A Harmful Interference Model for White Space Radios

Timothy X Brown

Interdisciplinary Telecommunications Program
Dept. of Electrical, Energy, and Computer Engineering
University of Colorado at Boulder

Visiting Professor, Carnegie Mellon University, Rwanda

Presented at the ICTP School on Applications of Open Spectrum and White Spaces Technologies
March 11, 2014

The Idea

- The spectrum is fully allocated.

- Urban measurements:
  - > 75% never used
  - > 90% unused on average
  - Rural areas - even more

- Cognitive Radio:
  - Avoid Licensed users
  - Communicate in “white spaces”
Cognitive vs. Traditional Radios

User Interaction Via

Operating System

Policy Input

Cognitive Engine

Geo locator

Sensor Radio

A CR does more than a traditional radio

Cognitive Radio Review:
Channel Avoidance Strategies

- Locate Unlicensed Device, check Database
- Detect Licensed Devices
- Licensed Device Beacons
Locate Licensed Device, Database

- Positioning can be sloppy
  - As long as can bound error
  - 100km OK in rural areas

- Proactive Database

Detect Licensed Devices

- Hidden Terminal Problem

- Networked Detection
  - Much more reliable

- Receiver Detection
  - Interference is receiver phenomena
  - Requires help from the receiver
## Licensed Device Beacons

- Per transmitter/receiver is laborious
- **Area Beacons:**
  - Combine best of Database and Beacons

![Diagram showing the connection between Licensed Users, Database, and Unlicensed Users]

## Avoidance Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Accurately:</th>
<th>Requires:</th>
<th>Appropriate for:</th>
<th>Cost Burden on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avoids Interference</td>
<td>Exploits Whitespace</td>
<td>Constant Monitoring</td>
<td>Standard</td>
</tr>
<tr>
<td>Database</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Detecting Transmitters</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Transmitter Beacons</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Area Beacons</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Unlicensed Signaling</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Receiver Beacons</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Unlic: Unlicensed, Lic: Licensed, Trans: Transmitter, Rec: Receiver
The Problem

- Technically functional radio
  - Detects primary users
  - Correctly picks channel
- You can’t turn just it on!

The “real world” challenges of CR

<table>
<thead>
<tr>
<th>Licensed Service Providers</th>
<th>FCC 04-186 NPRM Unlicensed Operation in the TV Broadcast Bands</th>
<th>CR Device Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>These rules will degrade my service!</td>
<td>Regulator</td>
<td>How do we test our equipment?</td>
</tr>
<tr>
<td>Any unlicensed use can interfere</td>
<td>This will create more problems then it will solve</td>
<td>Should I invest R&amp;D in this market?</td>
</tr>
</tbody>
</table>

CR Operators
What are the risks with this technology

A Harmful Interference Framework: The Idea

- Define interference up front:
  - How it is measured
  - By who
  - What levels constitute “harmful”
  - What to do if it is harmful
- Define so that:
  - Licensed users have sufficient protection
  - Unlicensed users/manufacturers have assurances
  - Regulators solve problem once a priori

Measurement Scenario
Unlicensed Transmitter Model

- Unbounded Deployment
- Bounded Deployment
- Per Device
- Per Usage

Licensed Receiver Model

- Expected Interference
- Widespread Extended Interference
- Extended Interference
- Widespread Interference
- Observed Interference
- Conceivable Interference

More Detail on this Later
Evaluation

- Who evaluates
  - Licensee
  - Licensed Receiver User
  - Unlicensed Device Manufacturer
  - Unlicensed User
  - Regulator

- How Evaluates
  - What conditions
  - What parameters

Remedy

- If harmful interference is found:
  - Turn off offending transmitter(s)
  - Change Unlicensed Rules
    - Operation parameters (Software Defined Radios)
    - Definition of harmful interference
    - Allowed/Prohibited Usages
  - Change Licensed Rules

Remedy should be incorporated into rules
Example 1: Simplest Model

- Licensee Evaluates
  - Observed Interference
  - Turnoff Device
  - Per Device

Example 2: Broadcast TV

- Monitor Stations
  - Expected Interference
  - Modify Rules
  - Unbounded Deployment

Example 2: Broadcast TV Monitor Stations

- Monitor TV outages at stations in coverage area

<table>
<thead>
<tr>
<th>Case</th>
<th>TV Signal</th>
<th>Cable Signal</th>
<th>Line Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Interference Outage</td>
<td>Bad</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Cable Outage</td>
<td>Good</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Broadcast Outage</td>
<td>Bad</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Power Outage</td>
<td>X</td>
<td>X</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Broadcasters: These rules will degrade my service!

- What does TV suffer already?
  - DBS is 99.8% "extremely reliable"
  - TV is 90% at grade B contour
  - Utility power is 99.9%

- Already many Wireless Microphones

Can we achieve an expected 1 in 10,000 TV outage in an unlimited unlicensed deployment?

Radio Interference Model

\[ F = \frac{r_{\text{min}}^2 PCEG_{UL} G_L M N_{UL}}{A} \]

- \( F \) = fraction of licensed devices suffering outage on average
- \( r_{\text{min}} \) = worst case min separation between unlicensed and licensed devices
- \( P \) = power control factor \((< 1)\)
- \( C \) = channel avoidance factor \((< 1)\)
- \( G \) = antenna gain factors \((< 1)\)
- \( M \) = model constants \((\sim 3)\)
- \( N_{UL} \) = number of unlicensed devices
- \( A \) = area of system

Helps Regulator
Sets “Cognitive” Requirement


Channel Avoidance Reliability

- Set 1000 unlicensed devices/km²

- For < 1 in 10,000 TV interference require
  - Low Power CR: 90% reliable
  - High Power CR: 99.99% reliable

- These are reasonable.

But not to the broadcasters!

Harmful Interference Model

- Broadcasters: Conceivable Interference
- Expected Interference

Harmful Interference Taxonomy

Provides a common framework for HI

Example 3: Wireless Microphones

- In TV bands
- Hard-to-detect

- 500,000 sold
- Cognitive Radios will harm them!

Example 3: Wireless Microphones

- No database exists
- No one is going to invest in beacons
- Detection is the only strategy

What can the CR do? What can the “Licensed” devices do?
Single Interferer Model:

Traditional Radio Interference

WM range, $R_0$ = 80m
Single Interferer Model:
Cognitive Radio Interference

Traditional CR Interferer Distance (m) Probability of Interference (%)

\[ R_d = 80 \text{m} \]
\[ R_{\text{det}} = 176 \text{m} \]
Single Interferer Model:

Optimum Detection Range

For < 1% interference, detection range ≈ 5 times Ro

Multiple CR Model:

Multiple Cognitive Radios

- So far:
  - Single Interferer
  - Worst-case location

- Now:
  - Multiple interferers
  - Spread randomly over area
  - Function of density
Multiple CR Model:

Cooperative Spectrum Sensing

- No Cooperation
- Partial Cooperation
- Full Cooperation

Detection Range of CR Devices

- Fully Cooperative Network
  - \( R_{\text{det}} \approx 4.5 R_0 \)
  - Detection: 10dB better
  - Easier to get better performance

For interference < 1%, \( R_{\text{det}} \approx 4.5 R_0 \), similar to single interferer analysis.

Single Interferer Model:

What if the Licensed user changes?

Traditional CR

Interferer Distance (m) Probability of Interference (%)

$R_0 = 80m$

$R_{det} = 176m$

What if WM get only 0.8 $R_0$?

It's a two-way street.

Conclusions

- Harmful Interference model should be considered up front
- Affords better protection to both incumbent and white spaces radio
- Many choices are possible.