Chapter 14

Cognitive Radio for Broadband Wireless Access in TV Bands: The IEEE 802.22 Standard
Outline

- Introduction
- Overview of the IEEE 802.22 Standard
- The 802.22 PHY
- The 802.22 MAC
- Summary
Introduction

- Cognitive Radios (CR) enable flexible, efficient and reliable spectrum use by adapting the radio’s operating characteristics to the real-time conditions of the environment.

- CRs have the potential to utilize the unused spectrum (e.g. TV White Spaces) in an intelligent way while not interfering with other incumbents.
Regulatory Scenario for TV White Spaces in the USA

IEEE 802.22 WG starts working on a CR based PHY/MAC spec

Source: Monisha Gosh and Dave Cavalcanti, CrownCom 2009 Tutorial “Cognitive Radio Networks in TV White Spaces: Regulation, Theory and Practice”

“Cognitive Radio Communications and Networks: Principles and Practice”
Overview of the IEEE 802.22 Standard

- Fixed point-to-multipoint wireless regional area networks (WRAN)
- Reuse of TV broadcast bands on a non-interfering basis
- Specify Cognitive Radio based PHY/MAC layers
- Cognitive Radio Entity for spectrum management

Master-Slave architecture:
- Base Stations (BS)
- Consumer Premise Equipments (CPEs)
Service Characteristics

- **Peak-throughput**
  - 18.72 Mbit/s

- **Communication Range**
  - Typical: 17-30 km
  - up to 100 km depending on EIRP

Source: IEEE 802.22 Draft 2.0, May 2009
Protocol Reference Model - BS
Protocol Reference Model - CPE

Source: IEEE 802.22 Draft 2.0, May 2009

"Cognitive Radio Communications and Networks: Principles and Practice"
The 802.22 PHY overview

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>54~862 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>6 and/or 7, and/or 8 MHz</td>
</tr>
<tr>
<td>Data rate</td>
<td>1.51~22.69 Mb/s</td>
</tr>
<tr>
<td>Spectral Efficiency</td>
<td>0.25~3.78 b/s/Hz</td>
</tr>
<tr>
<td>Payload modulation</td>
<td>QPSK, 16-QAM, 64-QAM</td>
</tr>
<tr>
<td>Transmit EIRP</td>
<td>Default 4W for CPEs</td>
</tr>
<tr>
<td>Multiple Access</td>
<td>OFDMA</td>
</tr>
<tr>
<td>FFT Mode</td>
<td>2048</td>
</tr>
<tr>
<td>Cyclic Prefix Modes</td>
<td>¼, 1/8, 1/16, 1/32</td>
</tr>
<tr>
<td>Duplex</td>
<td>TDD</td>
</tr>
</tbody>
</table>

"Cognitive Radio Communications and Networks: Principles and Practice"
The 802.22 MAC overview

- **TDMA access**
  - Frame structure and QoS model similar to 802.16

- **Superframe structure defined:**
  - Better self-coexistence, synchronization, and incumbent protection

- **Coexistence mechanisms:**
  - Incumbent avoidance and Spectrum measurements
  - Spectrum sensing support mechanisms (quiet periods)
  - Channel Management
  - Coexistence Beacon Protocol (CBP)
  - Normal mode and coexistence mode with dynamic resource sharing (frame based)
Super-frame Structure

Source: IEEE 802.22 Draft 2.0, May 2009
Time-Frequency structure of the MAC frame

“Cognitive Radio Communications and Networks: Principles and Practice”
Incumbent protection

Incumbents in TV bands:
  • TV broadcasting services (in the US, use 6 MHz channels in VHF and UHF bands)
  • Wireless microphones (in the US, regulated by Part 74 FCC rules, use 50 mW for a 100 m coverage and 200 KHz channel bandwidth)

802.22 protection mechanisms: combination of incumbent database and spectrum sensing
## Spectrum sensing requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value for Wireless Microphones</th>
<th>Value for TV Broadcasting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Detection Time</td>
<td>$\leq 2$ sec</td>
<td>$\leq 2$ sec</td>
</tr>
<tr>
<td>Channel Move Time</td>
<td>$\leq 2$ sec</td>
<td>$\leq 2$ sec</td>
</tr>
<tr>
<td>Channel Closing Transmission Time</td>
<td>100 msec</td>
<td>100 msec</td>
</tr>
<tr>
<td>Incumbent Detection Threshold</td>
<td>-107 dBm (over 200KHz)</td>
<td>-116 dBm (over 6MHz)</td>
</tr>
<tr>
<td>Probability of Detection</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Probability of False Alarm</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Spectrum Sensing: Key Challenges

- Incumbents must be reliably detected within the CDT
  - 802.22 specifies IDT of -116 dBm and CDT of 2 sec
- Reliable sensing requires network wide quiet periods (QP)
- For typical energy detection approach, integration time is low, however, neighboring WRANs may be detected as incumbent
  - Higher probability of false alarms
- Feature detection can accomplish more accurate detection of incumbents, however, the integration time required is the main issue
  - Long integration times mean poor QoS support, especially for VoIP
Example of a sensing architecture and strategy

```
Begin Sensing

Coarse Sensing
(Analog, RSSI, MRSS, FFT...)

Spectrum Usage Database (BS)

MAC
(Select single channel)

Fine Sensing

occupied?

Y
N

End Sensing
```

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Fine sensing algorithms

- We discuss two algorithms found in the current IEEE 802.22 draft specification

- FFT-based pilot detection
  - Pilot-energy detection: find maximum of FFT output-squared, and compare to a threshold
  - Pilot-location detection: compare location of maximum of FFT-output between multiple dwells

- Spectrum sensing of the DTV in the vicinity of the pilot using higher order statistics
  - Detect the DTV signals in Gaussian noise using higher order statistics (HOS)
  - Perform non-Gaussianity check in the frequency domain in the vicinity of the pilot of the DTV

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FFT-based pilot detection

- Demodulate the signal to baseband
- Filter with a low-pass filter, which should be large enough to accommodate any frequency offsets
- Down-sample the filtered signal
- Take FFT of the down-sampled (FFT size depends on the dwell time)
- Determine the maximum value, and location, of the FFT output squared
  - Pilot-energy detection: find maximum of FFT output-squared, and compare to a threshold
  - Pilot-location detection: compare location of maximum of FFT-output between multiple dwells

Performance of FFT-based pilot detection

- Low pass filter BW = 40KHz (±20kHz)
- Sampling rate from 21.52 MHz to 53.8 kHz (1/400)
- Dwell time = 1 ms (32-point FFT) and 5 ms (256-point FFT)

Note: 12 signals supplied by MSTV to IEEE 802.22 for testing different sensing algorithms

“Cognitive Radio Communications and Networks: Principles and Practice”
Performance of FFT-based pilot detection w/ 2 dB average noise uncertainty

"Cognitive Radio Communications and Networks: Principles and Practice"
Spectrum sensing of the DTV in the vicinity of the pilot using higher order statistics

Received Signal (IF) sampled at \( F_s \) Hz
\[ r_n = s_n + \text{noise} \]

Downconvert to Baseband
\( f_o = \text{Center frequency of the input signal at IF} \)

Exp(-j2\pi f_c t)

Image Rejection LP Filter - \( BW_1 = 8 \text{ MHz} \)

Exp(+j2\pi f_c t)

Antialiasing LP Filter
\( BW_2 = \frac{(N_{FFT})}{(T_{sensing} Z)} \)

Downsample floor\((F_s / BW_2)\)

S/P

FFT \((N_{FFT})\)

Freq. Domain Gaussianity Check Using HOS

Sensing Durations
\[ T_{\text{sensing}} = 0.005 \]
\[ Z = 1 \Rightarrow 5 \text{ mS} \]
\[ Z = 2 \Rightarrow 10 \text{ mS} \]
\[ Z = 4 \Rightarrow 20 \text{ mS} \]

\( N_{FFT} = 2048 \)


"Cognitive Radio Communications and Networks: Principles and Practice"
Performance of DTV sensing in the vicinity of the pilot using higher order statistics

\[ \gamma = 0.8, \quad P_D > 0.9 \text{ and } P_{FA} < 0.05 \]

\[ \gamma = 1.05, \quad P_D > 0.9 \text{ and } P_{FA} = 0.01 \]

Reference: A. Mody, IEEE 802.22 document no. 0359r1, August 2007.

“Cognitive Radio Communications and Networks: Principles and Practice”
Spectrum sensing support at the 802.22 MAC layer
Self-Coexistence in 802.22

- Normal mode
  - no channel sharing when there is spectrum available

- Self-coexistence mode
  - Resource sharing on frame basis
  - Random contention amongst neighboring BS through the CBP mechanism
Coexistence Beacon Protocol (CBP)

- CBP packets carry the schedule of the QPs and self-coexistence information
- Other cases also possible depending on location of the CPEs

Case 1:

Case 2:

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Channel management

- Incumbent detection notification
  - Sensing reports
  - UCS (Urgent Coexistence Situation) notification

- BS controls channel switching procedure through channel management commands
  - Schedules switching when needed within the required CMT (<2 sec)
Spectrum manager

- The SM centralizes all the decisions with respect to spectrum management:
  - Maintain up to date spectrum availability information combining incumbent database and spectrum sensing inputs;
  - Classify, prioritize and select channels for operation and backup;
  - Association control;
  - Trigger frequency agility related actions (i.e. channel switch);
  - Manage mechanisms for self-coexistence
Chapter 14 Summary

- **IEEE 802.22**
  - Fixed point-to-multipoint WRAN
  - Reuse of TV broadcast bands on a non-interfering basis
  - PHY/MAC air interface specification
  - Spectrum manager integrating incumbent database and spectrum sensing inputs

- **Draft standard is under development**
  - Currently on 2nd working group ballot

- **Key design challenges**
  - Primary protection (e.g., DTV, wireless microphones)
  - Secondary coexistence