

Illinois Institute of Technology Spectrum Observatory



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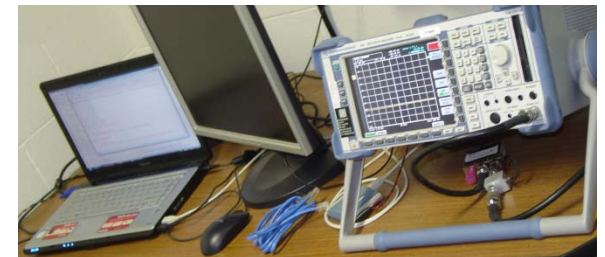
WinnForum, 2014

Overview

- Project History
 - Components and Design
 - Spectrum Occupancy Estimates
 - LMR Study
 - Monitoring Tools
- Current Work
 - Multi-site Observatory
 - Aircraft RADAR/LTE Study
 - International Observatory
 - Storage System
- Importance

Project History

- NSF grants for initial spectrum observatory (2007)
 - Wideband: 30 – 6000 MHz
 - Continuous, multi-year operation
 - Partnered with Shared Spectrum Company (SSC)
- Goal: Support dynamic spectrum sharing
 - Spectrum usage trends and anomalous events
 - Datasets for DSA and cognitive radio studies
 - Modeling, simulations, analyses
- Related NSF grants
 - Dedicated Land Mobile Radio (LMR) study
 - Multi-site observatory
 - Global observatory
 - Dedicated aircraft RADAR/LTE study



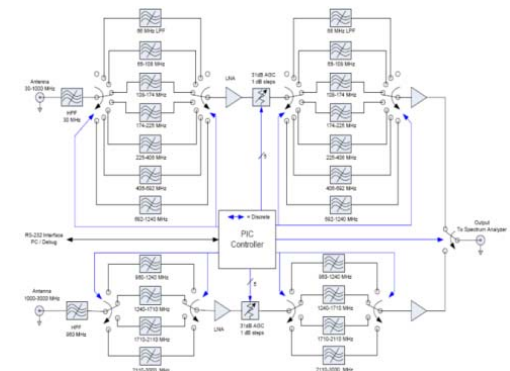
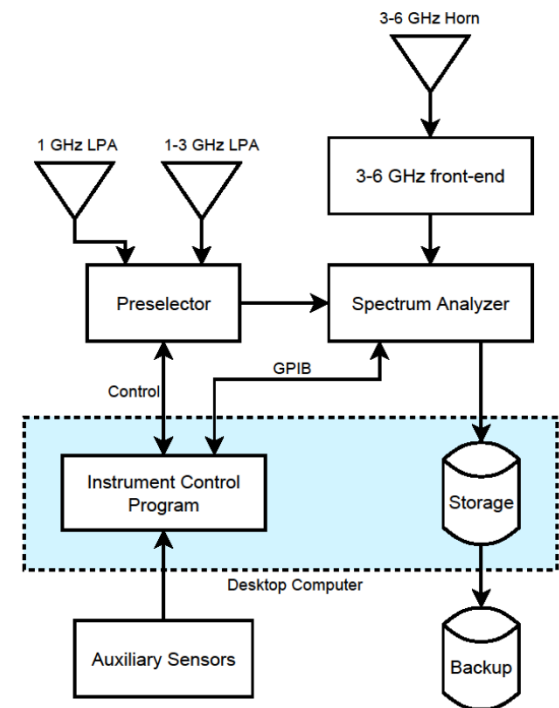
Wideband Spectrum Observatory

- Spectrum analyzer based system
 - First system implemented
 - Multiple antennas (pointed north)
 - Custom RF front-end (SSC design)
- Located on IIT campus
 - ~3 miles south of down-town Chicago
 - 21 story IIT Tower
 - Clear view of Loop
- Main parameters
 - ~1 minute scan period
 - 3 – 1000 kHz resolution (varies by frequency)
 - 30+ sub-bands



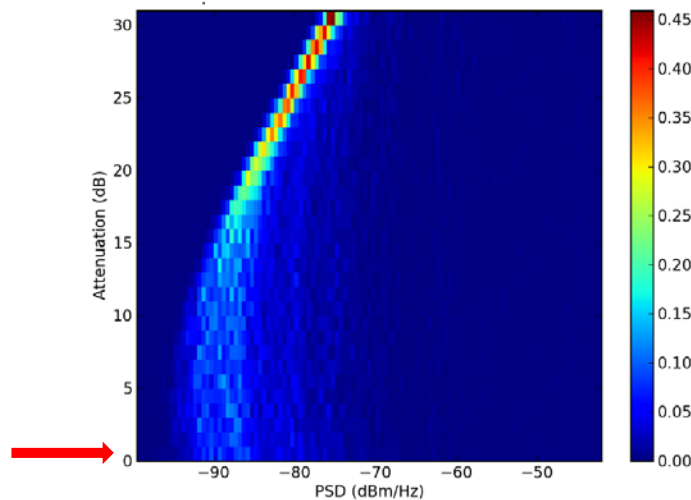
Observatory Components

- Antenna(s)
 - Choice of directionality, bandwidth
- Front-end
 - LNAs and fixed/programmable attenuators and filters
 - Maximize dynamic range
 - Distortion a challenge
 - Cables, lightning arrestors, biasing, etc.
 - 10+ dB loss at some frequencies
- Sensor
 - Swept spectrum analyzer (analog) or FFT-based sensor
 - 10 – 100x price difference
 - Spurs and I/Q imbalance
- Desktop or embedded computer

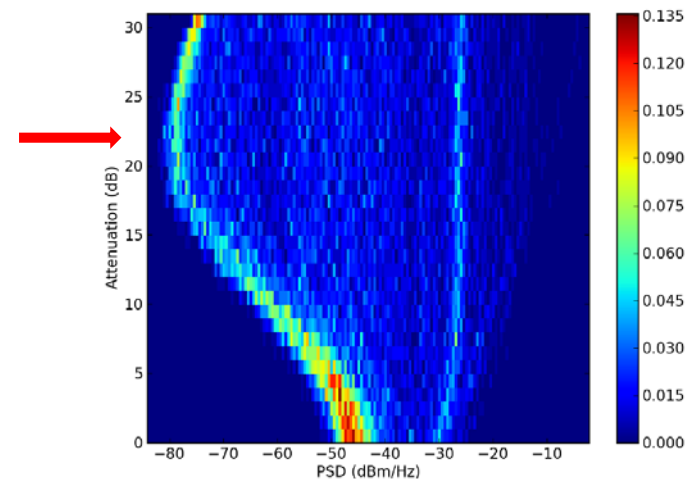


Band Design

- Divide spectrum into smaller bands
 - Typically narrow/wide at low/high frequencies
 - Signal power levels (e.g. FM), bands of interest (e.g. 2.4 GHz ISM)
 - Optimal measurement parameters
- Front-end attenuation to maximize dynamic range



Low-power signals →
low attenuation sufficient



High-power signals →
intermediate attenuation

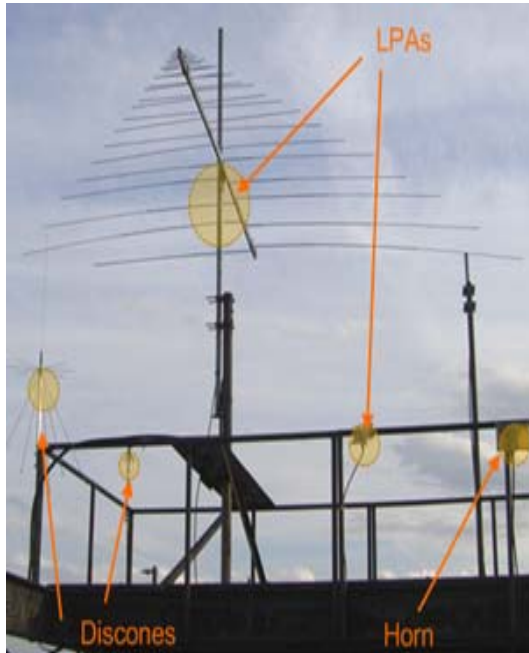
Additional Measurement Systems

- Wideband system offers limited resolution
 - Good overview, but limited by spectrum analyzer's speed
 - Narrow-band + transient/bursty signals problematic
- Grants and other support lead to more systems
- Additional Chicago systems
 - Auxiliary wideband:
 - 30 – 3000 MHz: Rockwell-Collins, FFT-based sensor
 - 10 – 6000 MHz: CRFS RFEye sensor
 - Dedicated LMR systems: 460 MHz, 700 MHz, 850 MHz
 - USRP2 based SDR
- Systems at two sites
 - IIT Tower and Harbor Point (east of downtown)

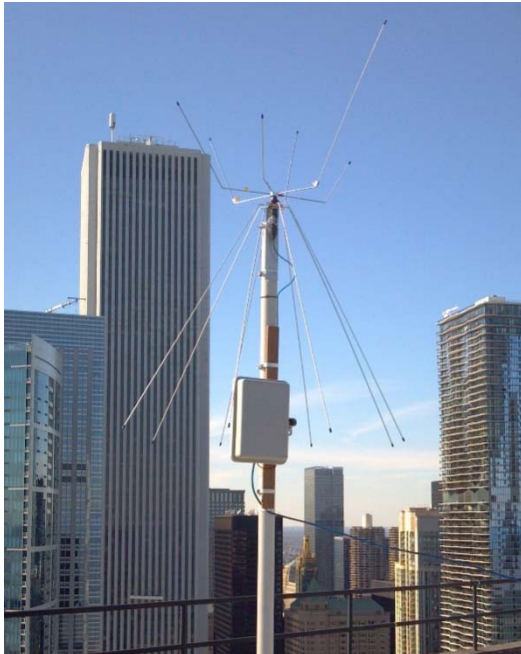


Harbor Point

Chicago Measurement Summary



IIT Tower



Harbor Point

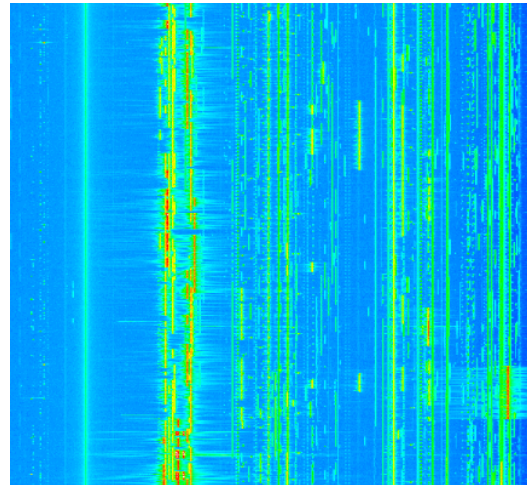


Mobile

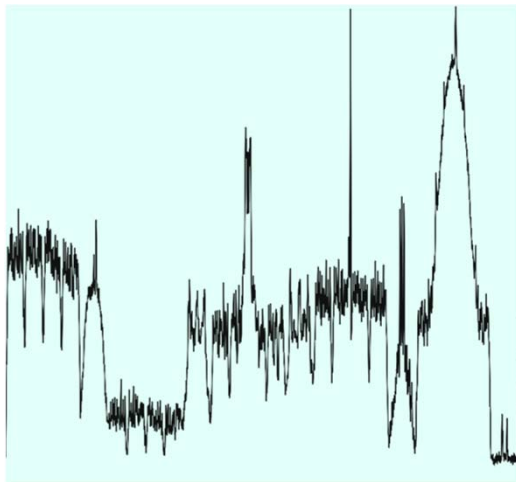
Measurement Device Summary



Long-term wideband
60 s period ■ variable RBW



Auxiliary
1 s ■ 12.5 kHz



Auxiliary
2 s ■ 12.5 kHz

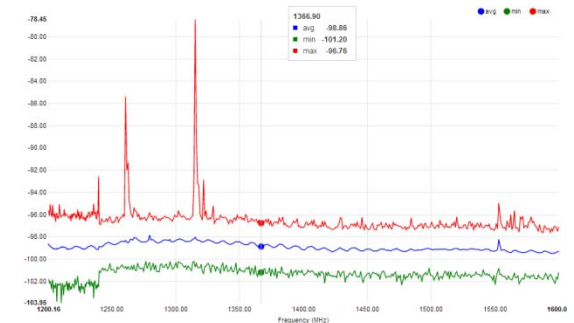


High-fidelity LMR
0.25 s ■ 6.25 kHz

Results

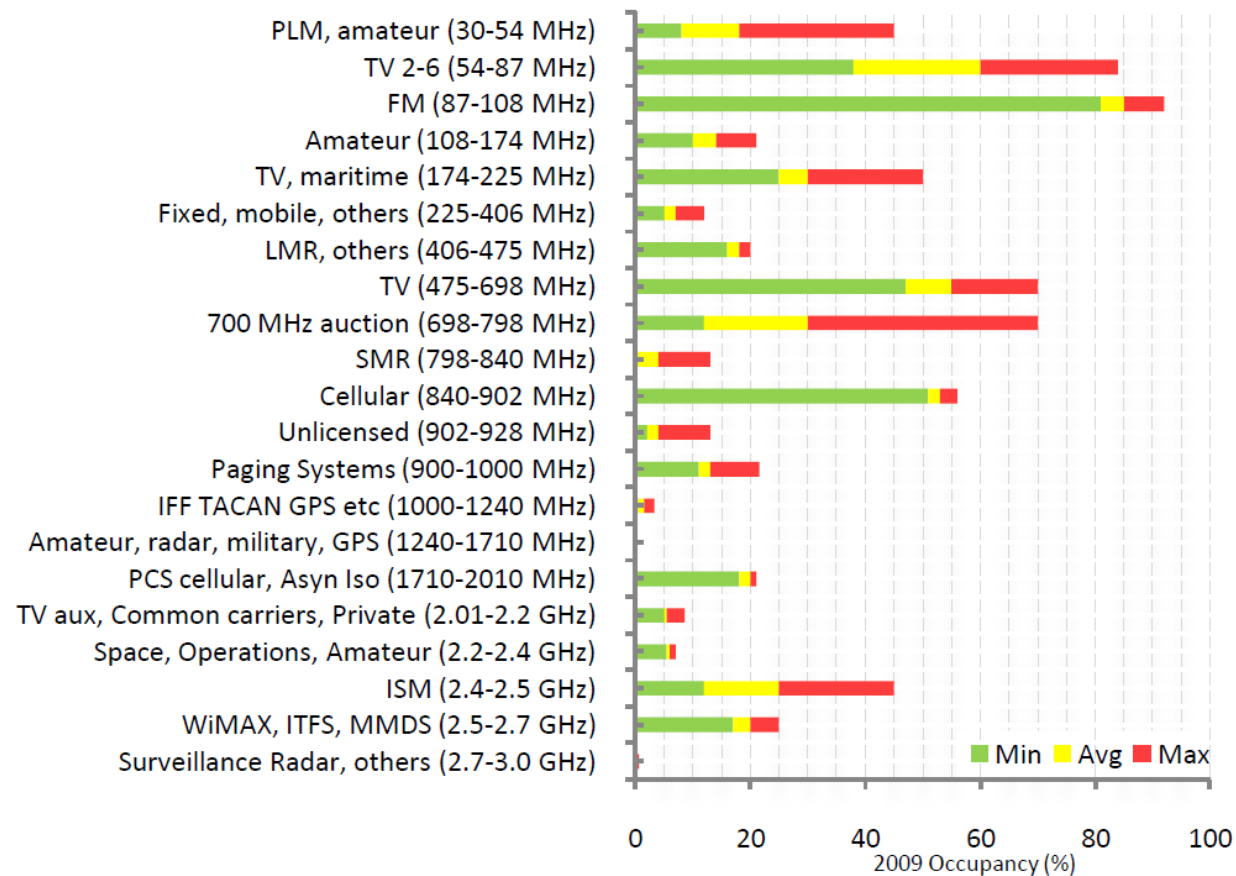
Spectrum Occupancy Definition

- Occupancy -- average spectrum over time/frequency where detectable power exceeds threshold
 - Energy detection
 - Threshold based on noise floor (constant false-alarm rate)
- Caveats
 - False-alarms and missed detection
 - Point-to-point/directional signals
 - Terrestrial signals
 - Reliable for powerful, broadcast signals



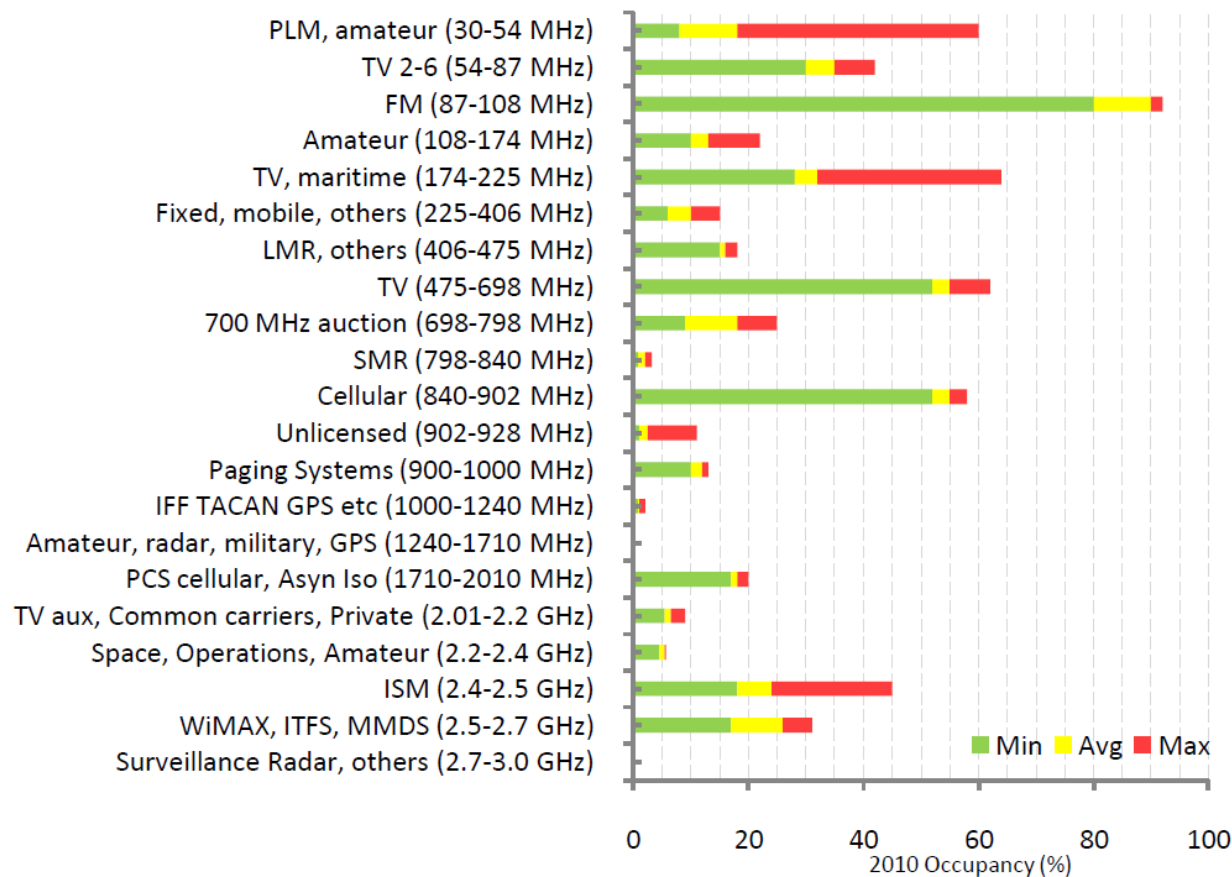
Spectrum Occupancy

- 14 % average occupancy in 2009 (up to 3 GHz)

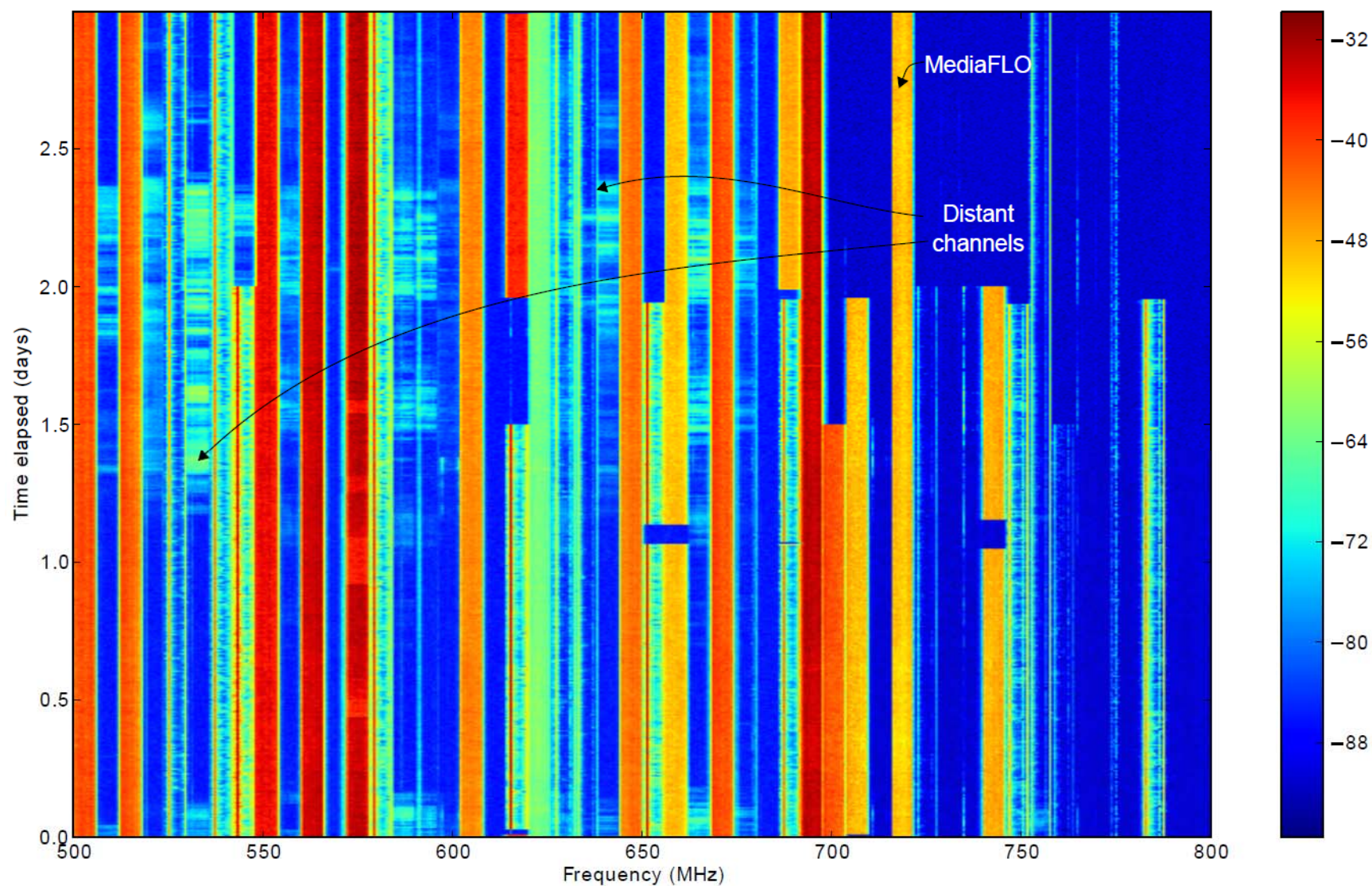


Spectrum Occupancy

- 15 % average occupancy in 2010 (up to 3 GHz)

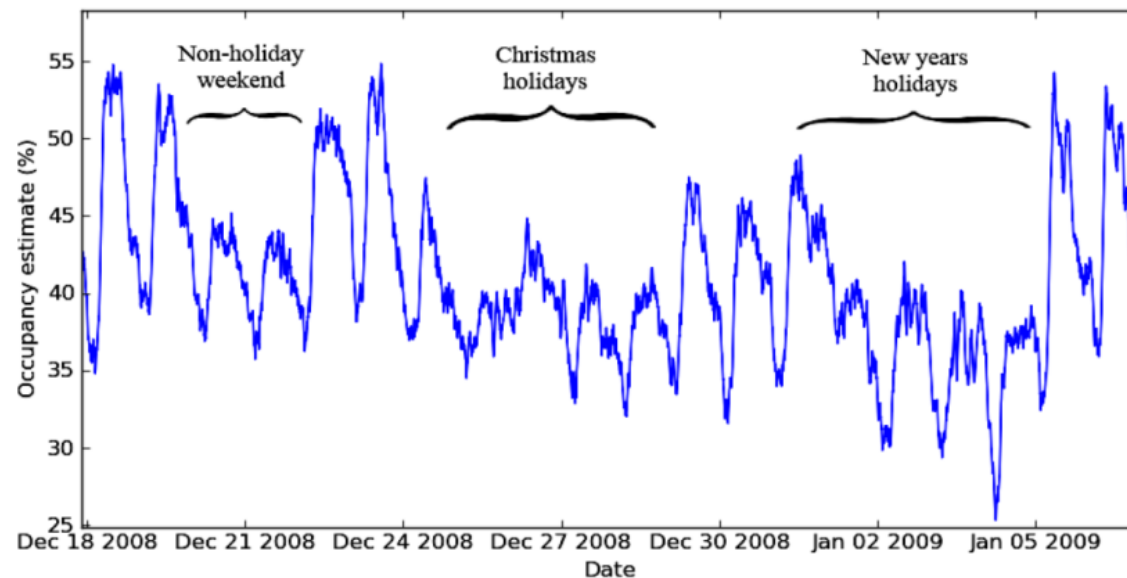
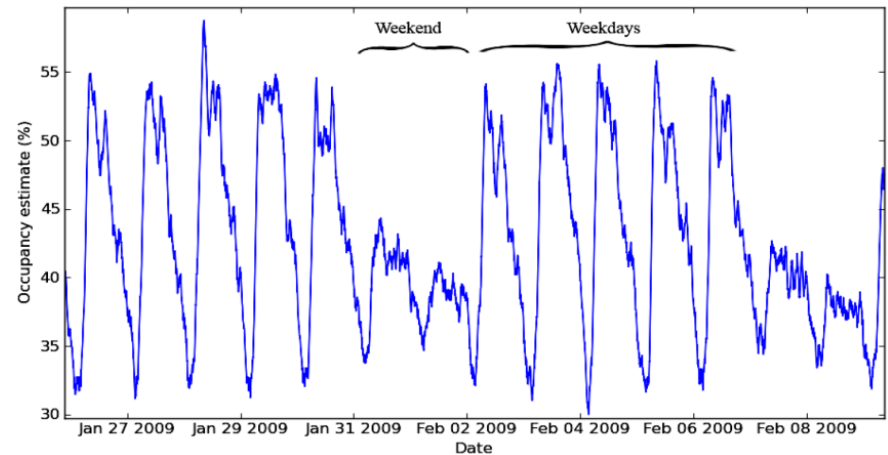


2009 Digital TV Switch-over

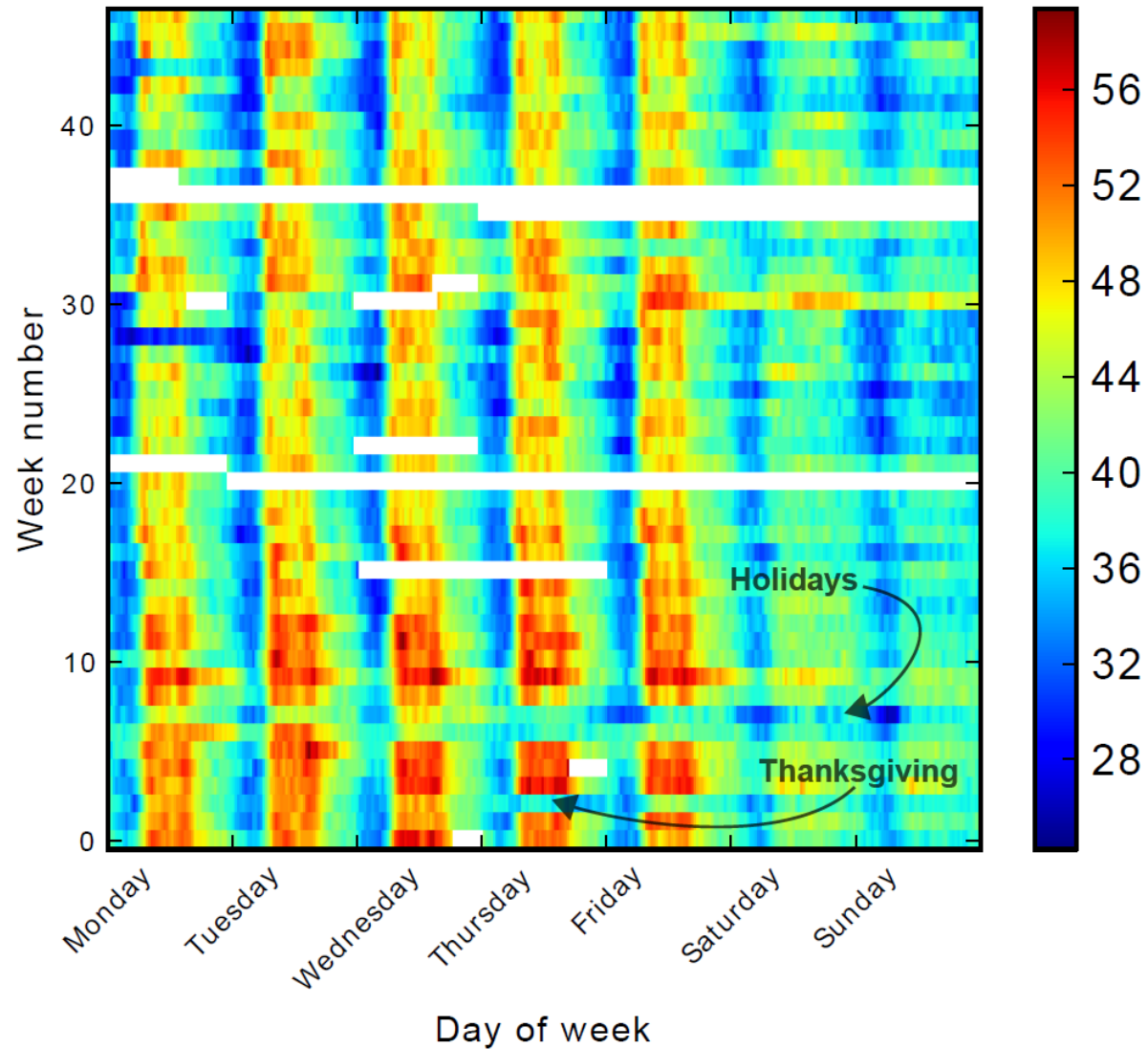


Cyclic Activity

- Cyclical patterns in activity
 - Daily, weekly and yearly trends have been observed
 - Weekends and nights are readily apparent in several bands
- 450-465 MHz LMR band

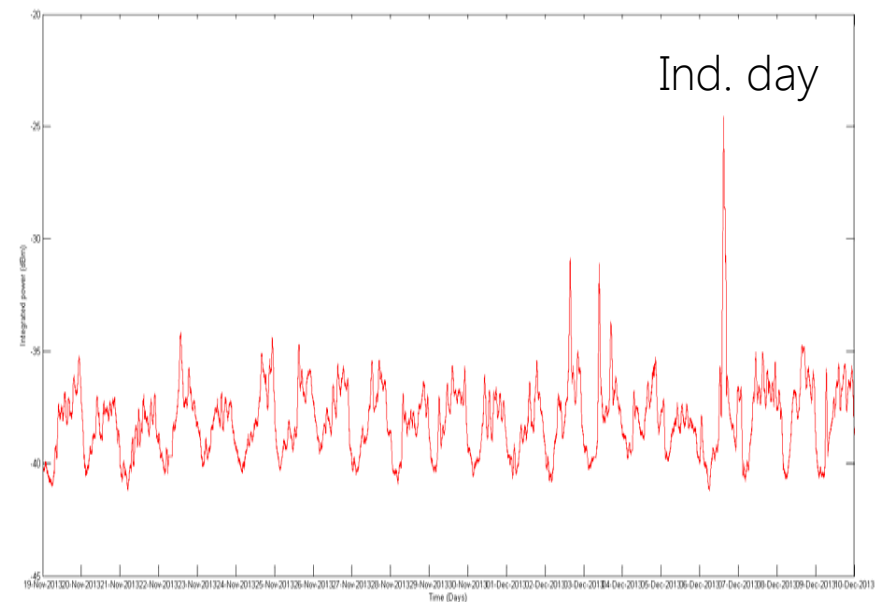
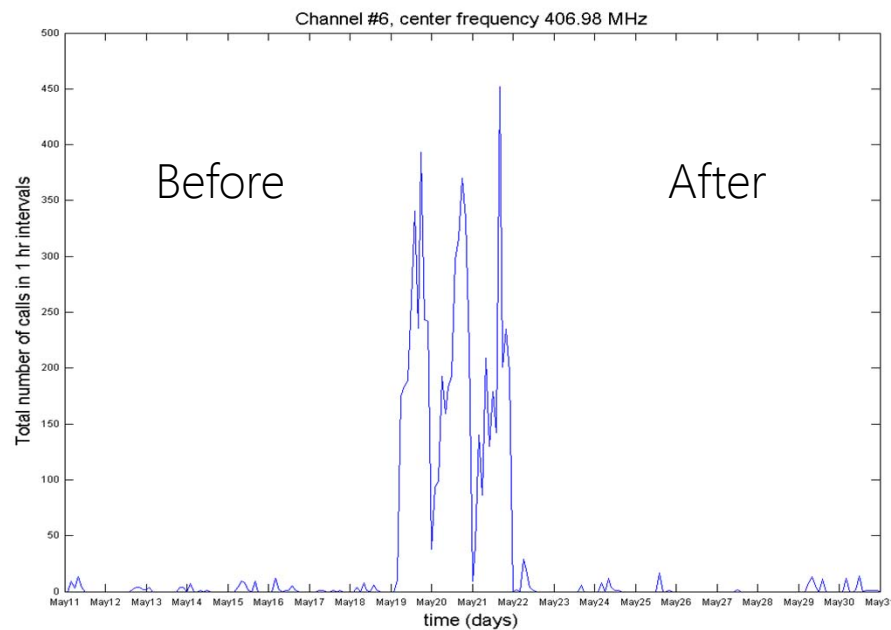


Cyclic Activity



Transient Activity

- NATO Summit (2012)
 - Held for two days in downtown Chicago
- Call-rate in 406 MHz (LMR)
- Finnish Independence Day (2013)
 - National holiday and ceremony
- Power 1835 – 1855 MHz (LTE/GSM)



Chicago Blizzard (2011)

- 20+ inches of snow
 - 1,300 flights cancelled, 900 cars and buses stranded
 - Third highest snow-fall on record



Lake Shore Drive (during storm)

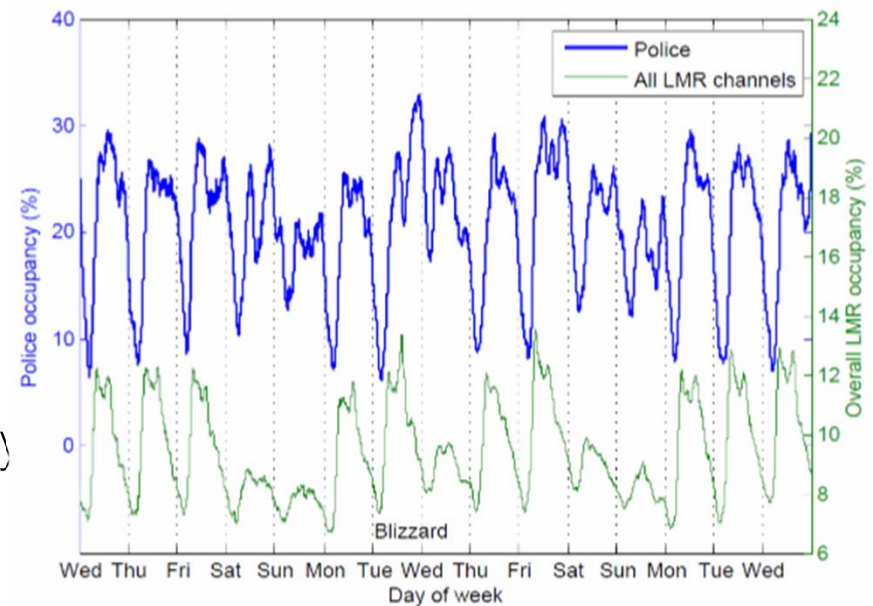


Residential neighborhood (after)

- Effect on spectrum usage?

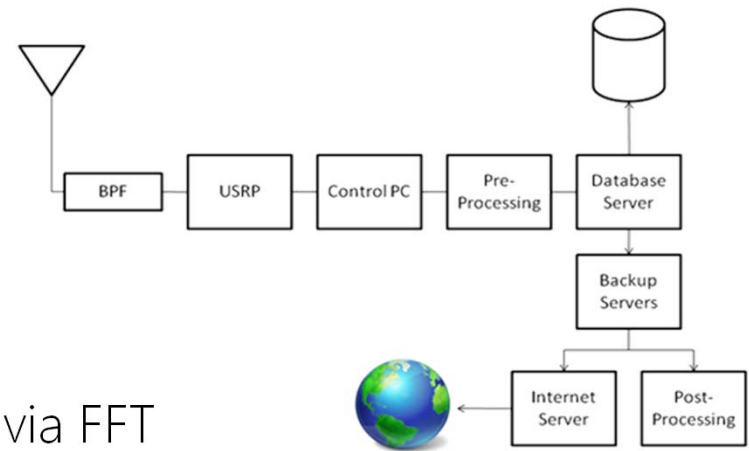
LMR Band Occupancy

- LMR used by both public safety (e.g. police, fire, etc.) and commercial users
- 460 MHz LMR occupancy
 - Different characteristics for police
- Snow storm effect
 - Overall occupancy approaches weekend levels
 - Peak in police band occupancy
- Disasters apparent in spectrum
 - Emergency reallocation opportunity



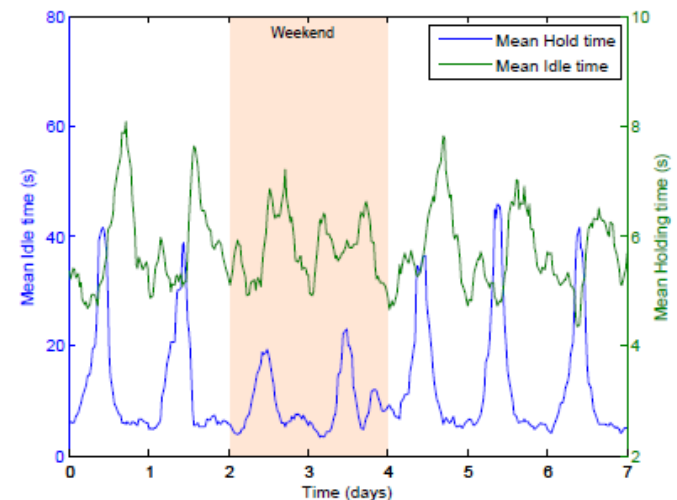
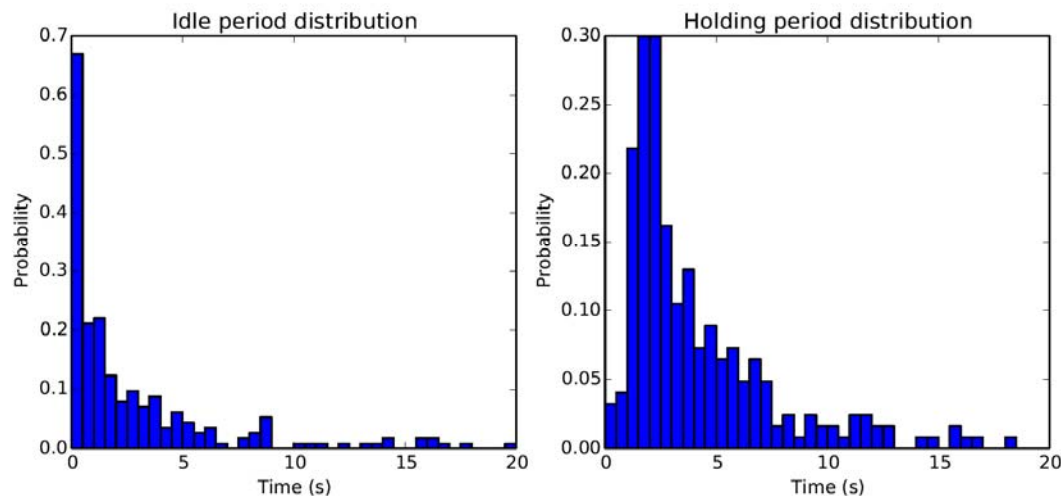
LMR System Overview

- Considerable interest in LMR band
 - Policy makers, developers, users, etc.
- LMR measurement system
 - Design based on USRPs
 - Power spectrum and channel powers via FFT
- Faster sweep rate and higher resolution
 - 10 MHz in 250 ms, with 6.25 kHz resolution (for 12.5 kHz channels)
- Monitored multiple LMR bands
 - 460 MHz
 - 850 MHz (NPSPAC)
 - 700 MHz (PSR narrowband)



LMR Measurements

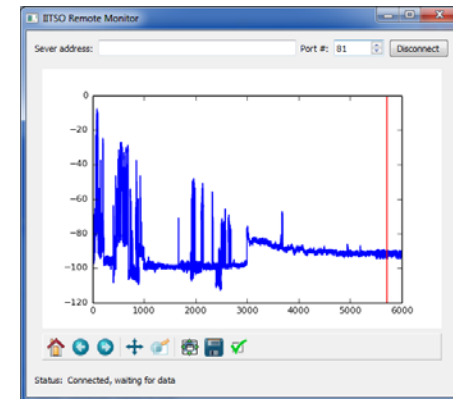
- Channel states statistics can be readily analyzed
 - Long-term trends
 - Idle and holding times, call rates, etc



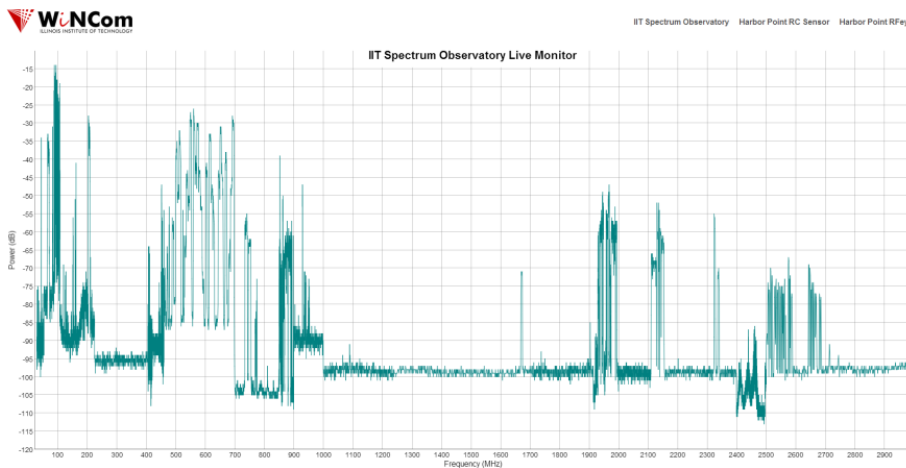
- Channel state models, time series, etc.
 - Non-stationary

Remote Monitors

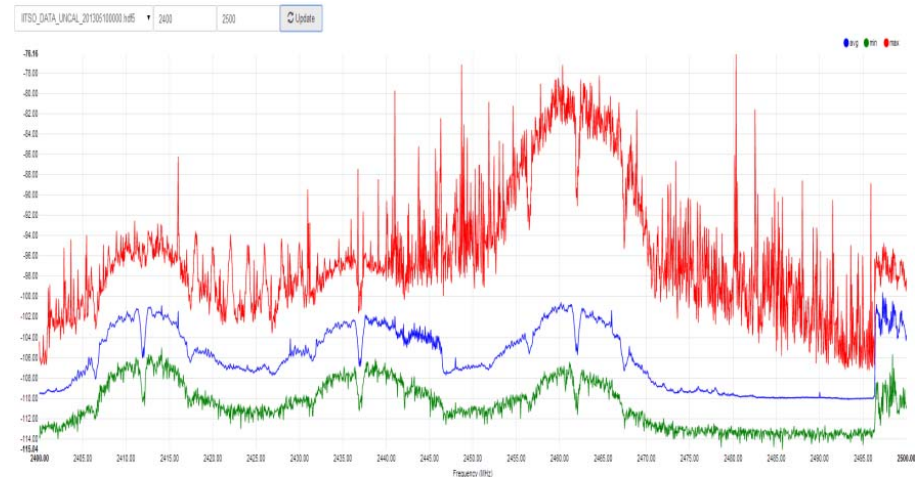
- Data accessible via remote clients
- All observatories (IIT, Harbor Point, Turku)
- Web-based system
 - JSON feeds available



Client software



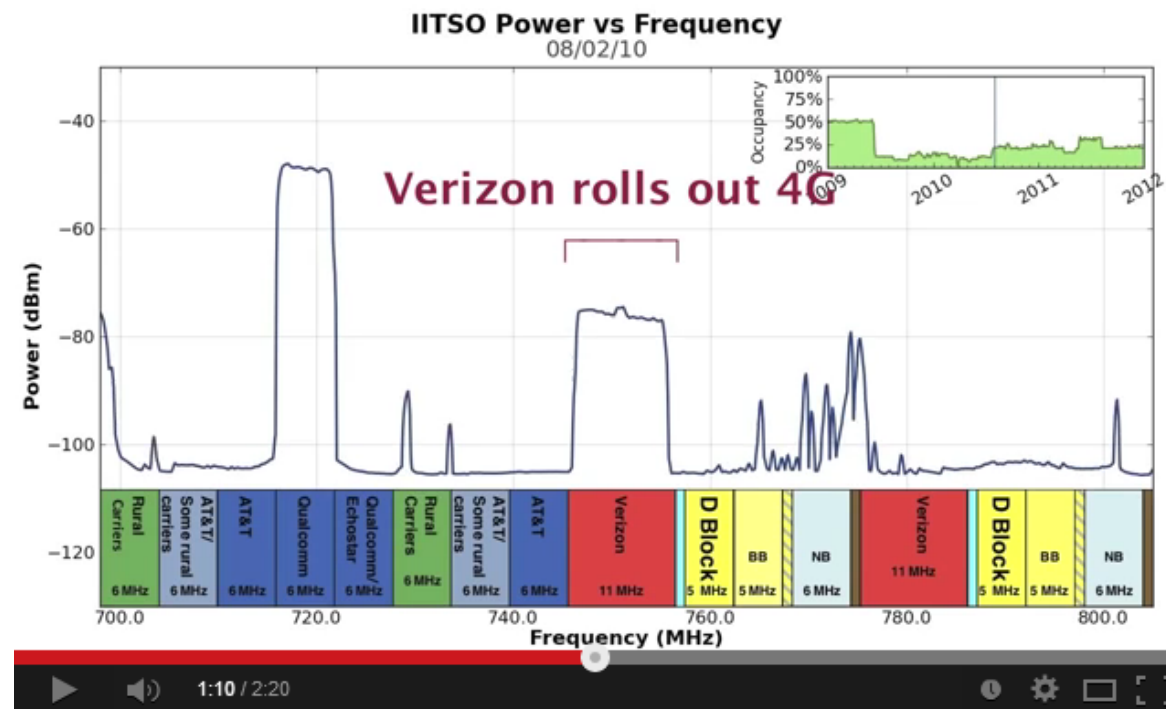
Dynamic web-based plotting interface in (near) real-time



Web interface for browsing historic data

Long-term Spectrum Visualization

- Three year animated video of spectrum
 - Utilize archive of spectrum data
 - <http://youtu.be/h-Ffq1kCvas>

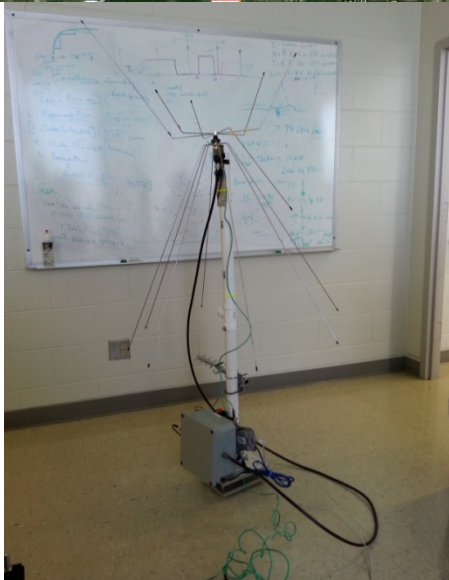


700MHz Spectrum Measurements

Current and Upcoming Work

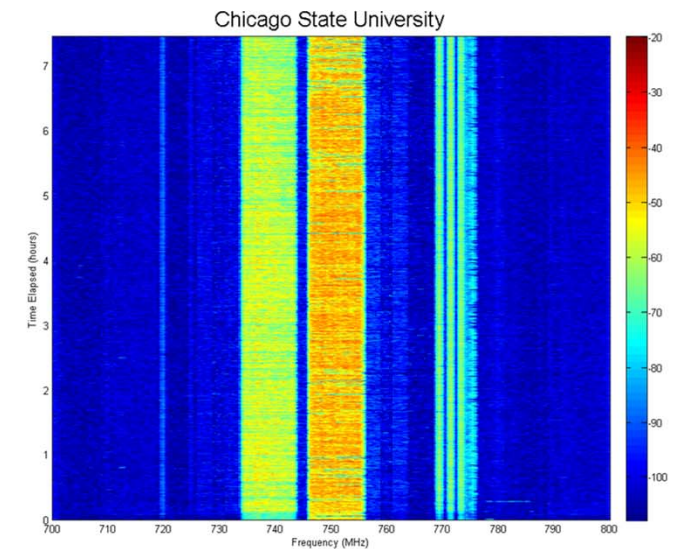
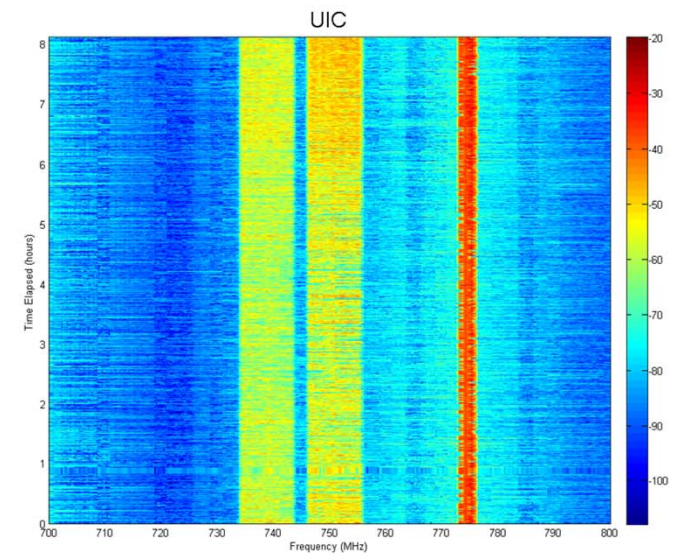
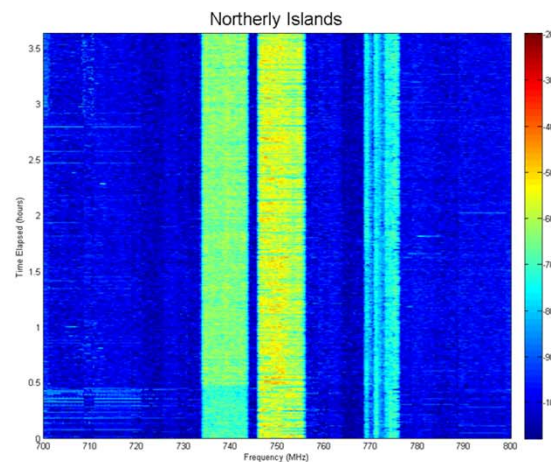
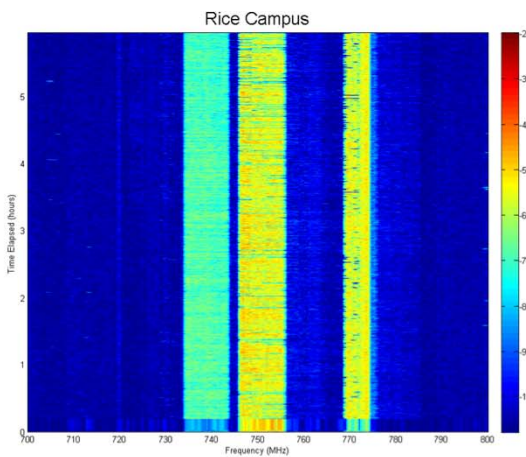
Multi-site Observatory

- Most measurements performed on IIT campus
 - Additional fixed site at Harbor Point
- Observe local geographic variability
 - Effects of shadowing and directional signals
 - Data fusion, source localization, etc.
- Subject of NSF grant
 - Expand to multiple sites in Chicago
 - Measurements of Federal bands optioned for sharing (NTIA Fast Track report)



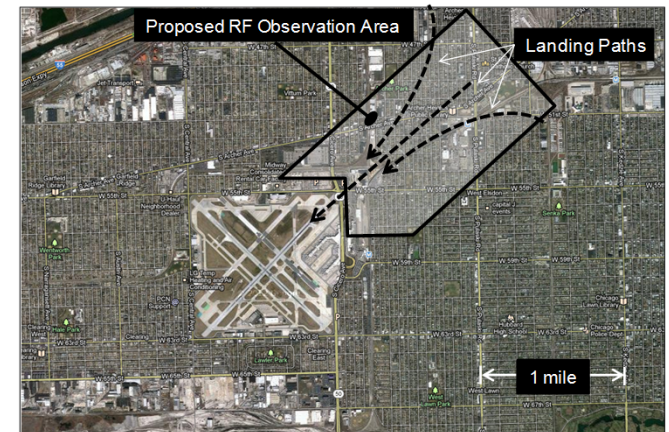
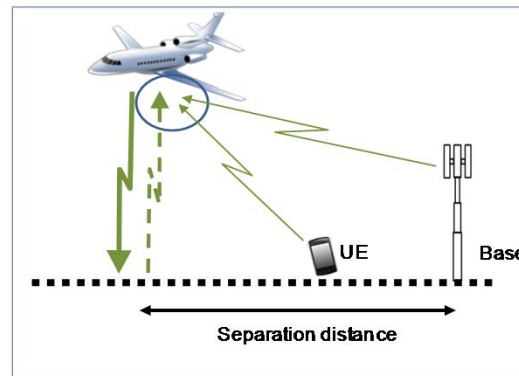
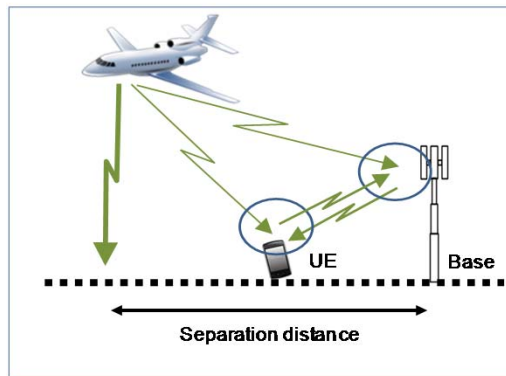
Snap-shot Study

- Preliminary measurements
 - Assess geographic variations in spectrum
 - 9 locations around Chicago
- 700 – 800 MHz LTE band
 - Commercial LTE + public safety
 - Power spectrum difference
- Similar for cellular (e.g. PCS)



Aircraft RADAR/LTE Study

- RADAR altimeter band only used during aircraft landing
 - Geographically and temporally localized
 - Candidate for spectrum sharing?
- Interference between RADAR and LTE (and vice versa)



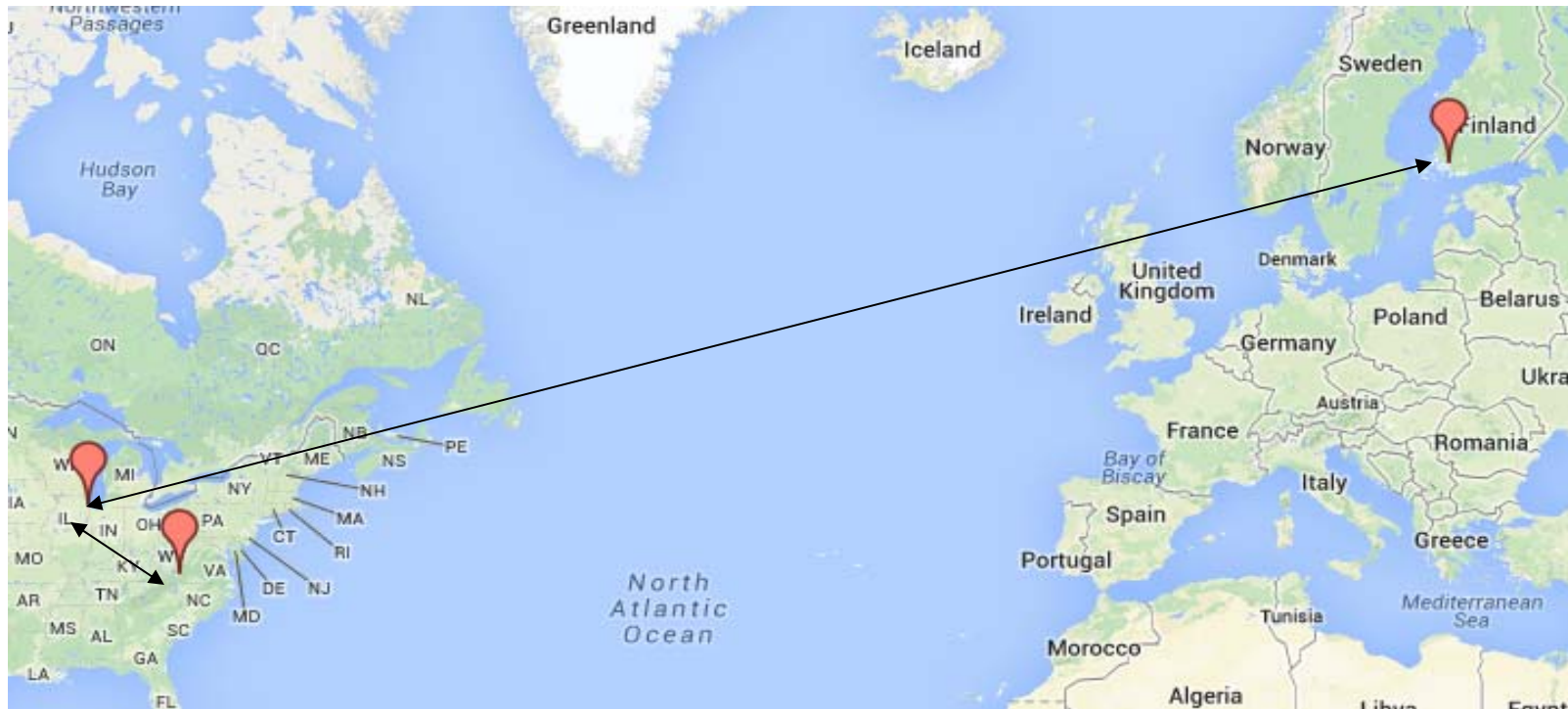
Midway Airport

- Goal: feasibility of sharing with LTE
 - Dedicated measurements of 4.2 GHz band
 - Modeling, simulation, algorithms

Global Spectrum Observation

- Deploy observatories over geographically dispersed locations
 - Compare spectrum usage over large scale
 - Develop and validate statistical models of spectrum usage
 - Promote dynamic spectrum sharing
- Locations
 - 2x Chicago (IIT)
 - 1x Virginia (Virginia Tech.)
 - 2x Finland (Turku University of Applied Science)
- Subject of current grant
 - Wireless Finland/US (WiFiUS)

WiFiUS Locations



Chicago – VA: 630 miles

Chicago – Turku: 4,000+ miles

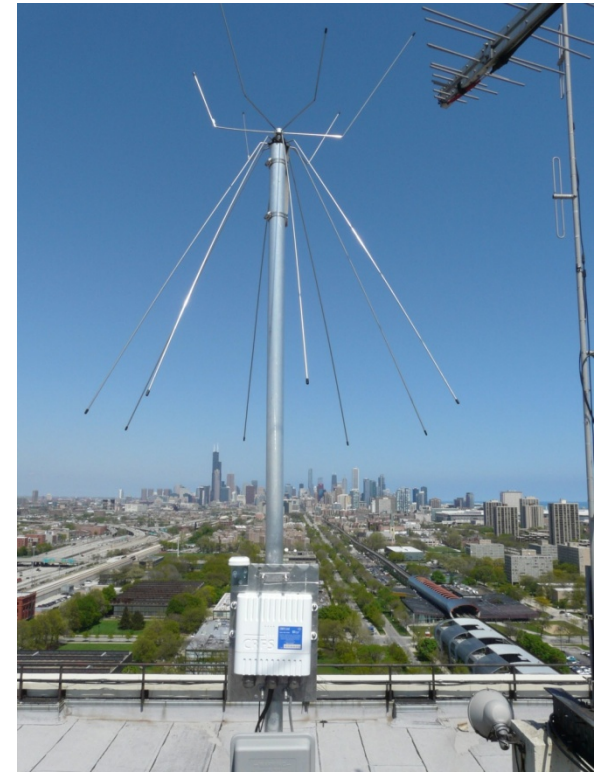
WiFiUS Sites



Harbor Point, Chicago



Turku, Finland



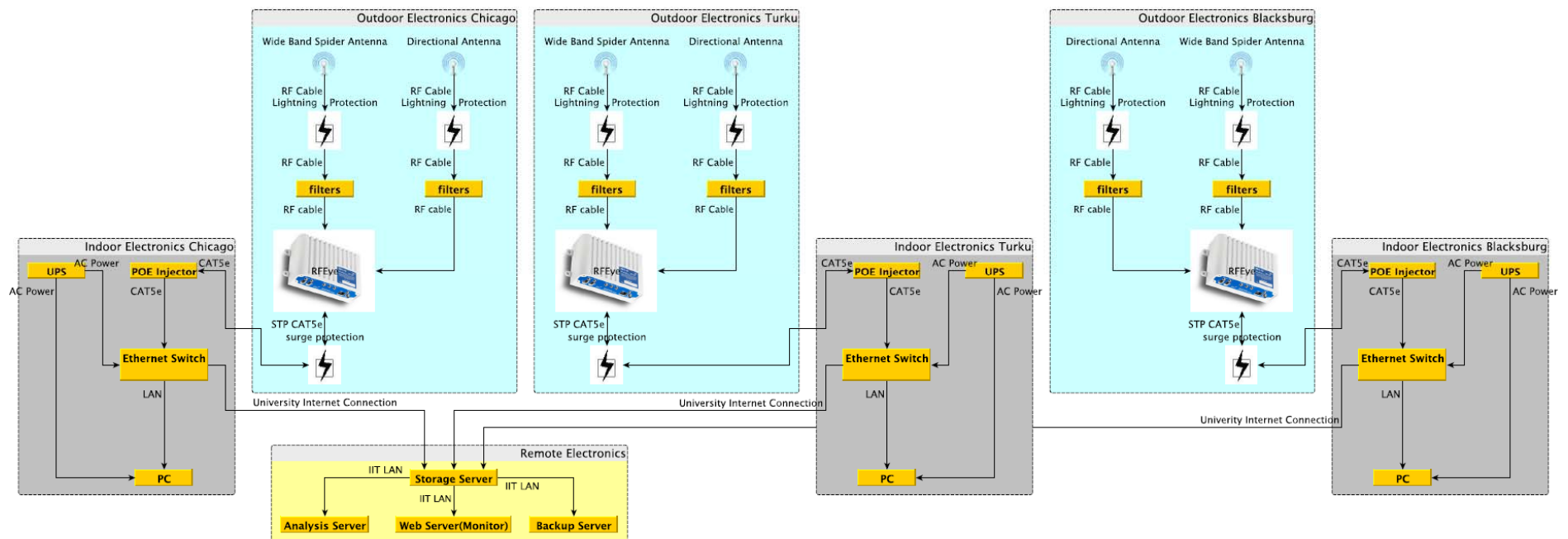
IIT Tower, Chicago

WiFiUS Measurement Systems

- Based on CRFS RF Eye
 - 100 – 6000 MHz
- Antennas
 - Wideband, omni-directional antennas
- Front-end
 - LNAs
 - Band-reject/pass filters
- Data archived in IIT server system

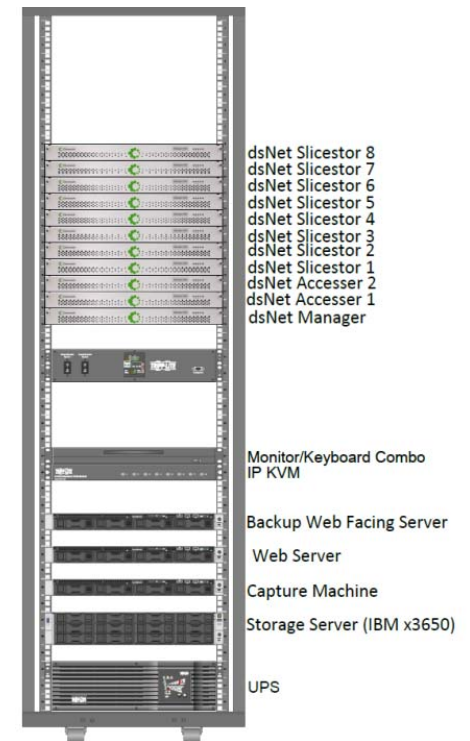


WiFiUS Measurement Systems



WiFiUS Server Overview

- Standard rack system
 - Cleversafe dsNet storage
 - High capacity + robustness
- Dedicated analysis machine
- Specifications
 - ~100 TB storage
 - 128 GB RAM
 - 10 Gbit networking



Importance of Spectrum Monitoring

- Facilitating dynamic spectrum sharing
 - Quantifying degree of spectrum usage
 - Datasets, modeling and simulations
 - DSA strategies and algorithms
- Human activity through spectrum “lens”
 - Normal activity
 - Daily, weekly, yearly, ... cycles and trends
 - Disasters/emergencies
 - Digital divide
 - Discrepancies due to economic conditions

Importance of Spectrum Monitoring

- Policy making
 - FCC/NTIA/ITU-R
 - PCAST report / Presidential memorandum
- Operations
 - Commercial and government
 - Cellular, energy, public safety, broadcast TV/radio
 - Spectrum audits
- Interference (intentional and unintentional)
 - Detection, quantification and localization
 - Mitigation strategies
 - Enforcement (FCC)

Selected Industry and University Collaborators and Sponsors

ILLINOIS INSTITUTE
OF TECHNOLOGY



Questions or comments?

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