Multi-Band, Multi-Location Spectrum Occupancy Measurements

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Outline

- Introduction
  - Support development of dynamic spectrum sharing radio technology
- Measurement locations
- Measurement equipment
- Sample spectrum occupancy data
- Summary data
- Next steps
- Conclusions
Introduction

Shared Spectrum Company conducted a series of spectrum occupancy measurements
- Initially supported by DARPA, later by NSF
- Started 2002, latest measurements in Nov 2005

Goals
- Prove that there are bands with low occupancy
- Estimate “whitespace”
- Determine characteristics of spectrum holes (time and frequency)

Approach
- Fixed locations, most with excellent line-of-sight
- Long-term (hours-days) data collections at most locations
- Optimized for best sensitivity (vs. revisit rate)
  - Spectrum analyzer with high dynamic range, “band-by-band optimized” pre-selector
# Spectrum Measurement Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Dates</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside in Shared Spectrum parking lot</td>
<td>4/6/2004</td>
<td>Urban location</td>
</tr>
<tr>
<td>Riverbend Park in Northern Virginia</td>
<td>4/7/2004</td>
<td>Rural location</td>
</tr>
<tr>
<td>Tysons Corner shopping center parking lot in Vienna, Virginia</td>
<td>4/9/2004</td>
<td>Urban location</td>
</tr>
<tr>
<td>National Science Foundation (NSF) building roof in Arlington, Virginia</td>
<td>4/16/2004</td>
<td>Elevated, urban location</td>
</tr>
<tr>
<td>New York City</td>
<td>8/5/2004 8/30/2004</td>
<td>Elevated, urban location</td>
</tr>
<tr>
<td>National Radio Astronomy Observatory, Green Bank, West Virginia</td>
<td>10/4/2004</td>
<td>Very quiet, rural location</td>
</tr>
<tr>
<td>IIT Building Roof in Chicago, IL</td>
<td>11/2005</td>
<td>Elevated, urban location</td>
</tr>
</tbody>
</table>

Note 1: Reports available on SSC website (except for Chicago report, which will be on website soon)
Measurement Location Photos (1 of 2)

Tysons Corner shopping center parking lot in Vienna, Virginia

National Science Foundation (NSF) building roof in Arlington, Virginia

Riverbend Park in Northern Virginia
Measurement Locations (2 of 2)

National Radio Astronomy Observatory, Green Bank, West Virginia

Shared Spectrum office roof in Vienna, VA

IIT Building Roof in Chicago, IL
Measurement Equipment

LPA antenna 1000-3000 MHz

Discone antenna 30-1000 MHz

Faraday cage used to reduce undesired collection equipment RF noise

New York City: Excellent line of sight to urban area
Pre-Selector Provides High Dynamic Range

- **Antennas**
  - Discone 30-1000 MHz
  - LPA: 1000-3000 MHz

- **Filtering and gain used to reject strong signals**
  - Computer controlled for each band

- **NF ~ 12 dB**


Very high-performance spectrum analyzer
High Utilization (Public Safety Band)

- High Bandwidth, Spread Spectrum Signal
- 17% Duty Cycle
- Upper Bound (Frequency Resolution 65 MHz/501=130 kHz/bin)

50% Duty Cycle is too High, 19% Utilization Measured Using Small Frequency Bins (450-455 MHz)
Mid-Level Utilization – TX Aux Band

Upper Bound (Frequency Resolution 120 MHz/501 = 240 kHz/bin)
Low Utilization Band

Less Than 1% Apparent Duty Cycle
Aviation Band

Max-Hold Plot

Threshold Value

Waterfall Plot

Duty Cycle Plot

Upper Bound (Frequency Resolution: 20 MHz/501 = 40 kHz/bin)

26 hour collection period

NYC Measurements 01-Sep-2004 20:39:32

Aero Nav

Aero Comms

Average Duty Cycle = 0.0403
UHF TV Band

Digital TV

Analog TV

Transmitter Turned Off At Night

Upper Bound (Frequency Resolution 108 MHz/501=216 kHz/bin)

Signal ducting
Maritime Mobile and Amateur Band

Upper Bound (Frequency Resolution 20 MHz/501=40 kHz/bin)
Base Stations
Easy to Detect
and Have High
Apparent Duty Cycle

SMR Provide
Has Higher
Usage Than
Cell Provider

Upper Bound (Frequency Resolution
96 MHz/501=192 kHz/bin)
Unlicensed Band

NYC Measurements 01-Sep-2004 20:41:24

-20
-40
-60
-80
-100
-120
dBm

2390 2400 2410 2420 2430 2440 2450 2460 2470 2480 2490 2500
fMHz

02:18
20:07
14:12
08:19
02:29
20:41

x 10^3

0 5
10

0 2390 2400 2410 2420 2430 2440 2450 2460 2470 2480 2490 2500

time (sec)
fMHz

Average Duty Cycle = 0.1551

0 0.5 1

0 2390 2400 2410 2420 2430 2440 2450 2460 2470 2480 2490 2500

Duty Cycle

fMHz
Satellite Band

Signals are not detected because
- Not there, or
- Too weak

Iridium 1621.35-1625.5 MHz

NYC Measurements
31-Aug-2004 15:45:30

Average Duty Cycle = 0.0024484

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Signals At Radio Quiet Zone

Sirius and XM Satellite Radio

NRAO GBT  04-Oct-2004 23:35:36

Average Duty Cycle = 0.055148
Low Utilization in a Rural Environment

Date - 4-7-04 Riverbend Park Start Time: 12:34 am

-20
-40
-60
-80
-100
-120

240 260 280 300 320 340 360 380 400

dBm
fMHz

0
1000
2000
3000

0
240 260 280 300 320 340 360 380 400

time (sec)
fMHz

0
0.02
0.04
0.06

0
240 260 280 300 320 340 360 380 400

Fraction of Time
fMHz
Average Occupancy In Each Band

Measured Spectrum Occupancy Averaged over Seven Locations

- PLM, Amateur, others: 30-54 MHz
- TV 2-6, RC: 54-88 MHz
- Air traffic Control, Aero Nav: 108-138 MHz
- Fixed Mobile, Amateur, others: 138-174 MHz
- TV 7-13: 174-216 MHz
- Maritime Mobile, Amateur, others: 216-225 MHz
- Fixed Mobile, Aero, others: 225-406 MHz
- Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz
- TV 14-20: 470-512 MHz
- TV 21-36: 512-608 MHz
- TV 37-51: 608-698 MHz
- TV 52-69: 698-806 MHz
- Cell phone and SMR: 806-902 MHz
- Unlicensed: 902-928 MHz
- Paging, SMS, Fixed, BX Aux, and FMS: 928-906 MHz
- IFF, TACAN, GPS, others: 960-1240 MHz
- Amateur: 1240-1300 MHz
- Aero Radar, Military: 1300-1400 MHz
- Space/Satellite, Fixed Mobile, Telemetry: 1400-1525 MHz
- Mobile Satellite, GPS, Meteorological: 1525-1710 MHz
- Fixed, Fixed Mobile: 1710-1850 MHz
- PCS, Asyn, Iso: 1850-1990 MHz
- TV Aux: 1990-2110 MHz
- Common Carriers, Private, MDS: 2110-2200 MHz
- Space Operation, Fixed: 2200-2300 MHz
- Amateur, WCS, DARS: 2300-2360 MHz
- Telemetry: 2360-2390 MHz
- U-PCS, ISM (Unlicensed): 2390-2500 MHz
- ITFS, MMDS: 2500-2686 MHz
- Surveillance Radar: 2686-2900 MHz

Spectrum Occupancy
Significant Occupancy Differences Between Similar Locations

Measured Spectrum Occupancy in Chicago and New York City

- PLM, Amateur, others: 30-54 MHz
- TV 2-6, RC: 54-88 MHz
- Air traffic Control, Aero Nav: 108-138 MHz
- Fixed Mobile, Amateur, others: 138-174 MHz
- TV 7-13: 174-216 MHz
- Maritime Mobile, Amateur, others: 216-225 MHz
- Fixed Mobile, Aero, others: 225-406 MHz
- Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz
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- U-PCS, ISM (Unlicensed): 2390-2500 MHz
- ITFS, MMDS: 2500-2868 MHz
- Surveillance Radar: 2686-2900 MHz

Chicago New York City
Average Occupancy at Different Locations

- ~10 X higher occupancy difference

Measured Spectrum Occupancy At Seven Locations

- Riverbend Park, Great Falls, VA
- Tysons Corner, VA
- NSF Roof, Arlington, VA
- New York City
- NRAO, Greenbank, WV
- SSC Roof, Vienna, VA
- Chicago, IL
- Average

Spectrum Occupancy

Significant spectrum for DSS radio to potentially utilize

~10 X occupancy difference
Establish a general and comprehensive estimate of spectrum occupancy
- 10 urban locations
- 10 suburban locations
- 3 international urban locations

Determine the size of spectrum holes
- Simultaneous fixed and nomadic measurements
- Synchronized spectrum analyzer trace triggering

Determine the cause of low spectrum occupancy
- Research the FCC/NTIA regulations and assignment databases
- Who are the “owners”? Why they are not using the bands?

Obtain long-term trends of spectrum usage and background noise levels
- Collect data over a continuous, two year period
- Determine seasonality variations
- Long-term peak-to average occupancy ratios

Determine the operating characteristics of the legacy users in bands with low occupancy
- Enable dynamic spectrum sharing systems to be better designed
- Signal parameters (transmission gaps statistics, transmitter mobility, number of transmitters, the signal bandwidths, and other parameters)
Amplitude Histogram of 2.4 GHz Band

Continuous Distribution Peaked at Low Values >> Many Transmitters at Many Distances

Large Amplitude Concentration >> Single Fixed Transmitter

Thermal Noise
Amplitude Histogram of Public Safety Band

NYC Measurements 31-Aug-2004 15:54:22

Large Amplitude Concentration >> Single Fixed Transmitter

Wide Peaked Distribution >> Single Transmitter with Amplitude Modulation

Flat Distribution >> ?

Number

Frequency in MHz

dBm

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Conclusions

- Measurements show there is significant spectrum “whitespace”
  - 13% in NYC – peak period
  - Many bands have minimal use
  - A low agility, contiguous waveform DSS radio provides high utility
- Large occupancy differences with location
- Significant band-to-band variations in “similar” locations
  - NYC vs Chicago
- Summarized needed follow-on work