Dynamic Spectrum Use

Briefing to:
COMMITTEE ON RADIO FREQUENCIES
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Introduction

- Company overview
- Dynamic Spectrum Access (DSA) Technology
- System design overview
- XG field tests
- Summary
Shared Spectrum Company Overview

- Leading developer of dynamic spectrum sharing technologies
- Located: Vienna, Virginia, USA
- Incorporated: 2000
- ~30 employees
- Customers
  - DARPA, ONR, Army, NSF, Air Force
DYNAMIC SPECTRUM ACCESS TECHNOLOGY
Access Holes in “Crowded Spectrum”

- SSC has made extensive spectrum occupancy measurements in multiple locations
- Actual spectrum use is low
- Latest measurement in Dublin, Ireland April 2007
Occupancy In Different Bands in NYC and Chicago

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
- 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

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# Spectrum Policy Types

## List Listen-Before-Talk based types
- LBT – Same up and downlink frequencies
- LBT – Different, but known, up and downlink frequencies
- LBT – Different, but known, up and downlink frequencies, band plan known
- LBT – TV band (TV detector)

## Spatial types
- Geographic border field strength limits
- Database geographic/TV coverage area based

## Temporal types
- Time of Day restrictions
- Authorization for finite time duration (with periodic renewals)

## Device based types
- Device Capability - Ability to measure second and third harmonic
- Device Capability - XG TX power spectrum density limit
- Adjustable I/N Limit for any policy (-6 dB (insignificant interference impact to Primary users), 20 dB (medium amount of interference impact to peer XG nodes)

## Connectivity based types
- Beacon reception required to use band
- Connectivity requirement for any policy (can use certain bands only if connected to Spectrum Manager)

## Group Behavior based types
- Type 1 Group Behavior - Abandon channel if any node within certain range detects Non-cooperative signal
- Type 2 Group Behavior - Determine XG TX power based on estimated interference probability (used Belief, Disbelief, and Ignorance estimates fused with Dempster-Shafer Theory)
- Node Identify restrictions (e.g., use while airborne prohibited, use only in fixed applications, Red Cross use only)

## Temporal types
- Database geographic/TV coverage area based

## Device based types
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## Distributed Control based types
- Automated policy updates if feedback indicates that existing policy is insufficient for non-interference operations
- Automated policy updates notification of policy revocation or update by policy authority
Policies Come from Many Sources

Equipment Data (DD1494 – NTIA/DoD) Policies
- ~200 radio types
- Frequency range, TX power, NF, BW,…
- Detection/false alarm rule sets – Radar pulse pattern, FM modulation, etc
- LBT rule threshold parameter spreadsheet
- Ex: RT-1107(V)9/WSC-3(V) operates from 225-399 MHz, 5 kHz BW,…

Regional Policies (Assignment Database)
- Limitations of frequency range, TX power, BW
- Service (Fixed, mobile, airborne,…)
- Frequency range, TX power, NF, BW,…
- LBT rule time parameters
- Geographic, time limitations
- Ex: AN/GRT-022 is used from 225-320 MHz only, -6 dB I/N

Local Party-to-Party Policies
- Geographic, time
- Spectrum leasing limitations
- User priority
- LBT threshold and time parameters
- Ex: 440 MHz is only used occasionally for radar testing. You can use this channel if you have a monitoring system with an elevated antenna within LOS of Andrews AFB is used to detect (every five minutes) if we are using the radar transmitter or not. Only groups that I provide a “certificate ” to are allowed this privilege.

National Rules Policies (NITA and FCC rules)
- Geographic, time
- Spectrum leasing limitations
- User priority
- LBT threshold and time parameters
- Policy dissemination limitations
- Ex: 243 MHz used only for emergency

XG System
- XG radio operates on all of the polices to decide “proper” operation

OWG-Based high-level descriptive language
DSA Must Be Trusted

**DSA Device is Cognitive**
i.e. makes own decisions on how to operate – this creates regulatory concern

- Executes heuristics to optimize the device and/or the network the device belongs to
- Continuously reconfigures the device and its components

How can we trust that the device behaves properly?
Policy Control Provides Necessary Trust, Security, and Assurance

- Regulators need assurance that devices access permitted spectrum only
  - Want to maintain control

- Operators need assurance that they can configure DSA properly

- Other users need assurance that their devices are not harmed
  - Significantly harmed…
Policy System Architecture
Also Requires Remote Components
Dynamic Spectrum Access Transition

• Anticipate Incremental Adoption on a Not to Interfere Basis (NIB)
  – Military on Military (10x Greater Packing of Radios)
  – Coordinated Sharing (Military with Coordinated Users)
  – Opportunistic (Widespread NIB Operation)

• Incremental Rollout Enables Near-Term Deployment as Appliqué Into Existing Systems
  – Add Protocols and Adaptation Software to Digital Networking Radios
  – Add Spectrum Sensing Algorithms

Not Necessary to Establish New Regulatory Framework, Either Nationally or Internationally
SYSTEM DESIGN OVERVIEW
XG System Operation

1. Spectrum Policy Analyst builds and edits OWL-based policies based on prior international coordination and force commanders goals.

2. Spectrum manager downloads and updates policies to all XG-enabled radios.
   - Minimal interference to Country A’s users or to non-XG enabled coalition forces.
   - No interference protection to Country B’s users.
   - Low interference (< -150 dB/Hz) to non-networked XG-enabled radios.
   - Available bands: f1-f2, f3-f4 (only if connected to network), ...

3. XG-enabled radios measure spectrum occupancy.
   - Periodically report findings to “Fusion Nodes”.

4. Disconnected XG-enabled Radio.

5. “Fusion Nodes” provide spectrum hole probability grid tables to all XG-enabled nodes.

6. XG-enabled nodes use policies, own measurements and probability grid tables to access spectrum to meet policy-specified interference requirements.

Disconnected XG-enabled nodes use policies, own measurements to access spectrum (within limited bands) to meet policy-specified interference requirements.
XG Software Architecture

- The Policy Analyzer validates externally created spectrum access policies for consistency and accuracy
- The Policy Administrator securely disseminates policies using PKI
- The Policy Enforcer ensures that each XG radio adheres to the policy rules
- Ultra-sensitive detectors identify unused spectrum
- The Rendezvous and Frequency Selection algorithms select which channels to use
- Scheduler manages which detectors are used, what frequency the devices use, and when the detectors and tuner/modems operate
- Group Behaviors use distributed spectrum occupancy measurements made by individual XG nodes and fused across a collection of nodes to provide a probabilistic estimate of the geographical location of spectrum holes
XG Block Diagram

- **GPP**
  - XG Modem Software
  - Scheduling
  - Interference Avoidance
  - Policy

- **GPS Sensor**

- **Rockwell Sensor**
  - Time, location
  - Trigger
  - Time Critical signals
  - Frequency data
  - Threshold
  - Status & Mon

- **Wavesat DM256 802.16 WiMAX Modem core**
  - Data
  - Control
  - Status & Mon
  - 802.16 native mode

- **XG Transceiver**
  - RF signal
  - RF Rx/ Tx

- **Other connections**
  - Ethernet
  - Serial
  - USB 2.0

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XG Node Hardware

**XG radio (2006):** An XG node consists of a computer, an 802.16 modem, a transceiver, an HPA, a GPS unit, and antennas. Frequency range of 225-600 MHz.

**XG radio (2007):** > 25 units. 4" x 4" x 6". Same features as 2006 model except increased frequency range (175 MHz – 4.9 GHz). Available 3Q 2007
XG FIELD TESTING
# AP Hill Test Metrics & Results Summary

<table>
<thead>
<tr>
<th>Metric</th>
<th>Threshold</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>XG Causes No Harm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abandon Time</td>
<td>500 msec</td>
<td>100% in 465 msec</td>
</tr>
<tr>
<td>Interference Limit</td>
<td>3 dB</td>
<td>Mean: 0.16dB, Max: 0.49 dB</td>
</tr>
<tr>
<td><strong>XG Works</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Formation</td>
<td>30 sec w/ 6 Nodes</td>
<td>90%: 3.6 s; 100%: 8.68 s</td>
</tr>
<tr>
<td>Net Join</td>
<td>5 sec</td>
<td>90%: 2.07 s; 100%: 4.36 s</td>
</tr>
<tr>
<td>Net Re-Establish</td>
<td>500 msec</td>
<td>100%: 165 msec</td>
</tr>
<tr>
<td><strong>XG Adds Value</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum Occupancy</td>
<td>60% w/ 6 Nodes</td>
<td>85% Occupancy at 83% Confidence</td>
</tr>
</tbody>
</table>

**XG Demonstrated Reliable Networking Without Harming Legacy Nodes In Dense Spectrum Environments**
Field Demonstration Scenarios

- **Goal**: Demonstrate XG networks in the presence of multiple, co-channel Legacy (Non-cooperative) systems

- **Scenario 1**
  - Maintain three XG network pairs on different frequencies

- **Scenario 2**
  - Maintain a single network on the same frequency using five XG nodes
Mobile Tests in Military Relevant Scenarios

- 6 test vans
- ~40 kph max speed
- Hilly, rough terrain
Legacy Radios

- PRC-117: Frequency Hopping to Force Dynamics
- PSC-5: Narrowband Voice
- EPLRS: DoD Networking Radio
- Micro-Lite: DoD Networking Radio
- ICOM F561: Widely Used in Public Safety

Legacy DoD Radio/Test Equipment

- Legacy DoD Radio (fixed)
- XG Radios (mobile)
- Microlight
- PRC-117
- Micro-Lite

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Legacy Commercial Radios

- Signal generator (Jammer)
- Midland GMRS
- ICOM
- Control computer GPS time aligned
### Radio Frequencies

<table>
<thead>
<tr>
<th>Legacy Radio</th>
<th>Frequency</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPLRS</td>
<td>TX 422.75 MHz</td>
<td>38.2836° N</td>
<td>-77.6480° W</td>
<td>Northern-most radio network</td>
</tr>
<tr>
<td></td>
<td>RX</td>
<td>38.1702° N</td>
<td>-77.3848° W</td>
<td></td>
</tr>
<tr>
<td>PRC-117</td>
<td>TX 369 MHz (10 seconds)</td>
<td>38.1656° N</td>
<td>-77.3797° W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RX 374 MHz (10 seconds)</td>
<td>38.1593° N</td>
<td>-77.3729° W</td>
<td></td>
</tr>
<tr>
<td>Microlite</td>
<td>TX/RX 433 MHz</td>
<td>38.1591° N</td>
<td>-77.3728° W</td>
<td>Southern-most radio network</td>
</tr>
<tr>
<td></td>
<td>RX</td>
<td>38.1591° N</td>
<td>-77.3728° W</td>
<td></td>
</tr>
<tr>
<td>PSC-5</td>
<td>TX 356 MHz</td>
<td>38.1436° N</td>
<td>-77.3566° W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RX</td>
<td>38.1459° N</td>
<td>-77.3510° W</td>
<td></td>
</tr>
<tr>
<td>Jammer</td>
<td>TX (All)</td>
<td>Observation building</td>
<td>Not a radio Network. TX only.</td>
<td></td>
</tr>
</tbody>
</table>

- XG and Legacy radios used the same six frequencies
- “Noise floor” measured every morning before tests to insure that channels were not used by outside radios
- Legacy radio frequencies were manually coordinated to operate at different frequencies – A big DoD problem
- A jammer was designed to move the XG frequencies around to ensure no XG was ‘stuck’ in a specific frequency
Example Scenario 1 Spatial/Frequency History

Node pair location and time

Color = Operating frequency
XG Node Frequency Agility

- XG nodes constantly change frequency
  - Avoid Legacy signals
  - Avoid other XG signals
  - Overcome spatial and temporal changes
- XG connectivity requires
  - An available channel
  - Proper algorithm operation

XG Frequency Operation, Node #2, 2006-08-16, 14:32 - 15:00
XG Connectivity During Experiment = 94.1194%

~30 minutes
No Harm: Interference to Noise Ratio

- Interference occurs when detector fails to detect Legacy signal
- Performance factors
  - Detection sensitivity and XG transmit power spectral density
- Lack of interference shows detection distance is much greater than interference distance
No Harm: Channel Abandonment

- Performance factors
  - Detection rate
  - Algorithm design
  - Algorithm response to block/missed messages
- Reduce abandonment time easily achieved
- Trade abandonment time with non-occupancy period to set overall level of “no-harm”
It Works: Network Formation Time

- Performance factors
  - Rendezvous algorithm
  - Detection capabilities
  - Implementation
- Separate laboratory test with repeated, controlled trials

![Network Formation Time - Cumulative Distribution Function](image)

Form Network of 6 Nodes, 6 Available Channels, 2006-09-18

Probability of occurrence

Time (ms)

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It Works: Channel Re-Establishment Time

“Kink” in the two node case is caused in the cases when the Base Station detects Non-cooperative and then has a delay after change frequency command to allow Subscriber queues to empty.

Three or more nodes takes longer than two nodes because Base Station has a delay after change frequency command to allow Subscriber queues to empty.

Additional nodes take more time because of messaging delays.

500 msec goal
Adds Value: Success in Channel Use

Scenario 1

What fraction of the time was the link closed (Did XG system do the right thing)?

Scenario 2

What fraction of the 6 A.P. Hill test channels were not being used at the specific XG node’s place and time?

60% goal

60% goal
Summary

- Dynamic Spectrum Access enables usage of unused spectrum
  - Multiple methods to avoid interference
- Key issue is stakeholder trust
  - SSC’s approach uses policy language based command and control system
- Demonstration was one of the first if not the first large scale field demonstration of dynamic spectrum sharing
- Technical goals were achieved
  - “No Harm” - Small (500 msec) Channel Abandonment Time and the low INR values
  - “It Works” - 5 second Network Join Time, the < 200 msec Network Re-Establishment Time, and the lack of pre-assigned frequencies
  - “Adds Value” - >95% Link Uptime, the 70% Whitespace Fill Factor, and the ~90% Success in Channel Use
- Demonstration and tests prove that Dynamic Spectrum Access (DSA) technology is viable