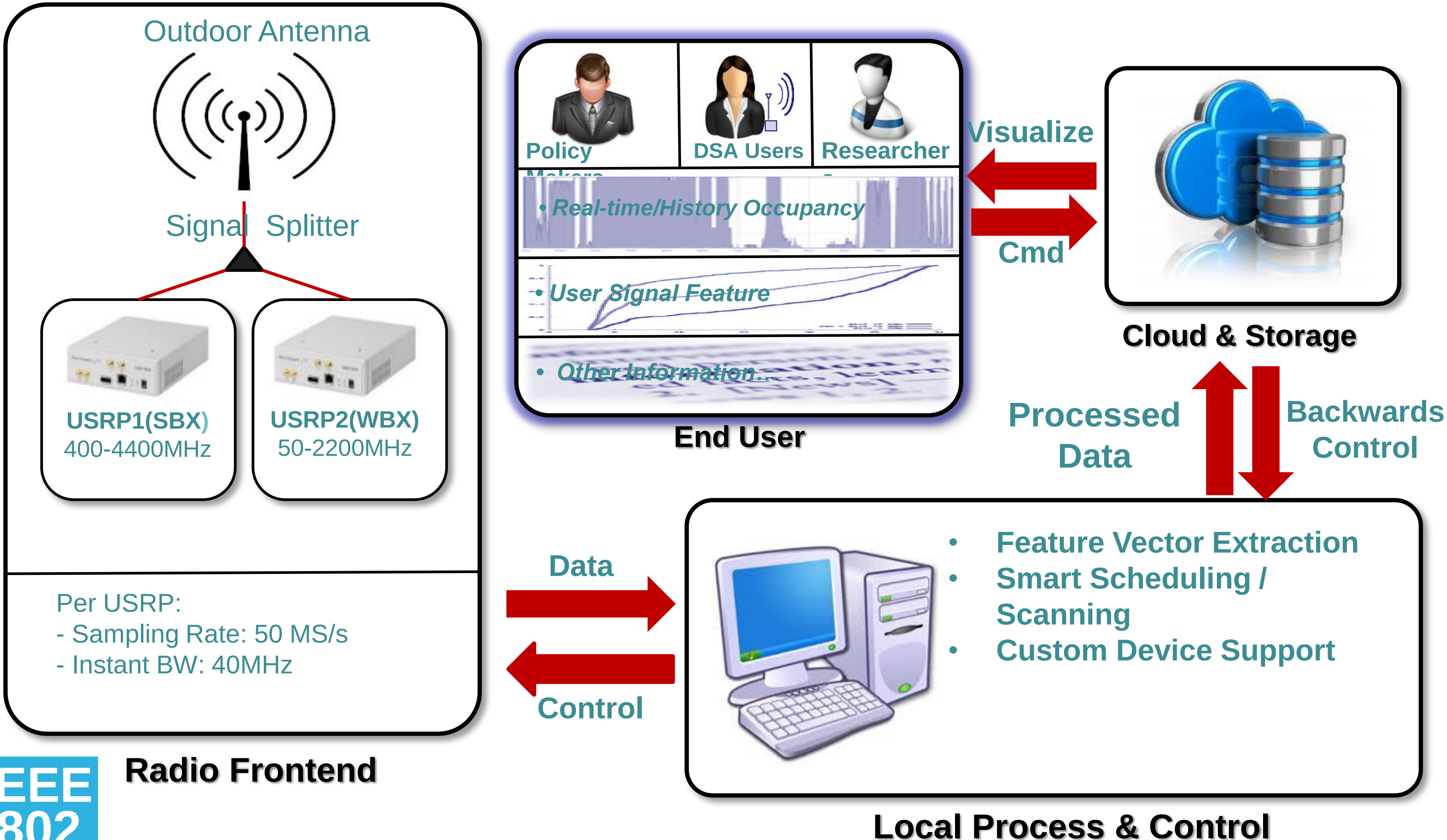
- University of Washington
- MIT
- Rice
- UCSB

open source initiative®

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



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

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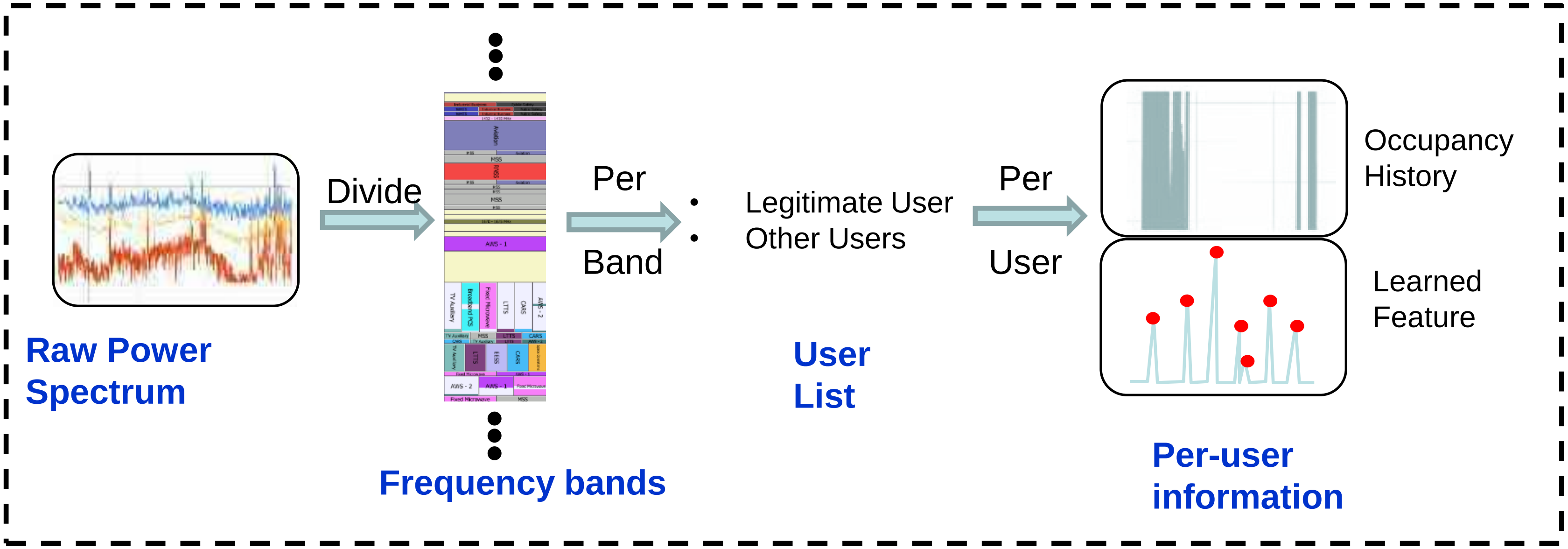
Real-time Database for DSA



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)

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Prof. Sumit Roy (Univ of Washington, Seattle)

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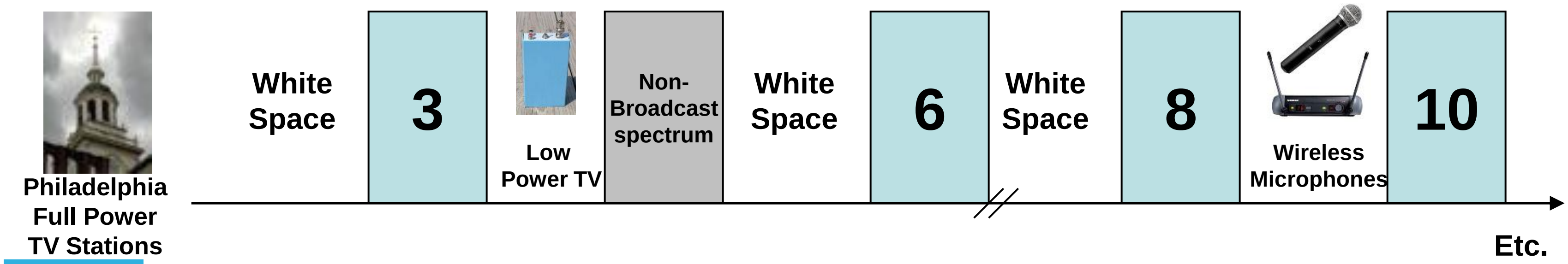
TVWS Final Rules: Databases

- 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

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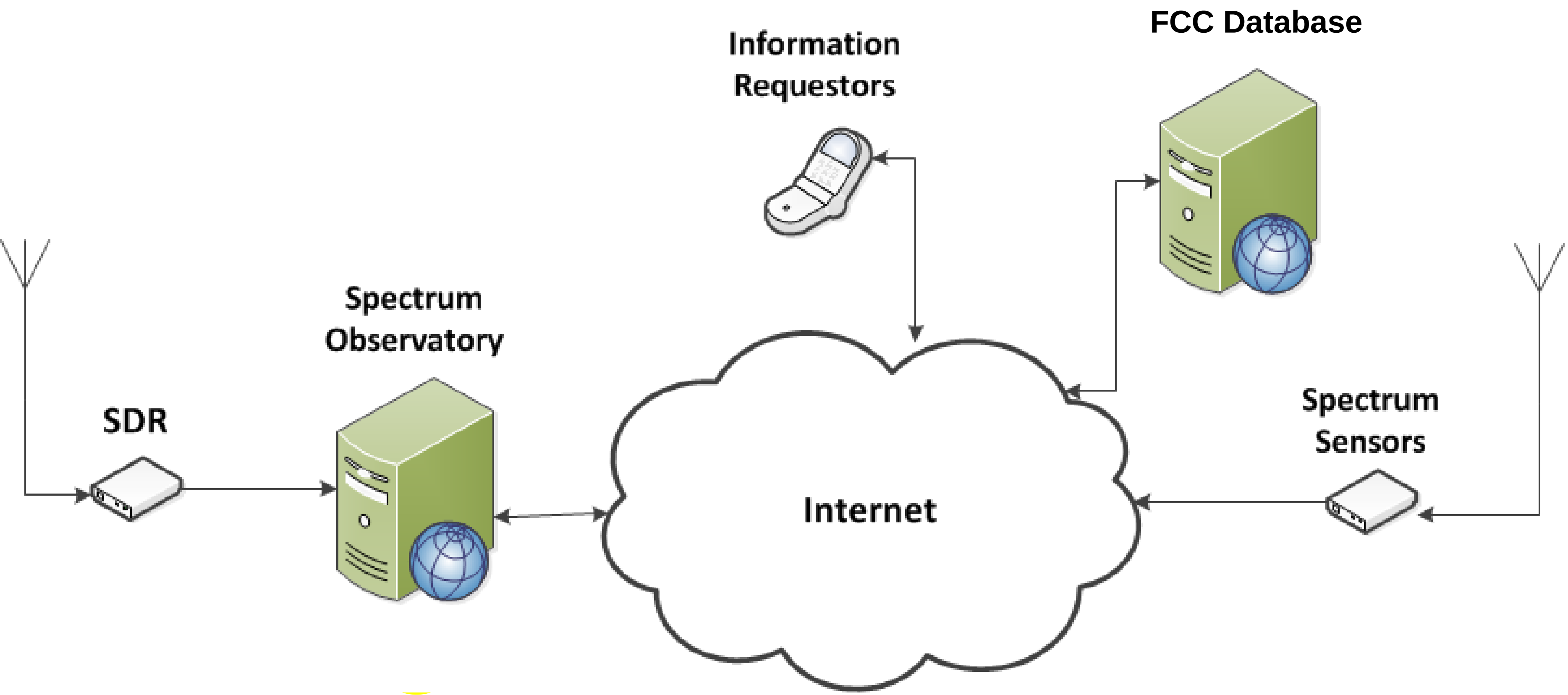
UW Spectrum Observatory (SpecObs) Database



http://specobs.ee.washington.edu/

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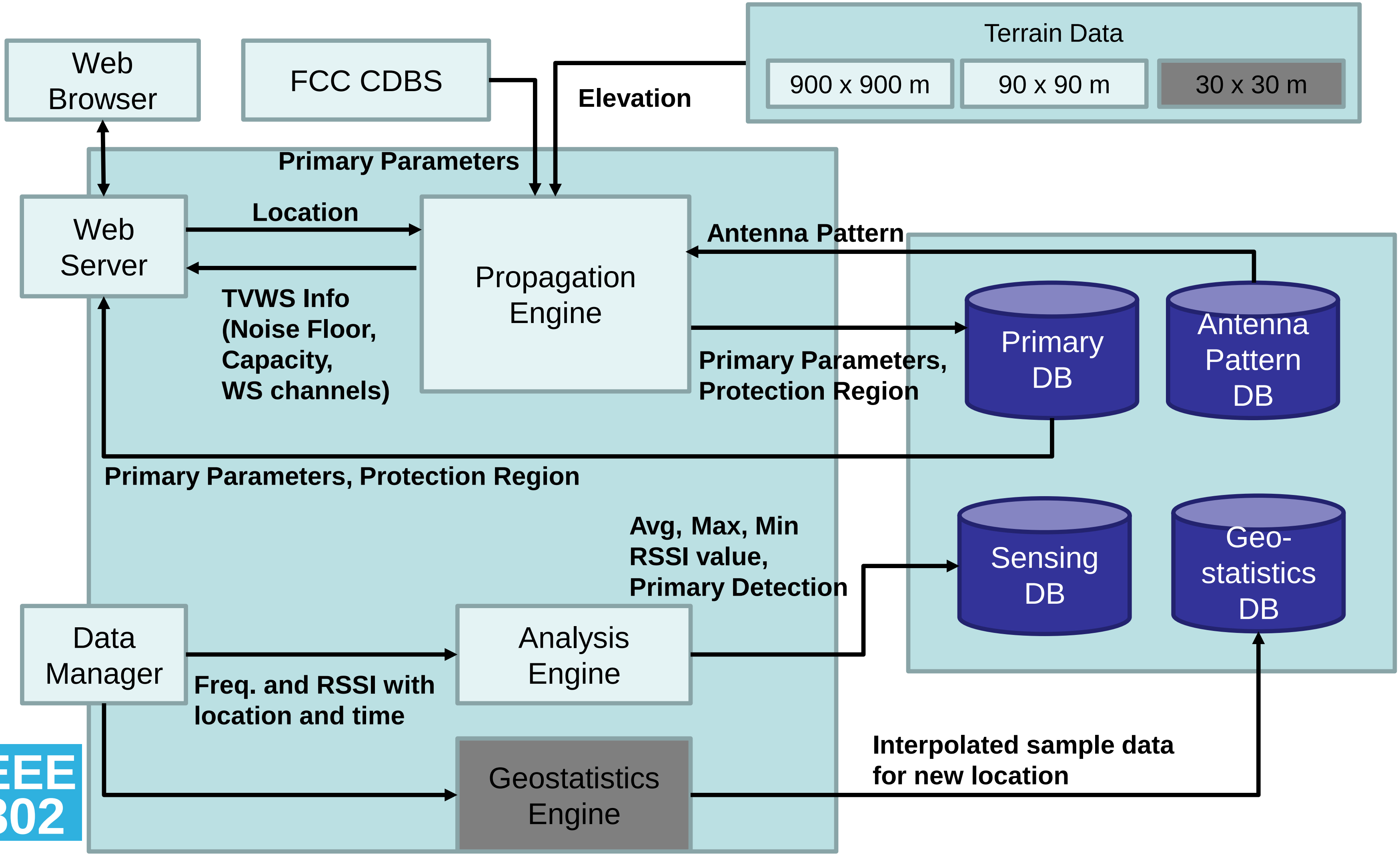
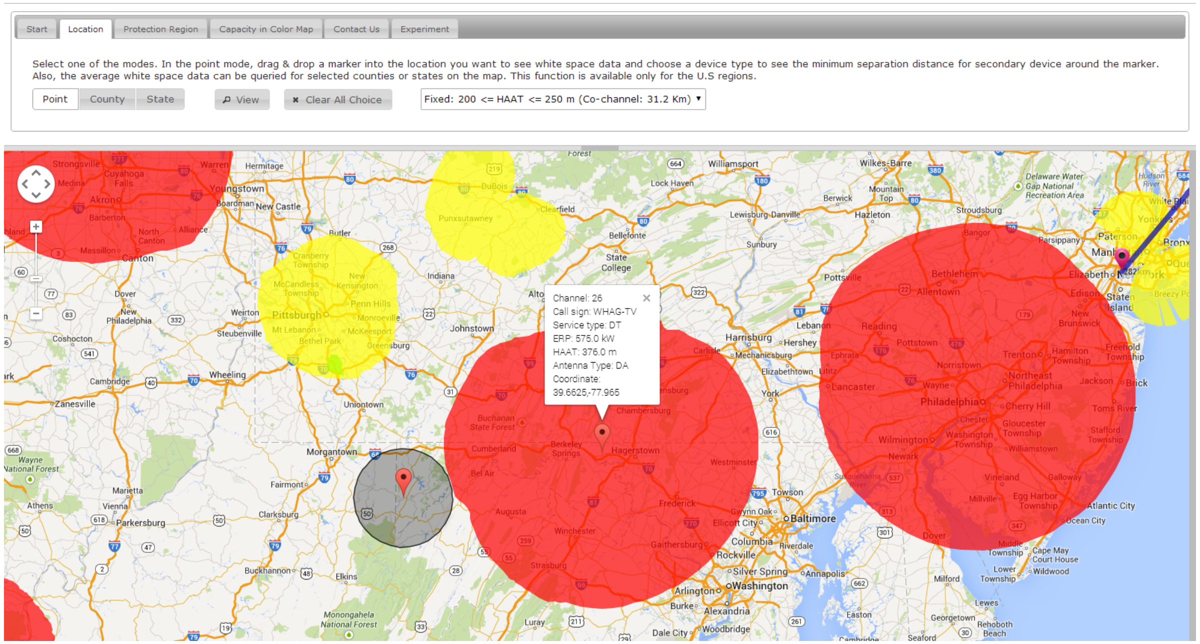
SpecObs Server Architecture



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

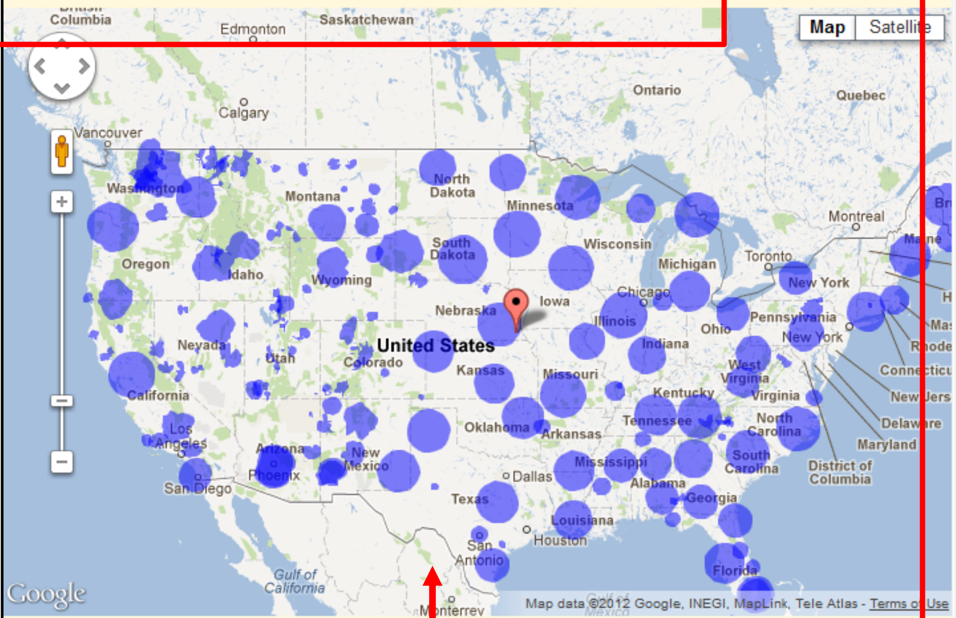
(Example Data for
latitude : 40.3832, longitude : -96.0511)

SPECTRUM OBSERVATORY UW FuNLab

Choose Mode : Channels Color Map

By Location By County By State View Clear

Choose TV Channel : 10 Clear



Fixed TVWS Device			
Channel Number	HAAT	Noise Floor (dBm)	Capacity (Mbps)
2	30.0	-34.98	141.52
5	30.0	-16.42	104.52
6	30.0	-96.05	263.23
14	30.0	-34.69	140.94
15	30.0	-31.86	135.3
16	30.0	-28.72	129.04
25	30.0	-96.05	263.23
27	30.0	-33.74	139.05
40	30.0	-39.13	149.78
41	30.0	-29.57	130.73
48	30.0	-25.21	122.04
49	30.0	-31.93	135.44
Total			1854.82

Mobile TVWS Device			
Channel Number	Max Power	Noise Floor (dBm)	Capacity (Mbps)
21	40.0	-29.06	97.79
24	40.0	-34.76	109.15
25	100.0	-96.05	231.3
26	100.0	-29.48	98.61
27	100.0	-38.31	116.23
28	40.0	-35.04	109.71
30	40.0	-43.83	127.22
31	100.0	-30.38	100.41
32	40.0	-31.0	101.64
34	40.0	-34.94	109.51
40	100.0	-42.56	124.69
41	100.0	-32.99	105.61
42	40.0	-37.26	114.12
44	40.0	-43.34	126.25
47	40.0	-36.43	112.47
48	100.0	-29.0	97.66
49	100.0	-35.59	110.8
50	40.0	-50.03	139.59
Total			2132.76

Channel Descriptions		
Channel Number	Channel Description	Measured Noise Floor
2	Free	**
3	Wireless Mic	**
4	Wireless Mic	**
5	Free	**
6	Free	**
7	TV-AdjChannel	**

Protection region of each TV channel

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Scenario 1: FCC Defined Coverage Area for Single TV Channel

– Geographic area within the TV station’s noise-limited contour

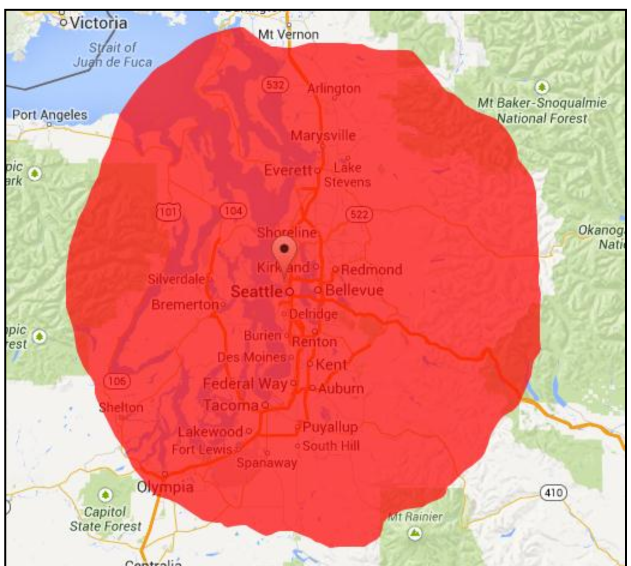
→ Defined with F-Curve and Field Strength Threshold

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)

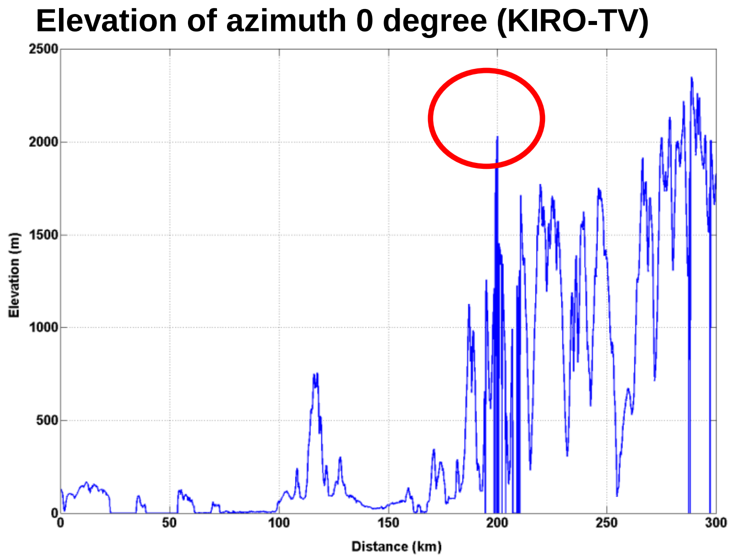


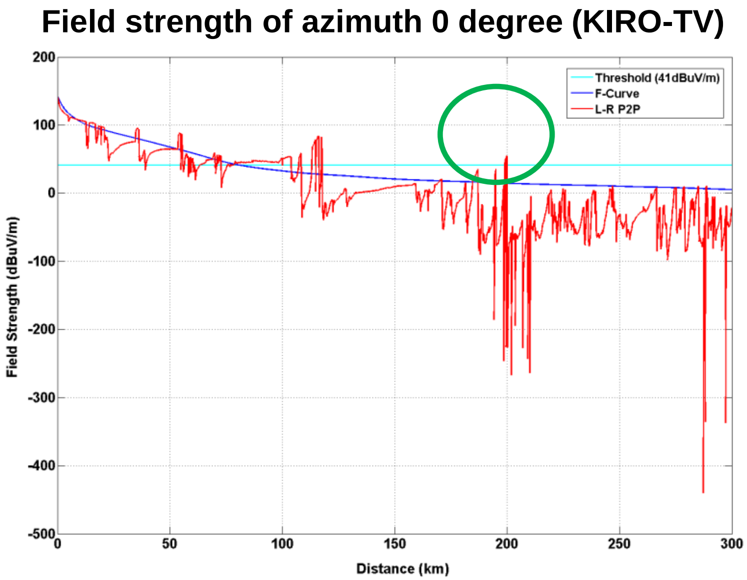
TV Type	Channel 2- 6	Channel 7 – 13	Channel 14 - 51
Analog	47	56	64
Digital	28	36	41

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

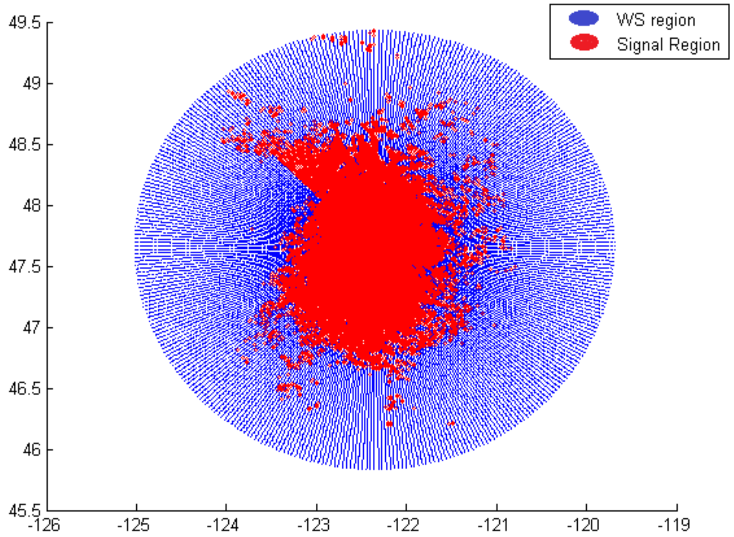




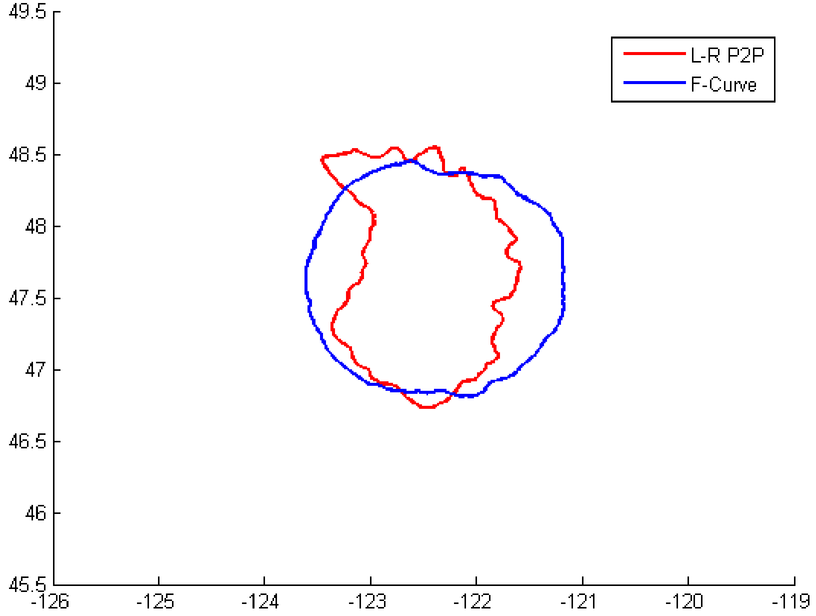
SpecObs Coverage using L-R P2P

- 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

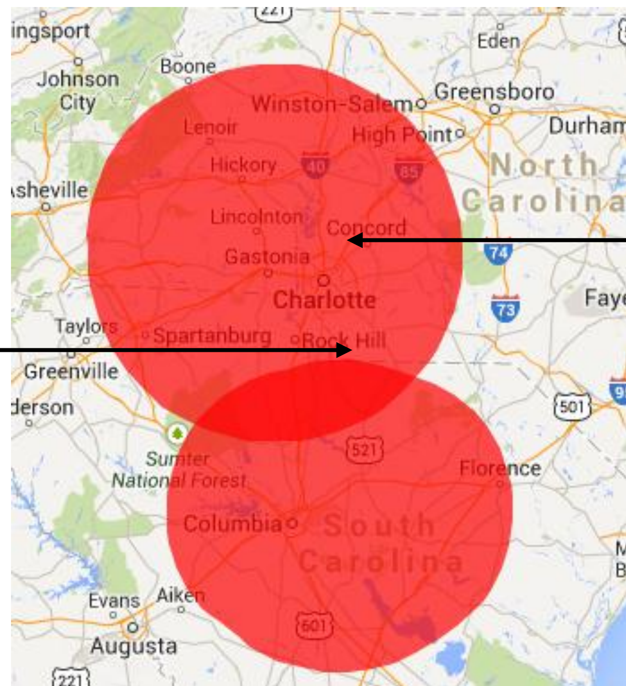


Scenario 2 : Two Co-channel TV stations

– **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

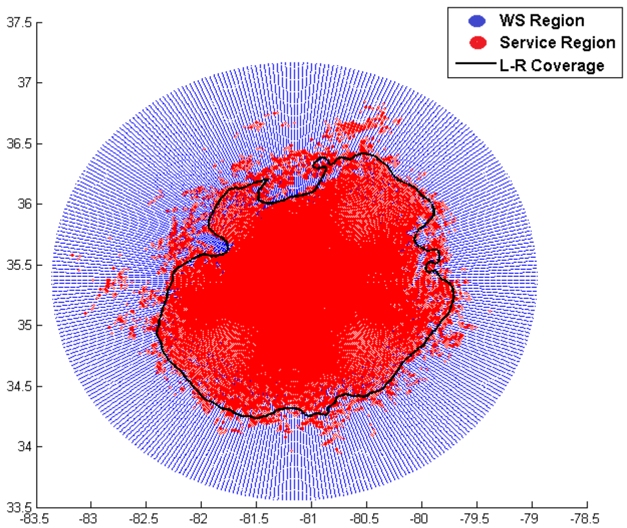


Desired Station
Channel: 39
Call sign: WMYT-TV
Service type: DT
ERP: 225.0 kW
HAAT: 571.0 m
Antenna Type: ND
Coordinate:
35.36222,-81.15528

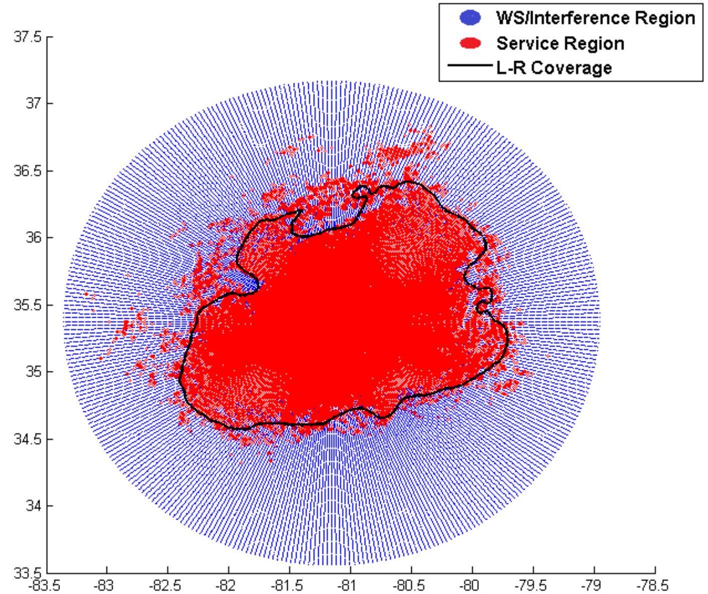
SpecObs Results

- 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 %)

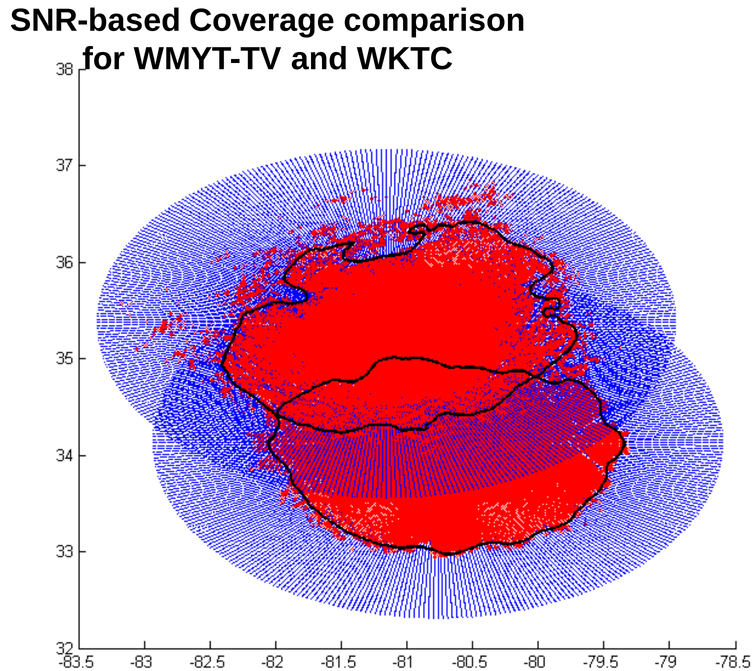


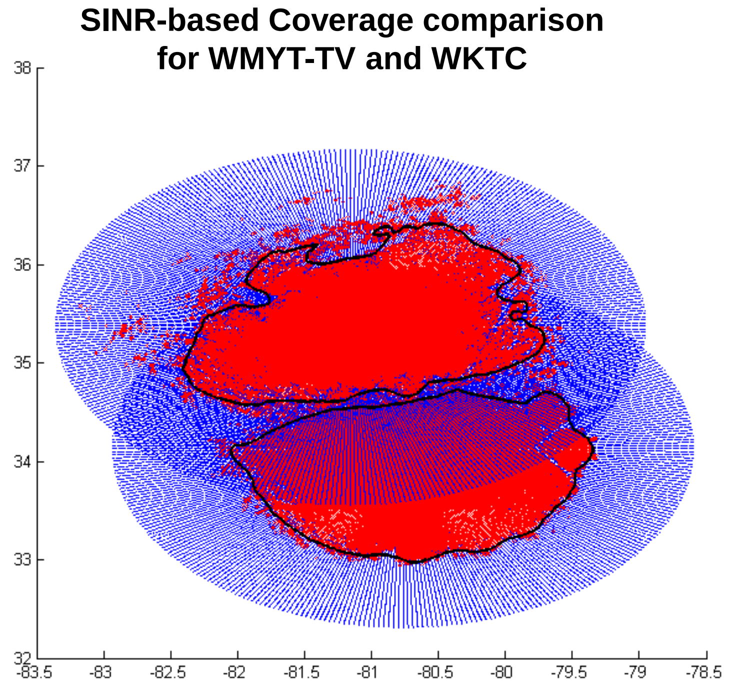
WMYT-TV service region and coverage based on SINR threshold (15.16 dB) and K = 250
Total error rate = 13.916 %
Type 1 (6.491 %) + Type 2 (7.425 %)



SpecObs Results Comparison

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





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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

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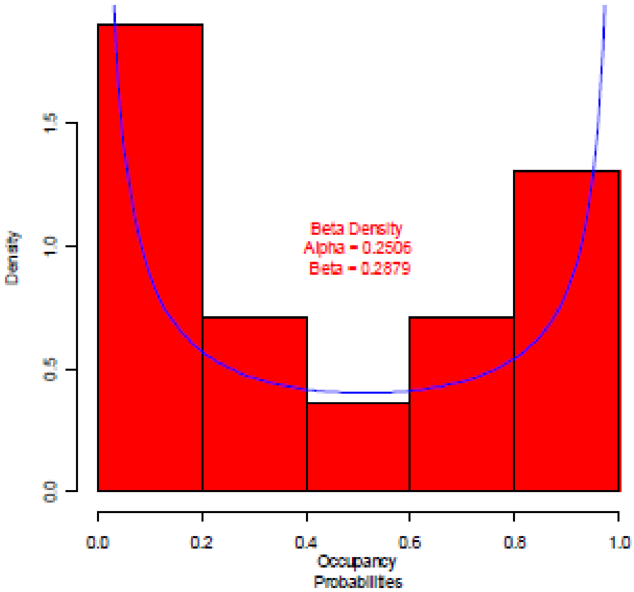
Channel Availability Statistics

Device Type	LVHF (2:6)	HVHF (7:13)	LUHF (14:51)	Total
Total Available	2.36	2.59	21.77	26.73
Fixed Devices	2.36	2.59	15.2	20.17
Portable/Personal	0	0	18.79	18.79
Microphone Reserved	2	0	2	4
Busy Channels by TV	0.45	2.22	10.43	13.11
Unused Channels	2.18	2.19	4.67	9.05
Channel Utilization Factor	%56	%68	%89	%81.5

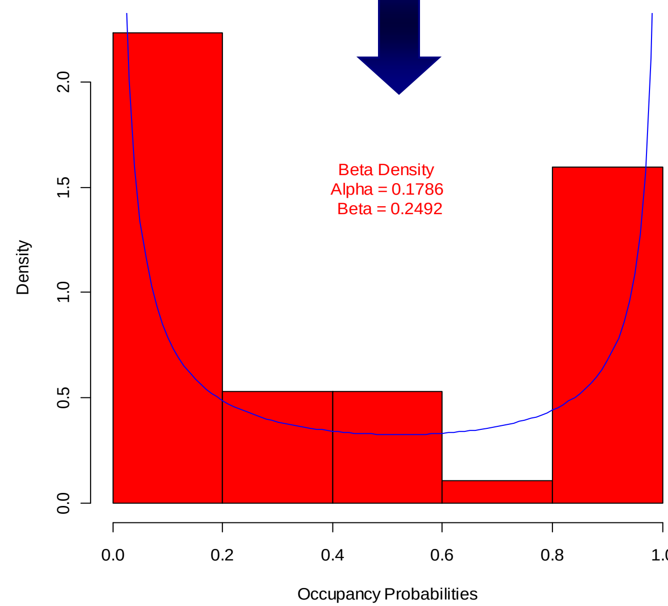
Modeling: Validation of Beta Distribution in Spectrum Occupancy



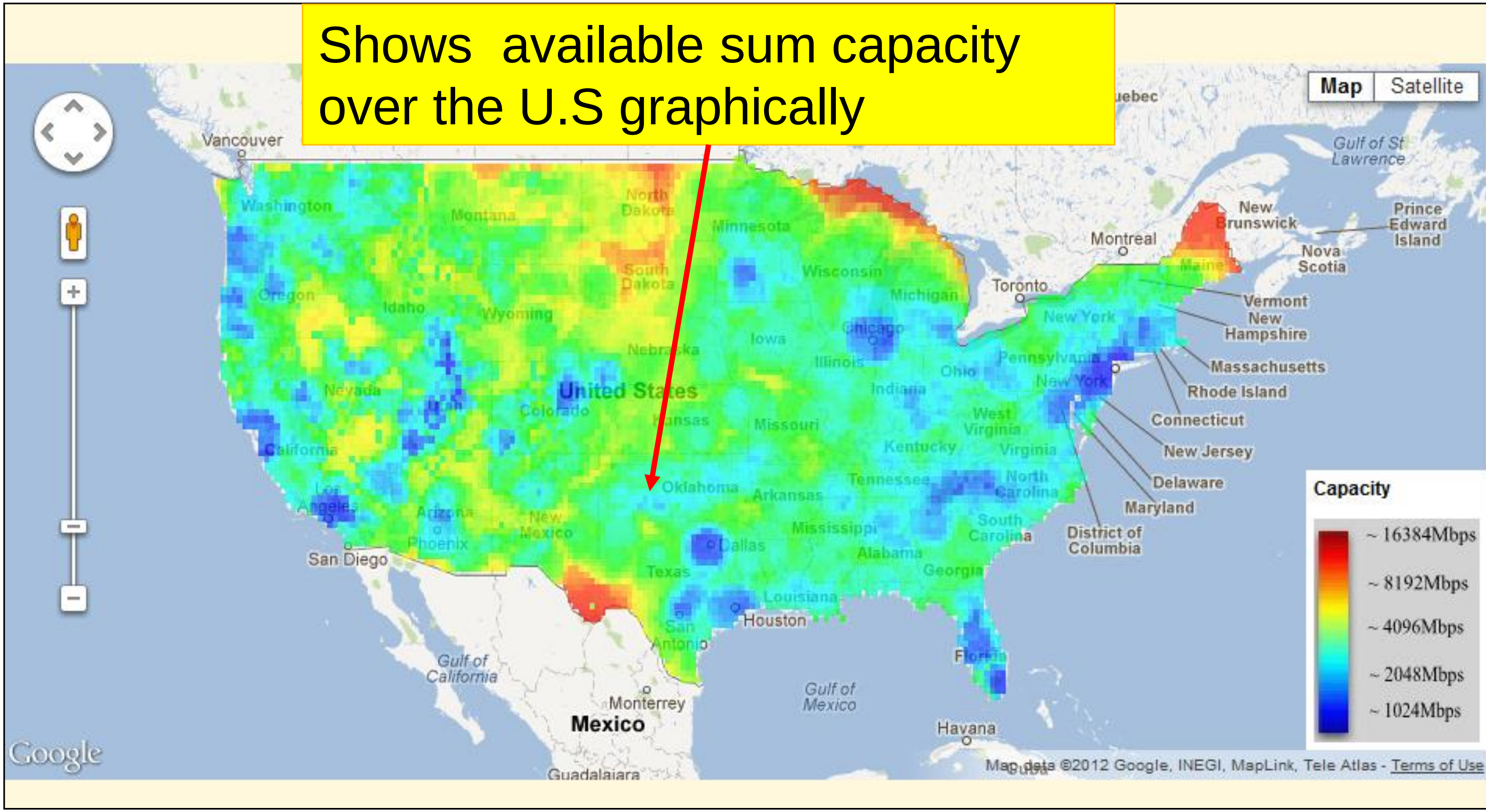
Beta Distribution with estimated α and β over expected channel availabilities between 3:00 - 4:00 pm (left) and between 7:00 to 8:00 am (below)

Table 1: Observed and Expected Frequencies of Spectrum Occupancy

Time of the day	Frequencies				
	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
$Observed(7-8am)$	21	5	5	1	15
$Expected(7-8am)$	22.27	3.72	3.11	3.49	14.4
$Observed(12-1pm)$	23	4	5	8	9
$Expected(12-1pm)$	23.3	5.56	4.55	4.76	10.83
$Observed(3-4pm)$	16	6	3	6	11
$Expected(3-4pm)$	16.86	3.98	3.41	3.85	13.9
$Observed(11p-12a)$	15	10	1	4	12
$Expected(11p-12a)$	15.6	5.16	4.47	4.87	11.9



Advantage of Combining SOS with Current Database Architecture



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Advances in Spectrum Sensing: Applying Cyclostationary Signal Processing to Cognitive Radio Problems

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NWRA
Since 1984

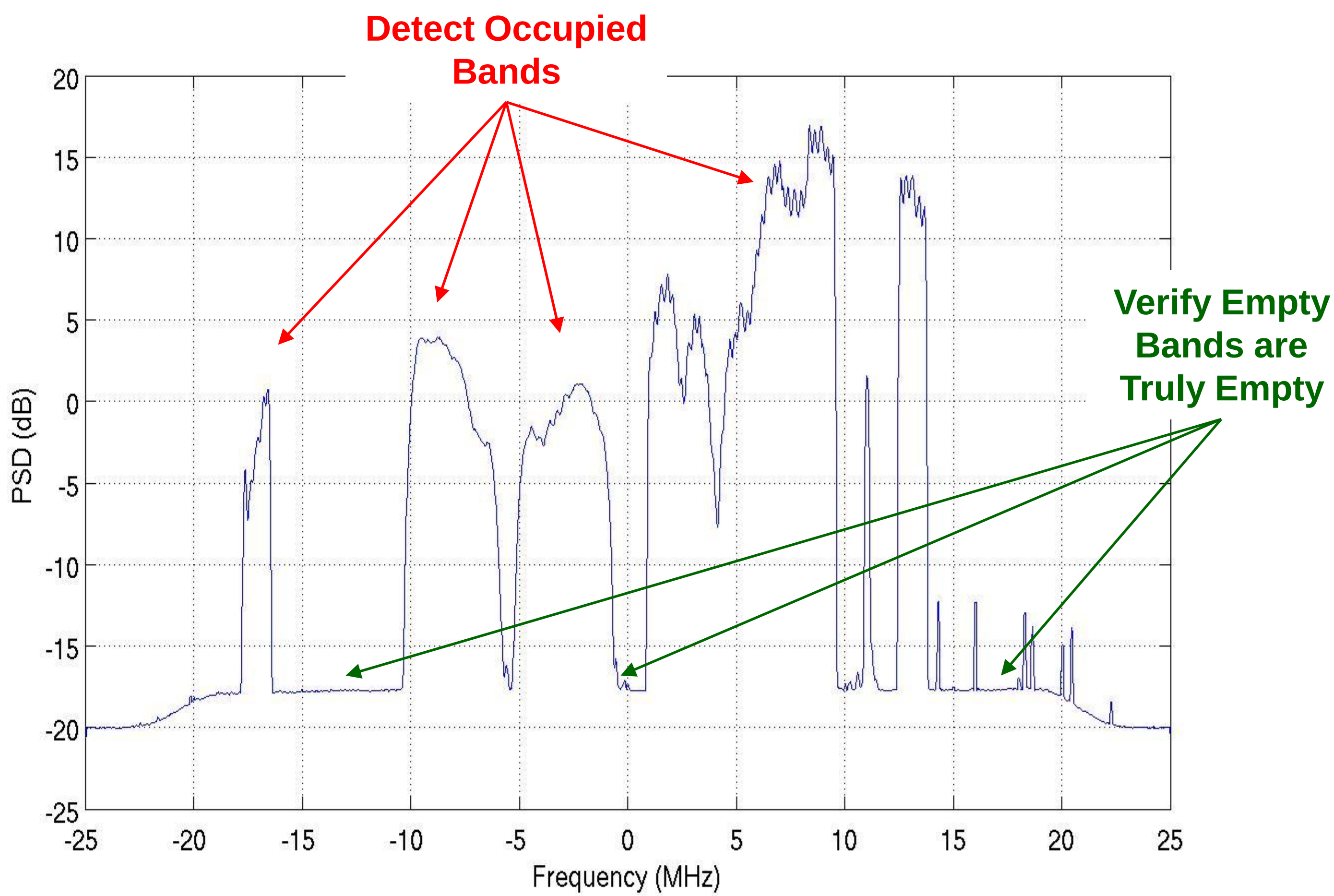
Outline of Presentation

- 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



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Energy Detection (ED): Inexpensive Spectrum Sensing

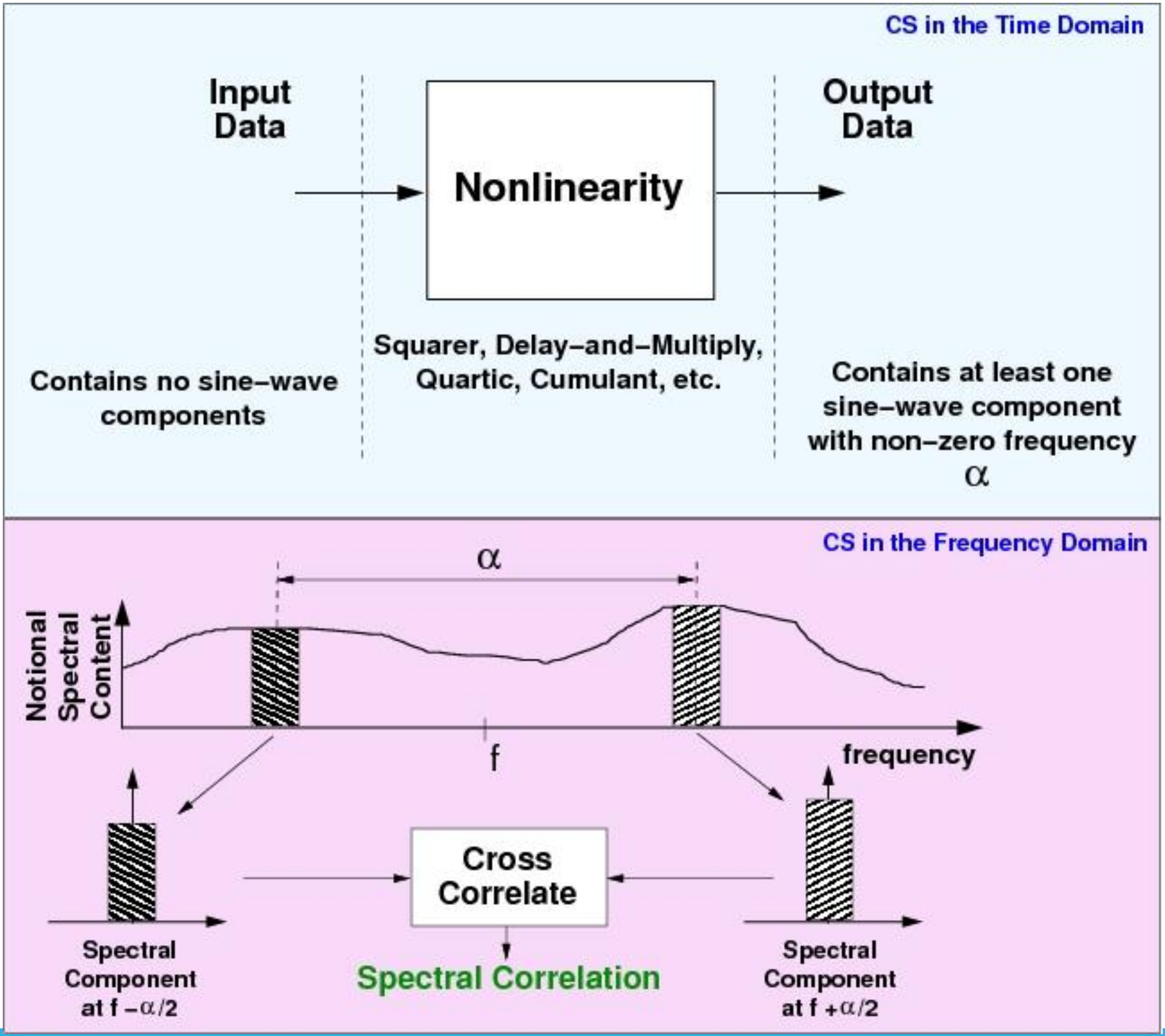
- Measure energy in any band of frequencies
  - Sum the squares of the complex samples, or
  - Integrate subband of PSD estimate
- Compare to energy expected due to known noise PSD
  - Requires knowledge of N_0
- Noise uncertainty and/or variability causes poor performance for weak signals (“SNR Wall”)
- 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**

[1] C. M. Spooner, “Multiresolution White-Space Detection for Cognitive Radio,” MILCOM 2007

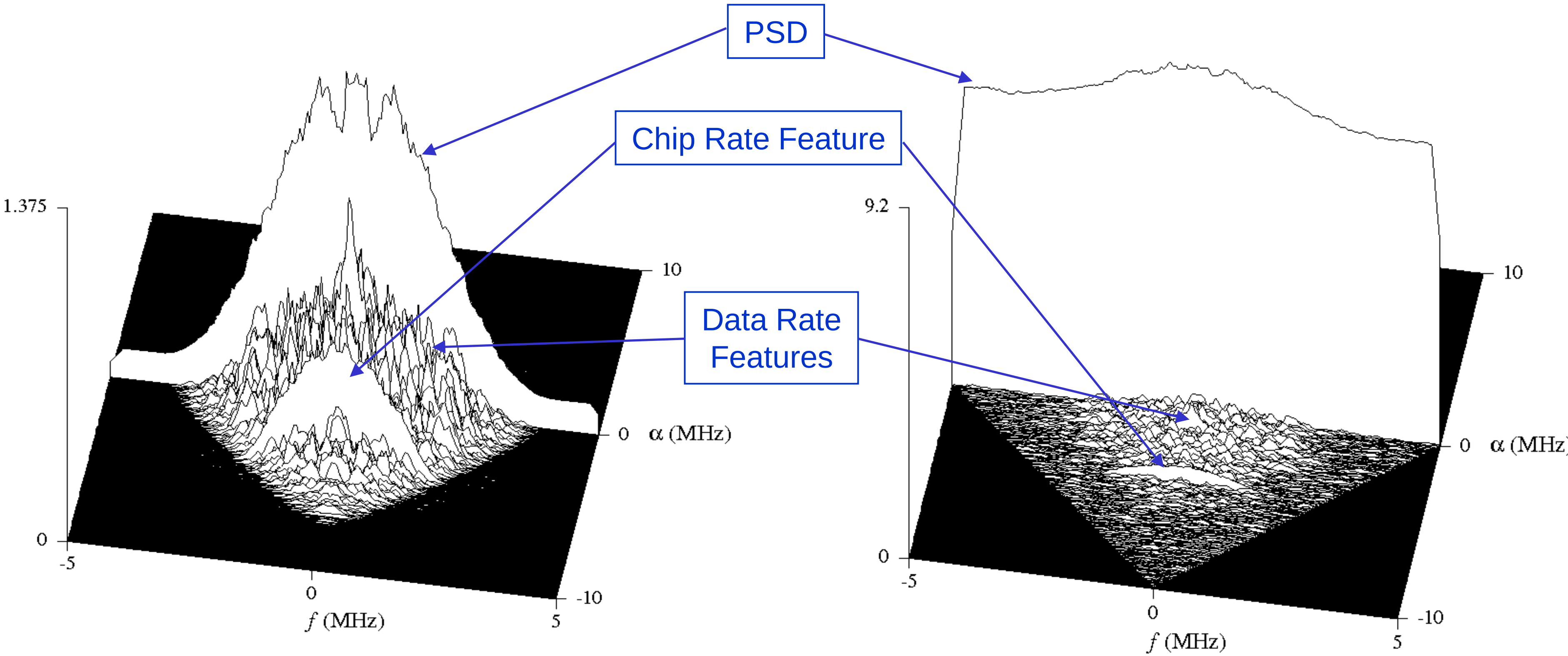
Beyond Energy Detection:
Cyclostationary Signal Processing (CSP)



- The cycle frequencies (CFs) α 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]

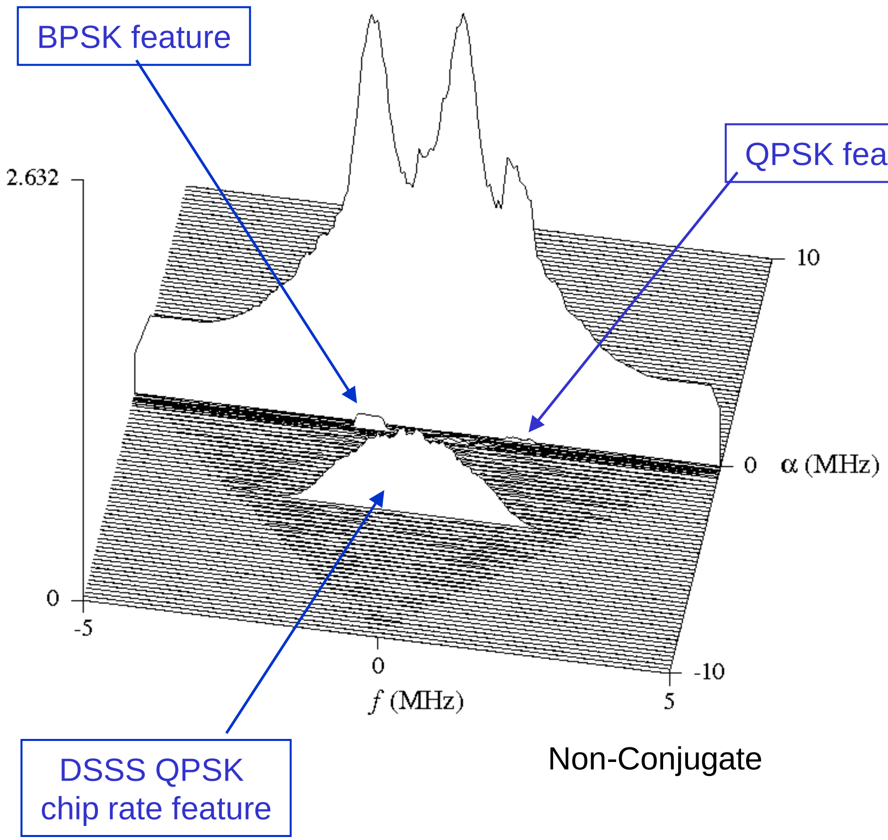
[2] Spooner and Gardner, "The Cumulant Theory of Cyclostationary Time-Series, Parts I and II," IEEE Trans Sig Proc, 1994

The Power of CSP: Noise Tolerance

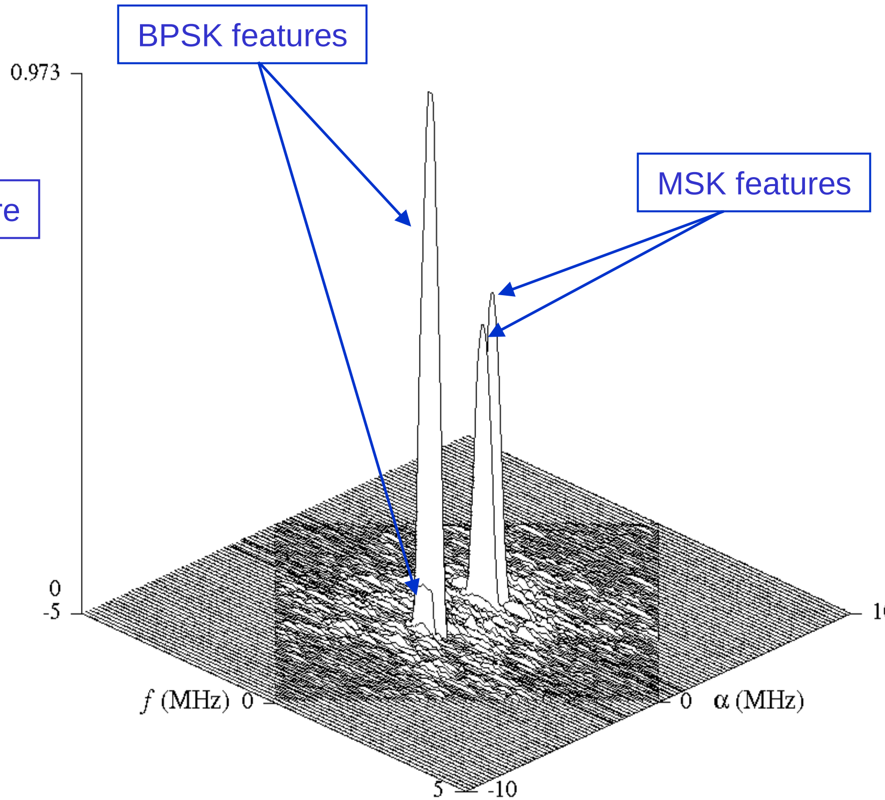


DSSS QPSK in moderate noise (left) and strong noise (right).

The Power of CSP: Interference Tolerance



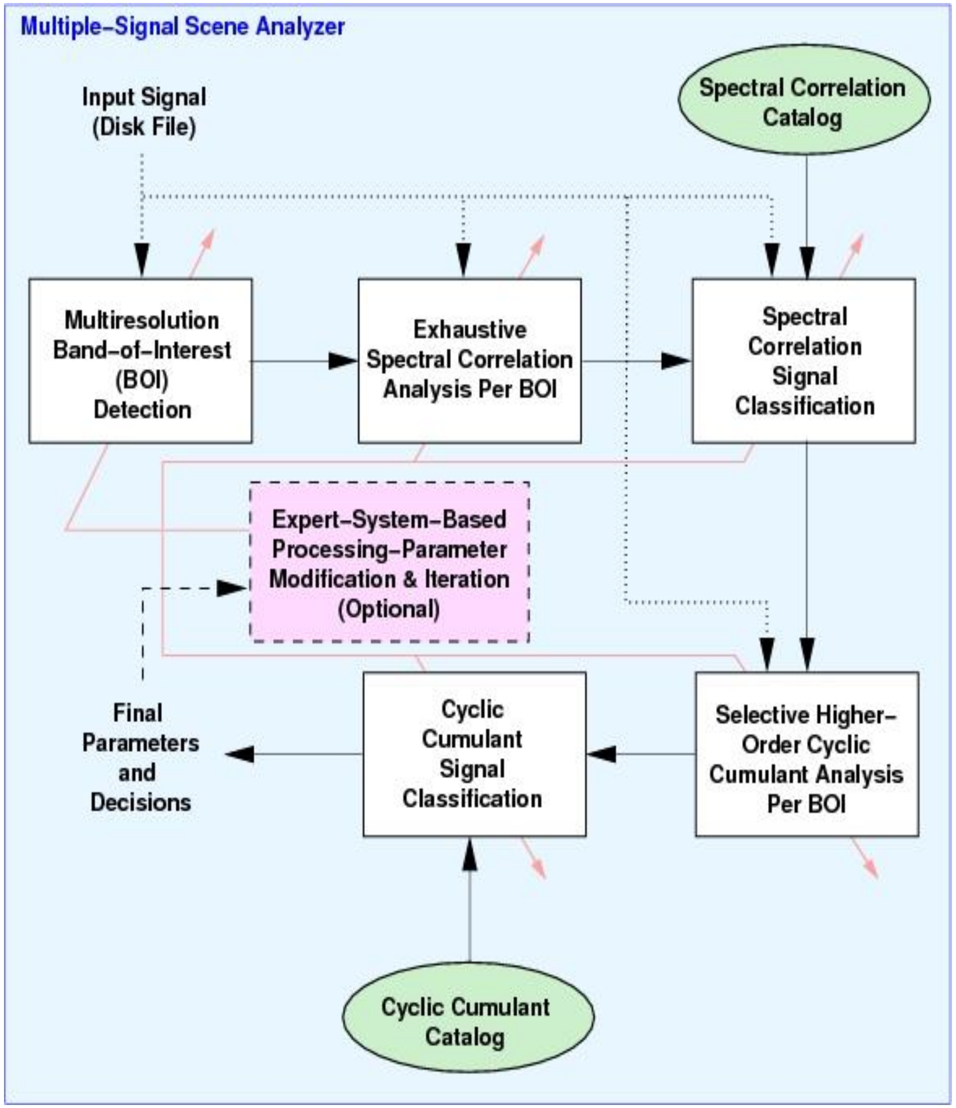
Non-Conjugate



Conjugate

DSSS QPSK in moderate noise and interference
with simplified cycle frequencies for easier feature viewing.

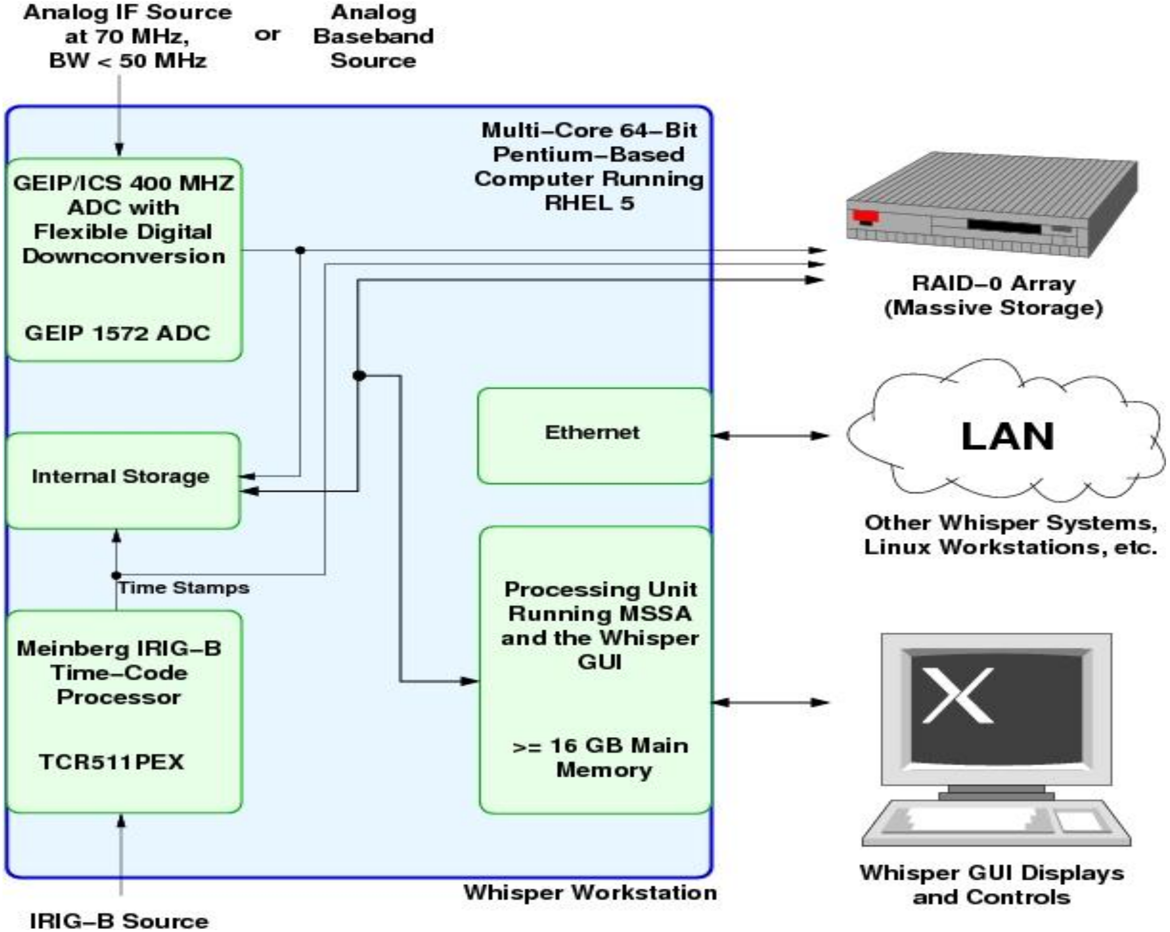
Applied CSP: The Multiple-Signal Scene Analyzer (MSSA) [3]



- 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

[3] Spooner et al, “Automatic RF Environment Analysis,” Asilomar Conference, 2000

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

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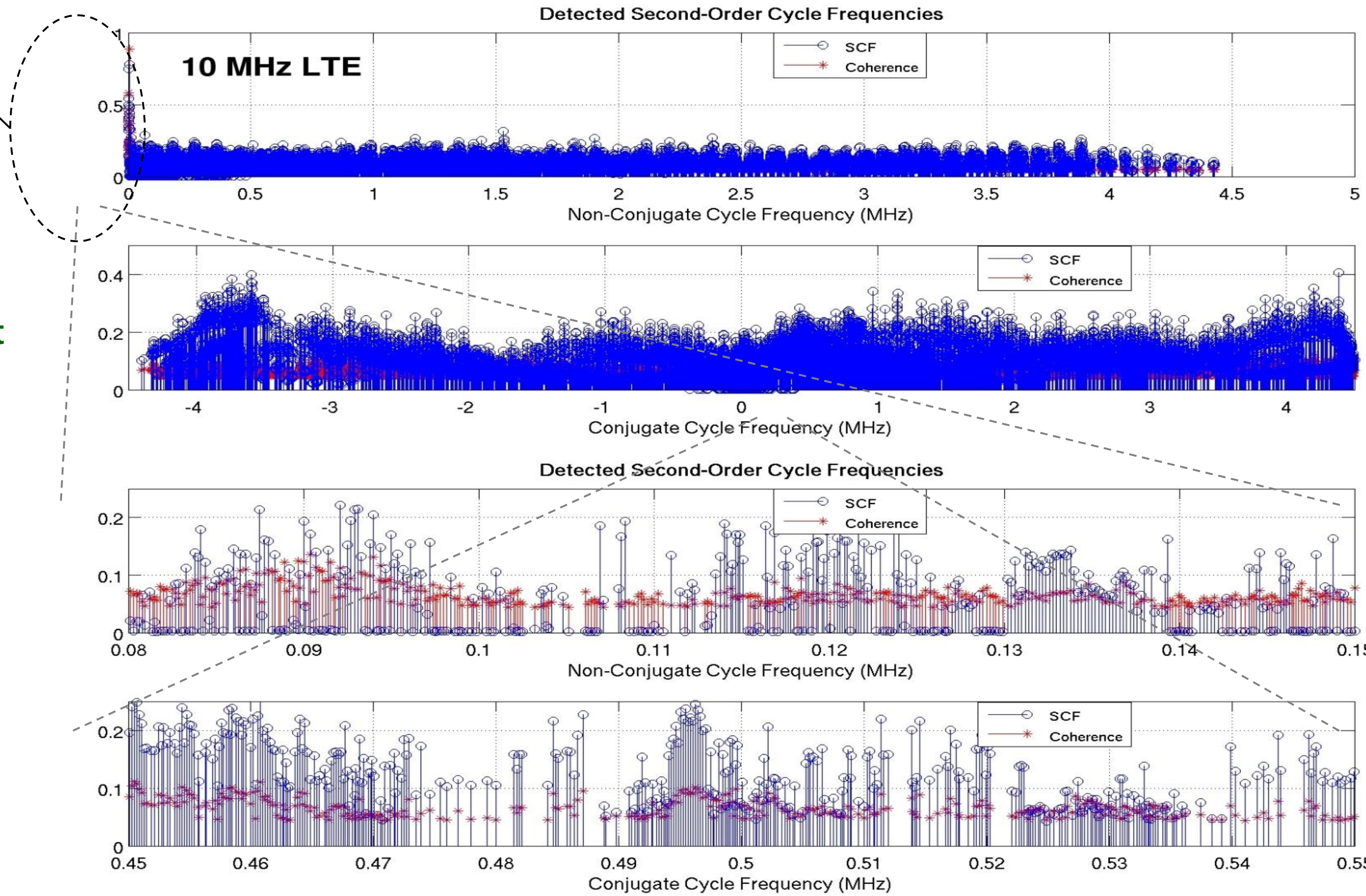
Applied CSP: Wideband Signal Detection Using A Few Narrowband Subchannels

Note many strong small CFs



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

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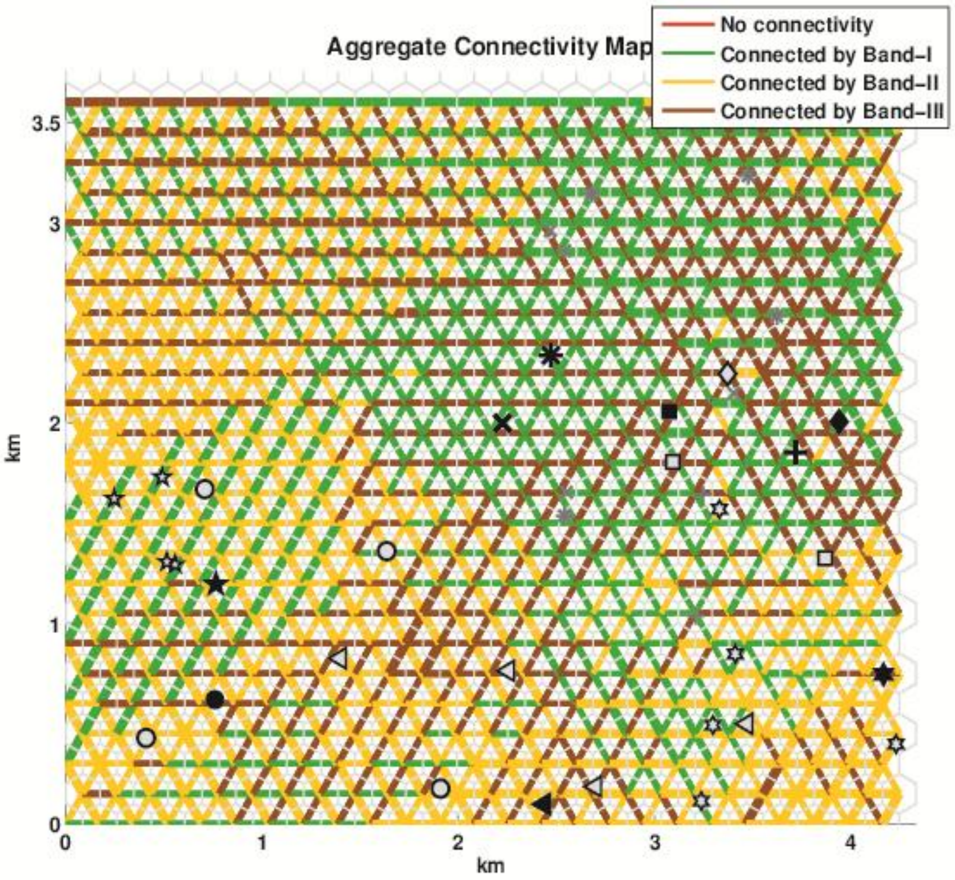
[5] Spooner, Mody, et al, "Tunnelized Cyclostationary Signal Processing: A Novel Approach to Low-Energy Spectrum Sensing," MILCOM 2013.

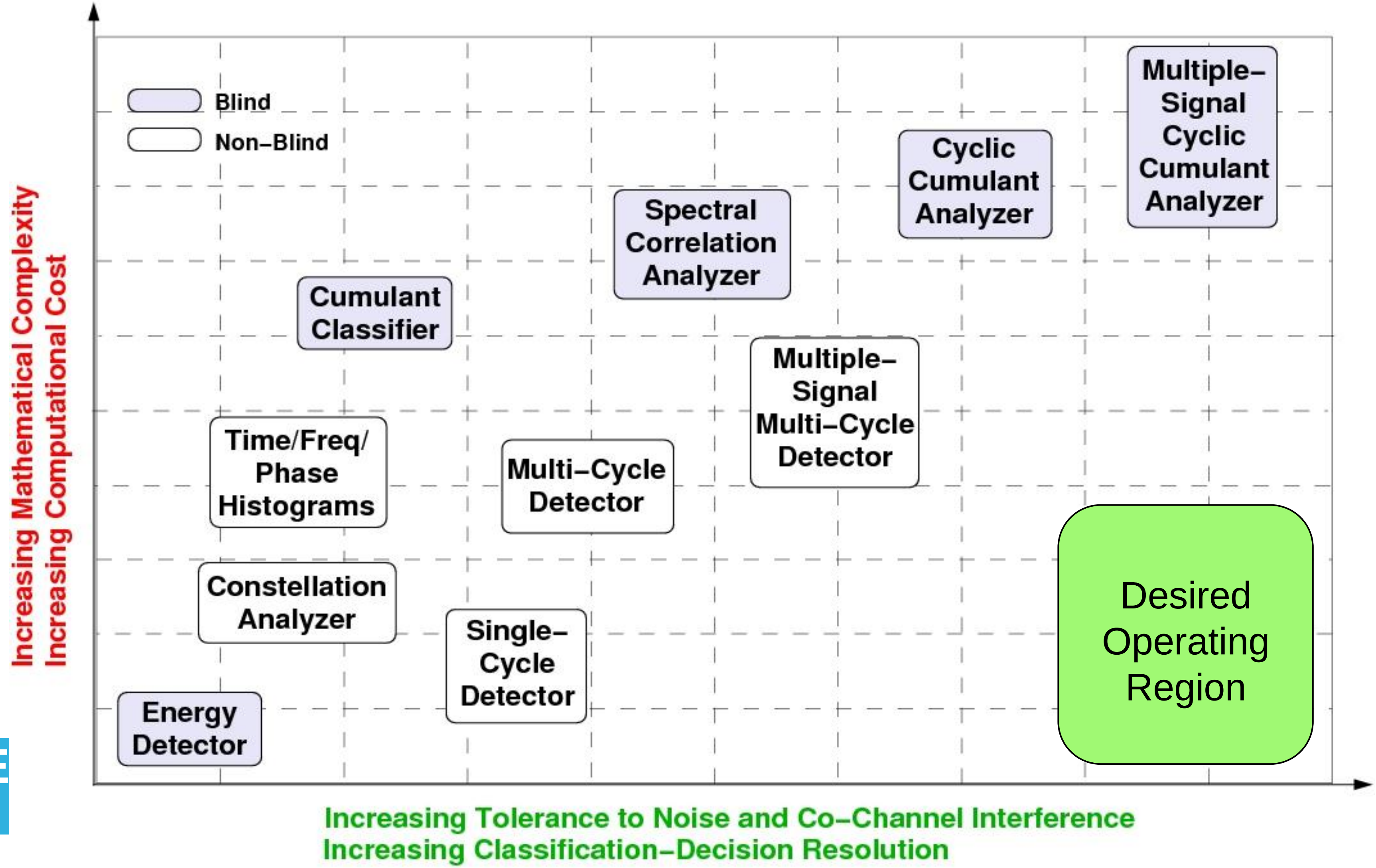
Applied CSP: Radio-Frequency Environment Map (RFEM) Estimation



- 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

[6] Spooner and Khambekar, "A Signal-Processing Perspective on Signal-Statistics Exploitation in Cognitive Radio," Journal of Communications, 2012.

Future Directions: Algorithmic Cost Reduction



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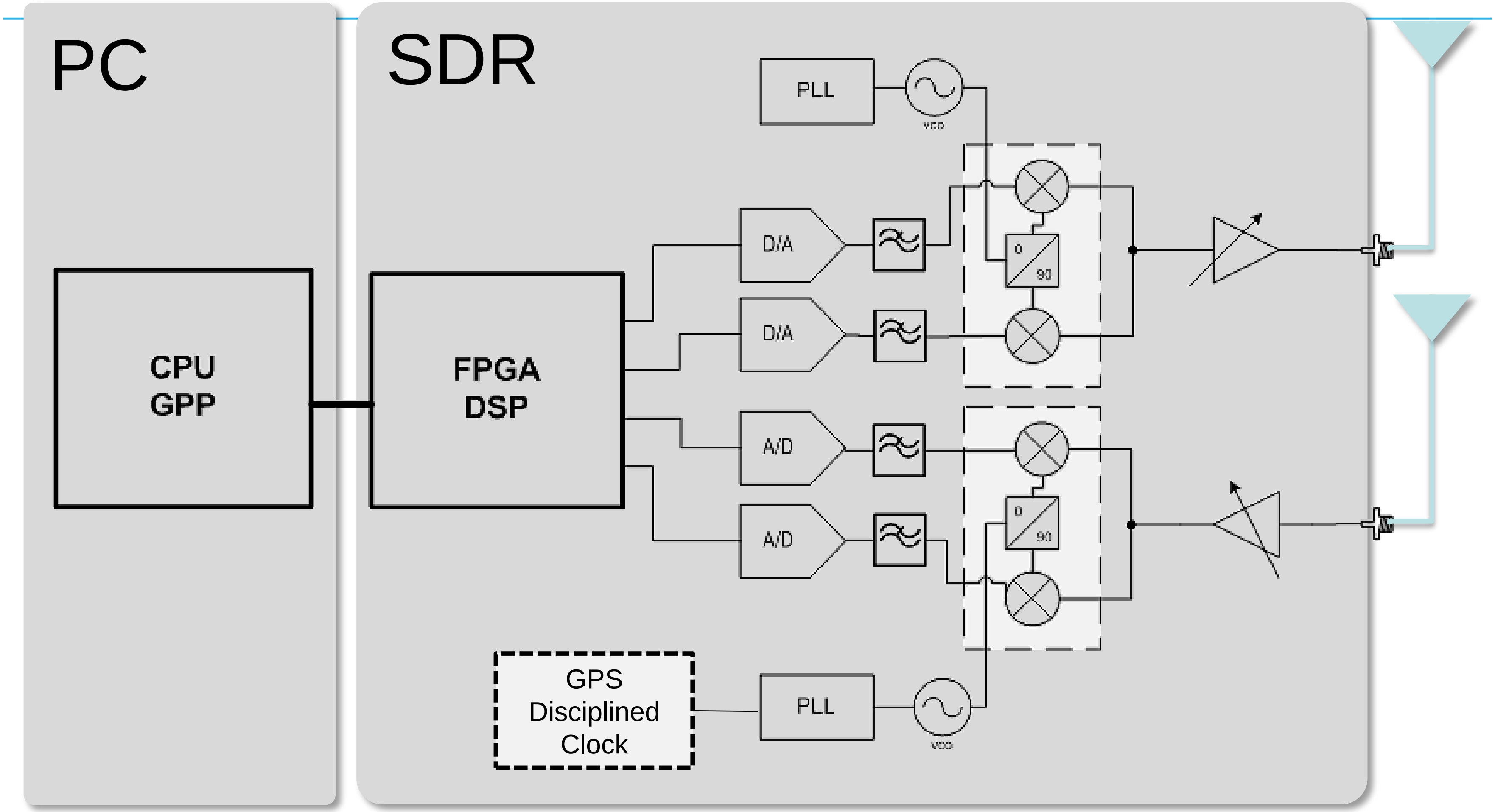
Software Defined Radio (SDR) for Spectrum Sensing

Erik Luther (Ettus Research / National Instruments)
erik.luther@ni.com

Common SDR Architecture



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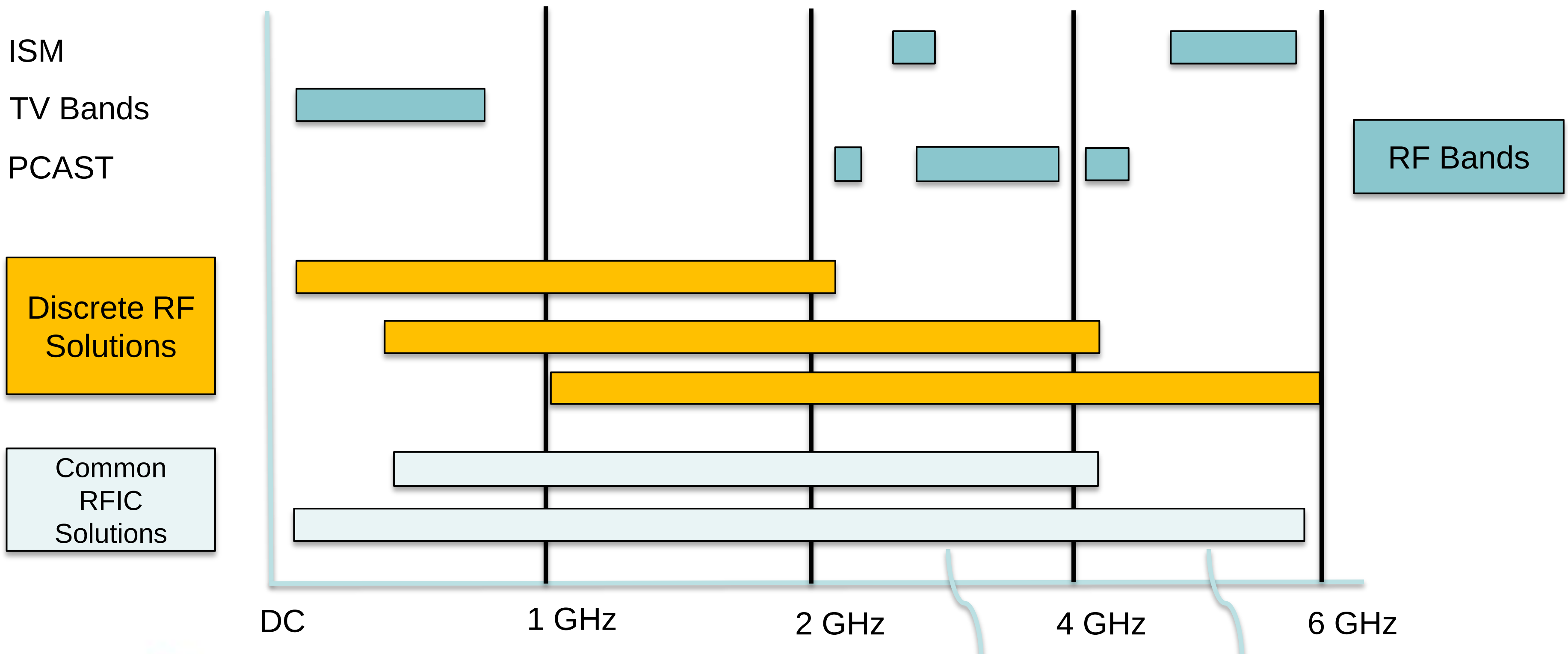
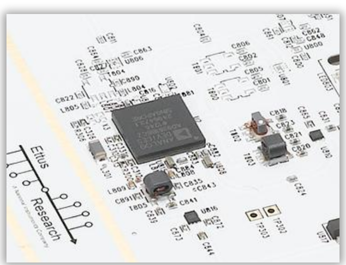
Candidates for Shared Spectrum

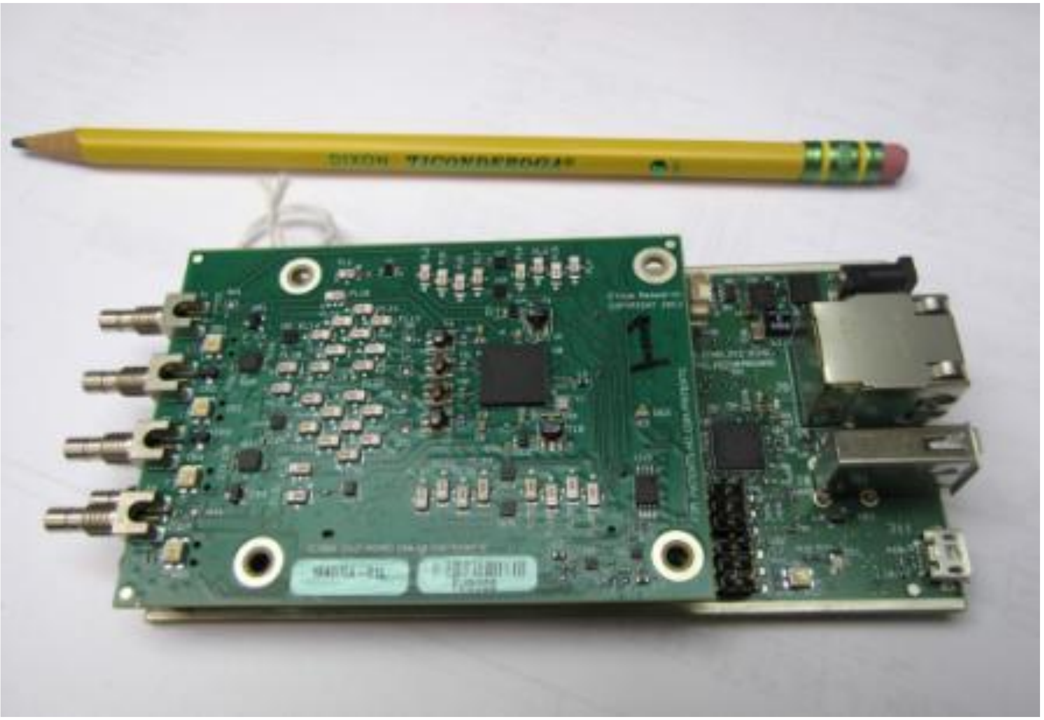


Discrete RF



RFIC

RFIC Enables Smaller Form Factors

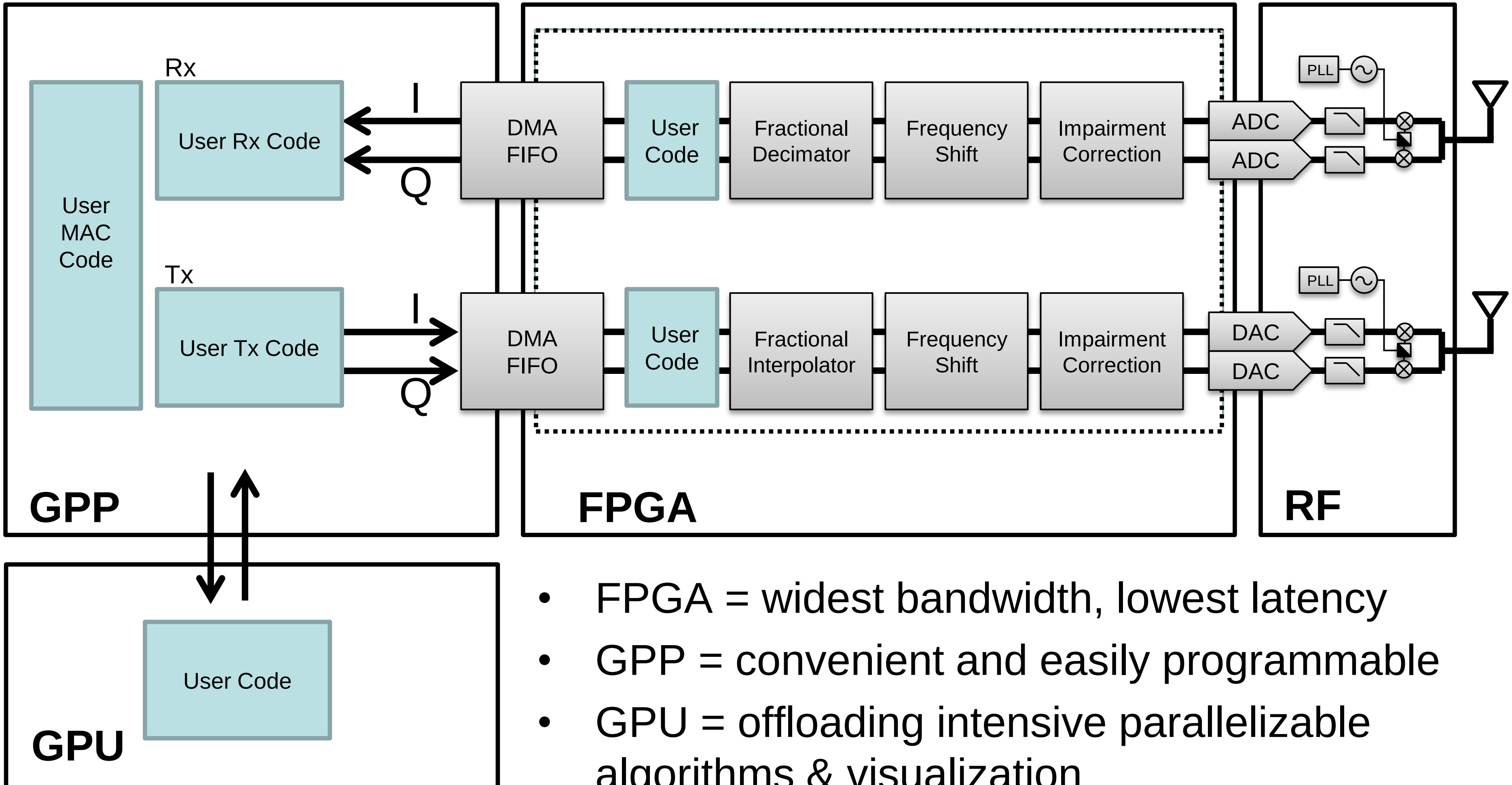


Size: 120x90x50 mm

Mobile phone sized package

- 70 MHz - 6 GHz
- Embedded Linux
- Embedded Ethernet
- Internal GPS
- USB Host connections

SDR Processor Example



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

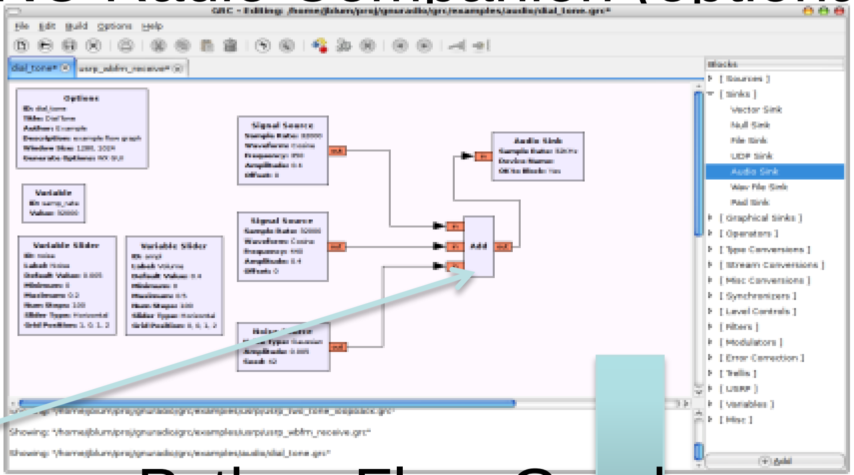
GNU Radio Design Flow Example

Open Source

DSP Block – C++ Work Function

```
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;
}
```

GNU Radio Companion (optional)

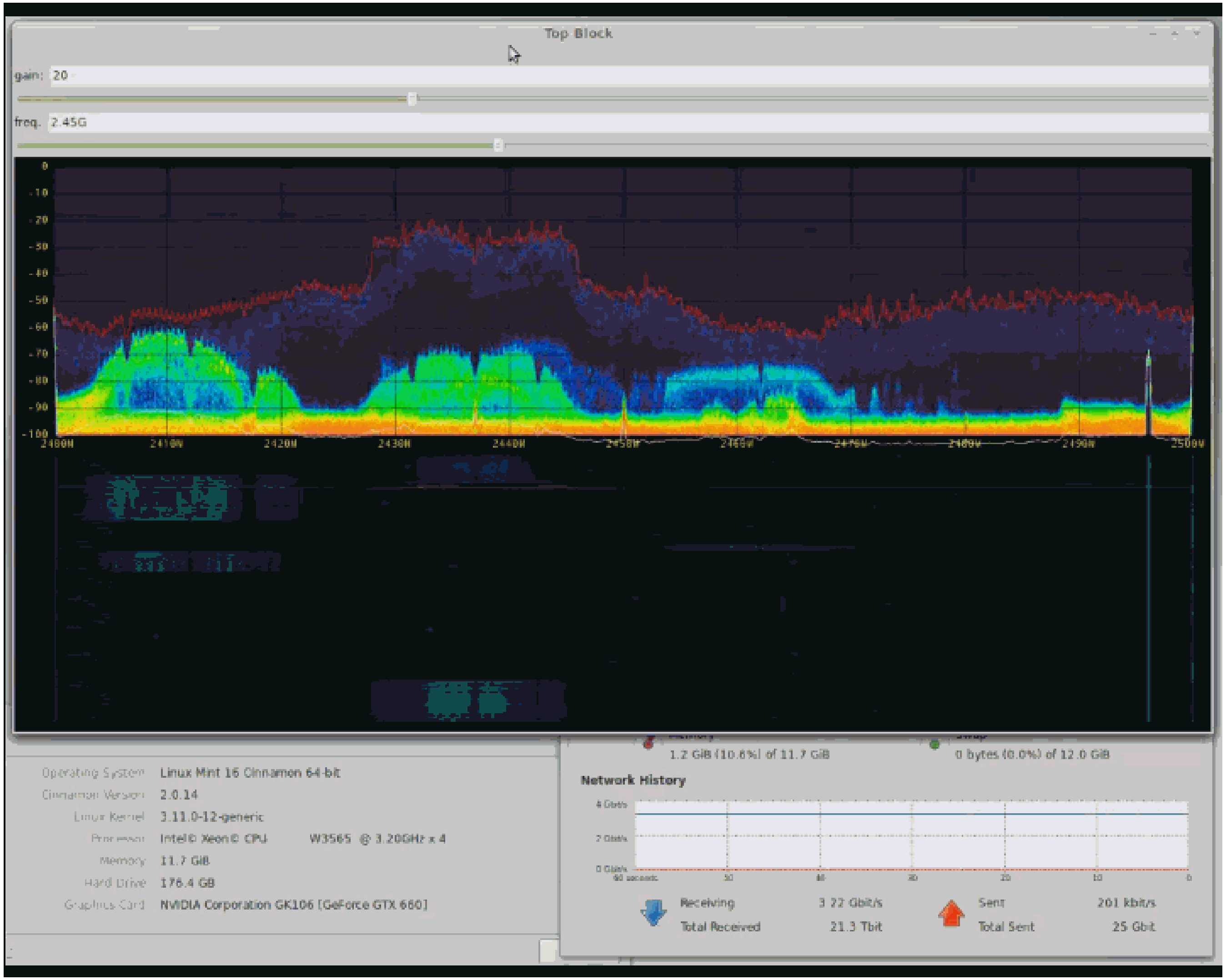


Python Flow-Graph

```
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()
```

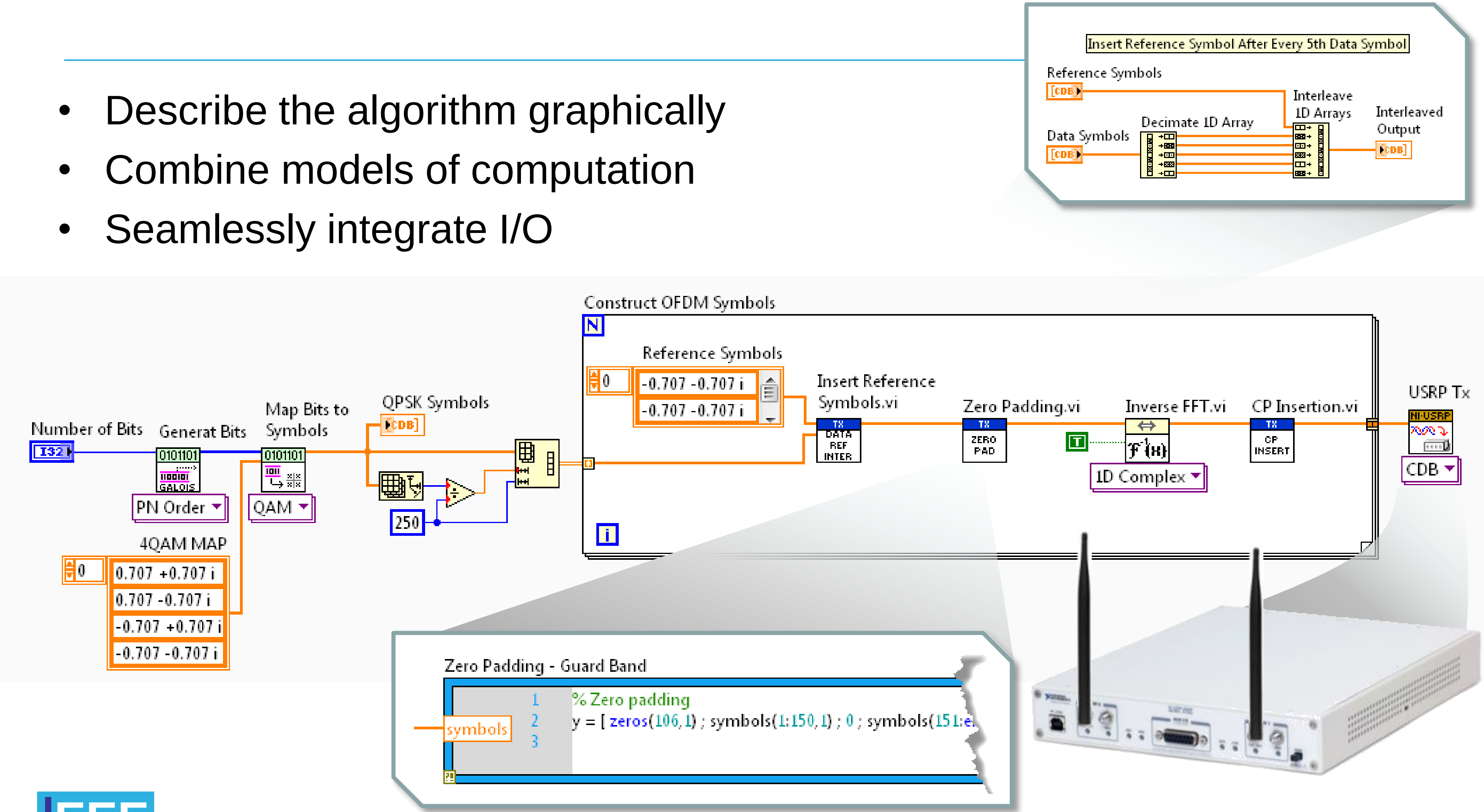
- Blocks
  - Large library of existing IP -> Mod/demod, filters, USRP I/O, GUI features, etc.
  - Write custom blocks – C++ or Python
- GNU Radio Companion (optional)
  - Import blocks
  - Connect blocks
  - Generate python source code for flowgraph
- Python Flow-Graph
  - Generate from GRC and/or hand-write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

GNU Radio spectrum visualization example



Combining Models of Computation

- Describe the algorithm graphically
- Combine models of computation
- Seamlessly integrate I/O



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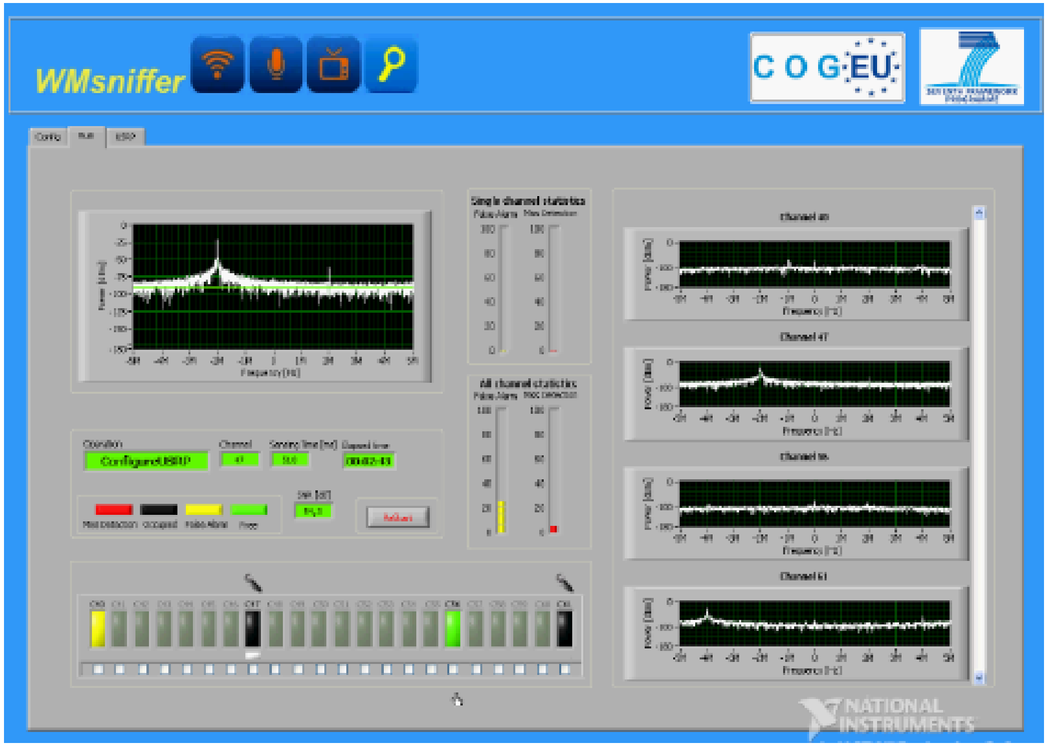
Cognitive Radio & WhiteSpace Implementation

Spectrum Monitoring Testbed

- Spectral sensing with blind detection
- GPS geographic localization
- Active database management
- Adaptive spectrum utilization



instituto de telecomunicações

SEVENTH FRAMEWORK PROGRAMME

C O G EU

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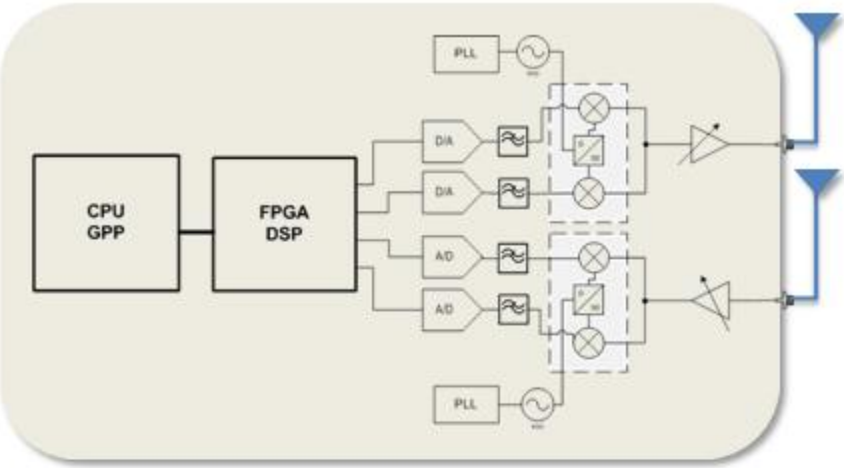
SOS Software Defined Radio Examples



Software Designed Instrumentation

Instruments

High Performance SDR Prototyping

Desktop SDR

Host Based SDR Prototyping

Deployable SDR

2 MHz BW SDR
(USB 2.0)

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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)

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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

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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
  - Example: RTL-SDR, Ettus Research, AmeriSys, Nutaq.
  - 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

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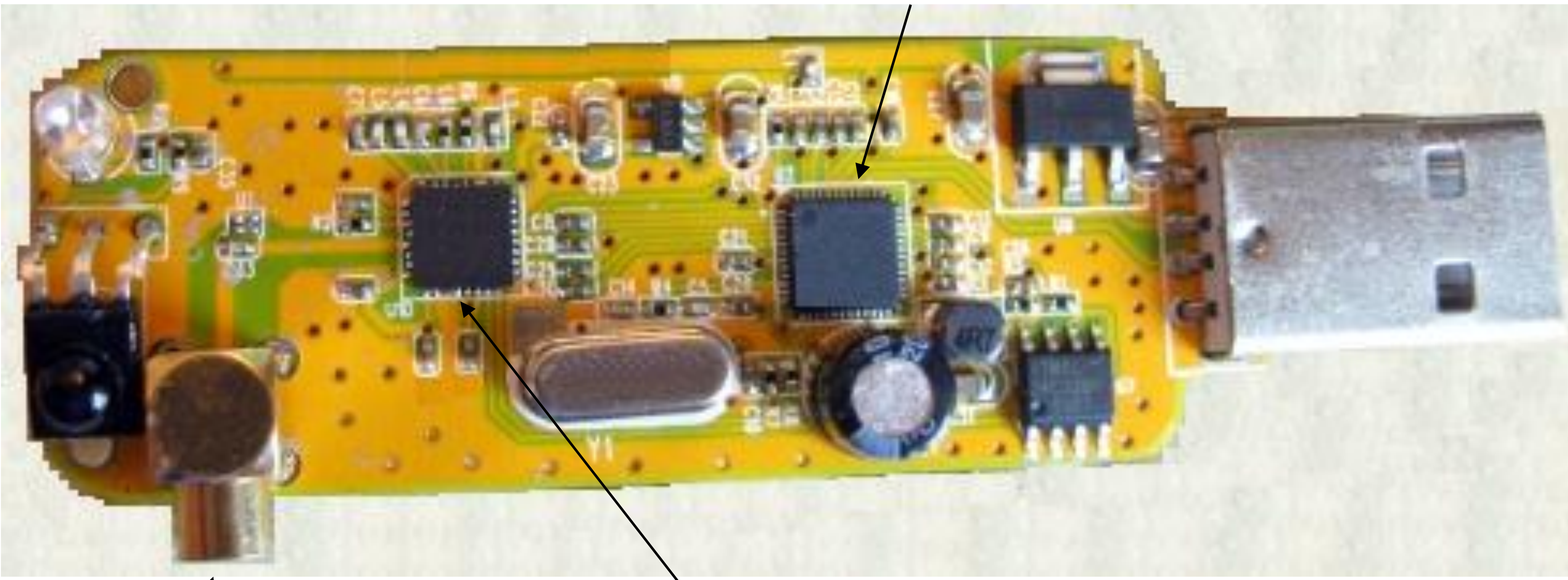
Example of SOS-IoT

Spectrum sensing can fit in a USB dongle

USB3 I/Q
2.5Ms/s A/D



Antenna
Port

Tuner
6/7/8 MHz BW
24-1766 MHz

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
Modesdeco
WxtoIMG
SoftFM
acars_ng
PDW
GNU Radio
NWRA
BAE Systems
SeeDeR
DStar
GR-AIS
ec3k
Orbitron
HDSDR
Studio1
Acarsd
Linrad
NRF905 Decoder
PowerSDR
cuSDR
SDR-J
AISMon
Redhawk
ADS-B Decoder and Radar
RTL-SDR
GR-Phosphor
OpenCPN
QtRadio
GQRX
DREAM
Nutaq
SDR-RADIO.COM V2
SDR_Lab
LibRadio
rtlamr
LTE-Scanner
Virtuel Radar Server
Trunk88
GR-Elster
DAB_Player
Unitrunker
WebRadio
Sdrangelove
AmeriSys
GlobeS
ViewRF
FunCube
Multimode
PlanePlotter
ShipPlotter
SRD#
ShinySDR
Radio Receiver for Chrome
Acarsdec
SDRWeather
GNSS
SDR Touch
GR-RDS
coca1090
adsbSCOPE
RDS_Spy
ADSB
Sodira
Ettus
TVSharp
NRF24-BTLE Decode
gr-air-modes
Airprobe
Wavesink Plus
dl-fldigi
Panorama
RTL_433
SondeMonitor

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

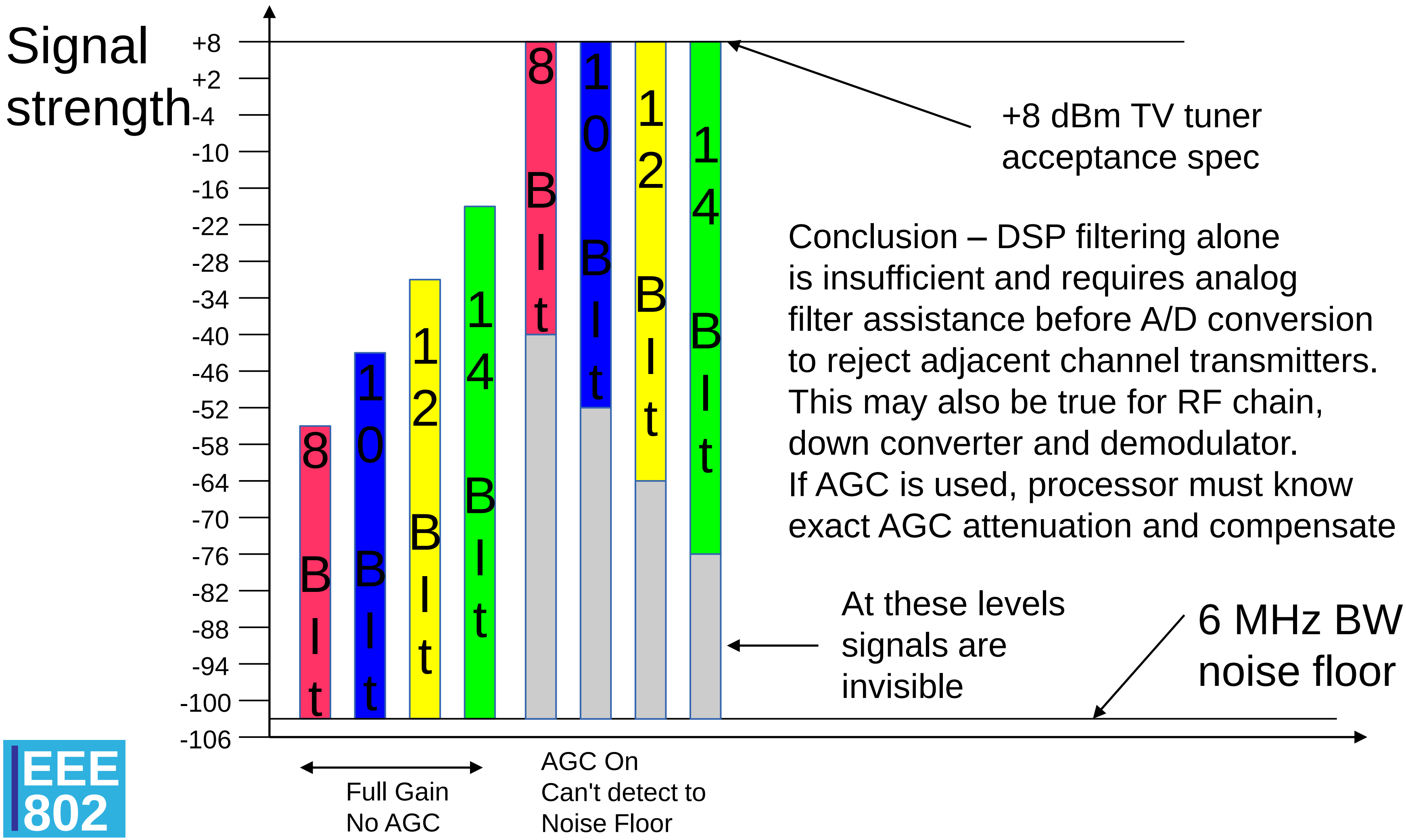
Spectrum Sensing Implementation

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 it's 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 form 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



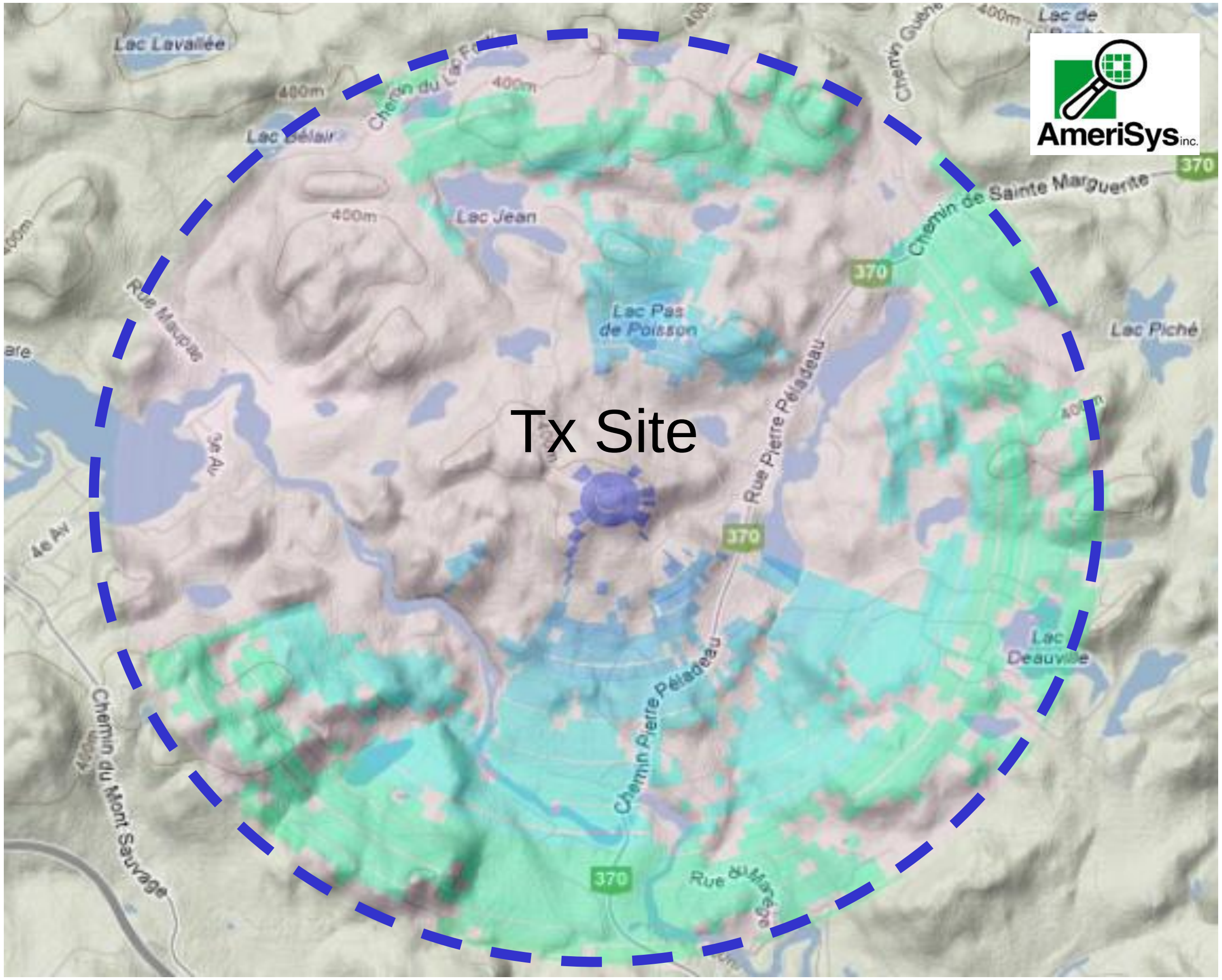
Conclusion – DSP filtering alone is insufficient and requires analog filter assistance before A/D conversion to reject adjacent channel transmitters. This may also be true for RF chain, down converter and demodulator. If AGC is used, processor must know exact AGC attenuation and compensate

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

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P802.22.3 Spectrum Occupancy Sensing PAR

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.

P802.22.3 Spectrum Occupancy Sensing PAR

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

- Spectrum Occupancy Sensing PAR - https://mentor.ieee.org/802.22/dcn/14/22-14-0075-02-0003-spectrum-occupancy-sensing-par-form.pdf
- Spectrum Occupancy Sensing Criteria for Standards Development - https://mentor.ieee.org/802.22/dcn/14/22-14-0061-05-0003-802-22-spectrum-occuoancy-sensing-criteria-for-standards-development.docx

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