802.22 based on CRs
General Information

802.22 based on Cognitive Radios
802.22 is a new 802 LAN/MAN standards
Wireless Regional Area Network (WRAN)
White spaces in TV frequency spectrum
General Information

Deployment Scenario

802.22 based on Cognitive Radios
General Information

Why CRs

Solution to low usage of the radio spectrum
Flexible, efficient, reliable spectrum use
Potential to utilize the large amount of unused spectrum
=> Required real-time measurement dissemination
General Information

Example of TV band occupancy over time and frequency

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Diagram of the channel bonding scheme illustrating 802.22 based on Cognitive Radios
General Information

- Used frequencies
  - 54-862 MHz in North America region
  - 41-910 MHz, ongoing debate
  - Standard shall accommodate various international TV Ch. Bw.
  - such as 6, 7, 8 MHz

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General Information

- Target market
  Wireless broadband access in rural/remote areas (less concentrated area)
  - e.g. single-family residential, multi-dwelling units, small office/home office (SOHO), small businesses, multi-tenant buildings, and public and private campuses
  South America, Africa and Asia

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- Service Capacity
  - Spectral efficiencies from 0.5 up to 5 bit/(sec/Hz)
  - If average of 3 bits/sec/Hz
  - then Total PHY data rate of 18 Mbps in a 6 MHz TV channel

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General Information

- Service Coverage
  - Go up to 100 Km (power isn’t an issue)
  - Current coverage range
    - 33 Km at 4 Watts CPE EIRP

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General Information

- **Service Coverage**

- **802.22 based on Cognitive Radios**
Physical Layer Standard

802.22 based on Cognitive Radios
Background

- Standard body – IEEE 802.22 WRAN Working group
- All documentation not available to general public (standardization ongoing). Some documents found at http://www.ieee802.org/22/
- Major players – Samsung, Philips, Huawei, Nanotron, ETRI and others
Requirements

- High performance, low complexity
- Support for variable number of users
- Efficient usage of available frequency
- Dynamic changes in bandwidth, modulation and coding

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Block Diagram – CR System

Analog Wideband Spectrum Sensing

Coarse Sensing → Fine Sensing → Low Speed ADC

Wideband Front-End

Tunable Filter → Wideband RX → LPF

Frequency-Agile Front-End

T/R → Power Amp. → Wideband TX → LPF

PHY

Adaptive Modulation → Interference Mitigation → TX Power Control

MAC

Spectrum Usage Recognition → Spectrum Allocation → Reconf. Control

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PHY Block Diagram - Transmitter

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PHY Block Diagram - Receiver
OFDMA

- Used as a Multi-access Broadcast scheme
- Simultaneous transmission from users
- Adaptive user-to-subcarrier assignment
- Robust against fast fading and co-channel interference
- Data rate and error probability for each user individually controlled

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Pulse Shape

Adaptive pulse waveform generation

Spectrum characteristics of adaptive pulse waveform
Coding Schemes

• Convolutional Coding, specifically turbo codes
  a. Close to Shannon limit of capacity
  b. Used in low-power applications
  c. High decoding complexity
  d. High latency applications

• 1/2, 3/4, 2/3 coding rates
Modulation Schemes

a. QPSK
b. 16-QAM

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c. 64-QAM

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Physical Layer

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About Proposed PHY...

- Which company proposed it?
What they have proposed...

- Adaptive OFDMA
  - Adaptively scalable to spectrum availability
    (1, 2, 3, 4, 6, 7, 8 MHz bandwidth)
  - New frame structure for CR-enabled operation

- Enhanced PHY features
  - Cyclic prefix and cyclic postfix
  - Adaptive pilot insertion
  - Enhanced channel coding, e.g., LDPC
Adaptive OFDMA

- Flexible Bandwidth Allocation using FFT
  - Channel bonding
  - Fractional bandwidth usage

- Adaptive resource allocation according to user environments
  - Channel selectivity
**OFDMA Symbol Time Structure**

- **Type I: Conventional**
  - 4K & 8K Modes
  - Cyclic Prefix

  - Type II: Hybrid
  - 2K Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>2K</th>
<th>4K</th>
<th>8K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclic Prefix Time</td>
<td>56 us</td>
<td>112 us</td>
<td>224 us</td>
</tr>
</tbody>
</table>

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Frame Structure: TDD

- 100 ms Superframe
- 10(5) ms Frame

<table>
<thead>
<tr>
<th>Frame #0</th>
<th>Frame #1</th>
<th>Frame #2</th>
<th>Frame #3</th>
<th>Frame #8 (Frame #18)</th>
<th>Frame #9 (Frame #19)</th>
</tr>
</thead>
</table>

- **Preamble**
  - FCH
  - DL MAP
  - UL MAP

- **Downlink (DL)**
  - DL Burst #1
  - DL Burst #2
  - DL Burst #3
  - DL Burst #4

- **Uplink (UL)**
  - UL Burst #1
  - UL Burst #2
  - UL Burst #3
  - UL Control (ACK, CQI etc)
  - Ranging

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Frame Structure: FDD

102.06 ms Superframe

10.206(5.103) ms Frame

| Frame #0 | Frame #1 | Frame #2 | Frame #3 | Frame #8 (Frame #18) | Frame #9 (Frame #19) |

UL Burst #1

UL Burst #2

UL Burst #3

UL Control

Ranging
Advantages of Adaptive OFDMA

- **Flexible Bandwidth Allocation**
  - To use the partial bandwidth (1, 2, 3, 4, 6, 5, 7, 8 MHz) adaptively, depending on the channel state information (availability)
  - To fully utilize available bandwidth under a unified PHY framework

- **Single Sampling Frequency**
  - Sampling frequency is the same, i.e., 64/7 MHz, for all FFT modes.

- **Constant Subcarrier Spacing**
  - The subcarrier spacing is constant for all different channel bandwidths ➔ Robust to the frequency offset

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MAC Layer
802.22 MAC

• Based on the specifications for 802.16d (WirelessMAN), with some modifications.
• Issue with Cognitive Radio Systems: Situations in which the IU is detected by just one of the BS or the CPE.
• Proposed solution “Implicit signal based co-operative sensing”.
• Features: Minimal Changes, Channel Management, Scanning and Radio Resource Management
Superframe Structure

802.22 based on Cognitive Radios
Frame Structure

- Frame Structure : TDD

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Channel Maintenance

• Definitions: Active Set 1, Active Set 2, Candidate set, Occupied Set, Disallowed Set, Null Set.

• Channel Set Maintenance
Channel Maintenance

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Radio Resource Management

• Channel grouping for MAP overhead reduction in the multi-FA system
• Active set update to maximize the average system throughput
Scanning Operation: Implicit Signaling

- Rendezvous procedure for band switching
Spectrum Sensing Technologies

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Problems to be solved

- Provide spectrum occupancy information to MAC
- Identify type of incoming signal
- Fast tracking time to improve data throughput
- Flexible resolution for adaptive and scaling searching
- Simple computation for low power
- Easy implementation for low cost

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Features

- Sensing clock is separated from transceiver
- Multiple sensing strategy: Coarse and Fine
- Sensing while in communication and not in communication
- Critical computation is performed at analog domain
Features

- Transmitter (RF/IF)
- Receiver (RF/IF)
- Coarse “MRSS”
- Fine “AAC”
- Low Speed ADC
- Sensing Receiver
- PHY (Baseband)

Proposed sensing scheme

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Sensing technique

- Multi-Resolution Spectrum Sensing (MRSS)
  : Coarse sensing, detect existence of signal

- Analog Autocorrelation (AAC)
  : Fine sensing, categorize the signal type
Advantages

- Sensing block is separated from transceiver
  - performed without waking-up PHY
  - performed, while not in using & in using
- Multiple sensing strategy
  - coarse sensing for spectrum occupancy
  - fine sensing for indentifying incoming signal
- this reduces the false detect rate
Advantages

- Critical computation is performed at analog domain
  - no significant computation in baseband
    : FFT nor Correlation -> faster recognition time
  - drastically reduce power consumption
  - require very low speed/low resolution ADC

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Coarse Spectrum Sensing

- Multi-Resolution Spectrum Sensing (MRSS)
- It detects spectrum occupancy
MRSS implementation

a. MRSS detects spectral components of incoming signal by the Fourier Transform
b. Fourier Transform is performed in analog domain
c. MRSS may utilize wavelet transforms as the basis function of the Fourier Transform
d. Bandwidth, resolution and center frequency can be controlled by wavelet transform
Spectrum Sensing Technologies

\[ y(t) = x(t) * w(t) \]
\[ = \int_0^T x(\tau)w(t - \tau)d\tau \]

MRSS Schematics

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MRSS simulation result (example)

The spectrum of the wireless microphone signal

The corresponding signal spectrum detected with the MRSS technique

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Fine Spectrum Sensing

- Analog Autocorrelation (AAC)
- Identifies incoming signal
AAC implementation

a. An input RF signal $x(t)$ is divided and delayed by a certain delay value $T_d$

b. The correlation between $x(t)$ and $x(t-T_d)$ is performed at analog domain

c. If the resulting integrator output shows sharp pulse, that $T_d$ indicates the feature of the incoming signal

d. Since AAC is performed at analog domain, low speed ADC is sufficient
Spectrum Sensing Technologies

**AAC Schematics**

- **Sensing Antenna**
- **x(t)**
- **Delay Td**
- **x(t-Td)**
- **Multiplication**
- **Integrate**
- **FIR**
- **Low Speed ADC**
- **Decision Making**

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Spectrum Sensing Technologies

- Recognize the periodic features of the input signals unique for each modulation format or frame structure
- Auto correlation is done at the analog domain
- AAC can recognize the following input signals: IS-95, WCDMA, EDGE, GSM, Wi-Fi, Wi-MAX, Zigbee, Bluetooth, Digital TV (ATSC, DVB), etc.
AAC simulation result (example)

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# Summary of spectrum sensing block

<table>
<thead>
<tr>
<th>Specification</th>
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<tbody>
<tr>
<td><strong>ADC resolution</strong></td>
<td>6 bits (MRSS)</td>
</tr>
<tr>
<td></td>
<td>1-3 bits (AAC)</td>
</tr>
<tr>
<td><strong>ADC sampling time</strong></td>
<td>&gt; 5M sample/sec (MRSS)</td>
</tr>
<tr>
<td></td>
<td>&gt; 120k sample/sec (AAC)</td>
</tr>
<tr>
<td><strong>Sensing time</strong></td>
<td>&lt; 1 ms (while in communication)</td>
</tr>
<tr>
<td></td>
<td>&lt; 4 ms (while not in communication)</td>
</tr>
<tr>
<td><strong>Sensing threshold</strong></td>
<td>&lt; -110 dB</td>
</tr>
<tr>
<td><strong>Baseband processing in PHY</strong></td>
<td>No significant computation, such as FFT nor convolution, is required at the base band</td>
</tr>
<tr>
<td><strong>Baseband processing in MAC</strong></td>
<td>Noise reduction, harmonic suppressions</td>
</tr>
</tbody>
</table>

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Conclusion

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## What is the performance improvement

<table>
<thead>
<tr>
<th></th>
<th>WRAN Functional Requirements</th>
<th>Proposal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum Data Rate</strong></td>
<td>DL: 1.5 Mbps/subscriber&lt;br&gt;UL: 384 kbps/subscriber</td>
<td>DL: 2.8 Mbps/subscriber&lt;br&gt;UL: 400 kbps/subscriber</td>
</tr>
<tr>
<td><strong>Service Coverage</strong></td>
<td>Typical: 33 km&lt;br&gt;Maximum: 100 km</td>
<td>Typical: 42.5 km (2K mode), 60.6 km (4K mode)&lt;br&gt;Maximum: 145.5 km (8K mode) (*)</td>
</tr>
<tr>
<td><strong>Spectral Efficiency</strong></td>
<td>Minimum: 0.5 bits/s/Hz&lt;br&gt;Maximum: 5 bits/s/Hz</td>
<td>Minimum: 0.73 bits/s/Hz&lt;br&gt;Maximum: 5.16 bits/s/Hz</td>
</tr>
<tr>
<td><strong>Maximum Excess Delay</strong></td>
<td>Pre-echo: 3 us&lt;br&gt;Post-echo: 60 us</td>
<td>Pre-echo: 3.5 us (2K mode)&lt;br&gt;Post-echo: 112 us (4K mode), 224 us (8K mode)</td>
</tr>
</tbody>
</table>

(*) It is calculated from the point of view of TTG time, not from link budget.

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Applications

- Cognitive radio: an integrated agent architecture for software defined radio
- Wireless Internet
- Emergency Services