Overview of IEEE 802.22 Standard and Core Technologies

IEEE P802.22 Wireless RANs

Date: 2010-05-11

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Outline

- IEEE 802.22 Standard Overview
  - Overview of the IEEE 802.22
  - CONOPS
  - Reference Architecture
  - Frame Structure
  - PHY
  - MAC
  - Cognitive Radio Capabilities
  - Spectrum Sensing
  - Geo-location
  - Interface to Incumbent Database Service
  - Security
Overview of the IEEE 802.22 Standard

- Cognitive radio based standard with tangible worldwide frequency bands
- Representation – Commercial industry, Broadcasters, Govt., regulators, and Academia
- Membership – 40 on an average
- VHF and UHF band operation allows long range propagation and cell radius of 17 – 33 km
- PHY - Optimized for long channel response times and highly frequency selective fading channels.
- MAC – Provides compensation for long round trip delays
- Unique features introduced for Cognitive Radio based operation: spectrum sensing, spectrum management, intra-system co-existence, geo-location and security
- Current version of 802.22 (as defined by the Project Authorization and Regulatory Domains) does not allow mobility. However, 802.22 PHY can support mobility of up to 114 km/hr.
IEEE 802.22 CONOPS


- **Network Topology** – Point to Multi-point (PMP)

- **Max EIRP and Cell Radius** – (For 4W EIRP, Cell Radius 17 km), (For 100W EIRP, Cell Radius 30 km).

- **Tx / Rx antenna** – BS uses sectorized or omni-directional antenna. At the subscriber Tx /Rx antenna is directional with 14 dB of front to back lobe suppression,

- **FCC R&O, BS Antenna height <= 30m, Subscriber Antenna = 10m** (typical), but up to 30m allowed in the US.

- **Sensing antenna** requires isotropic (at least horizontal and vertical polarization) sensitivities to sense TV and microphone signals.

- **Geo-location** - GPS based geo-location is mandatory, but terrestrial geo-location (triangulation) is supported.
IEEE 802.22
Cognitive Node: Reference Architecture

• The proposed Protocol Reference Model (PRM) separates the Cognitive Plane from the Data, Control and Management planes
### IEEE 802.22 – Frame Structure

- **802.22** supports **Time Division Duplex** (TDD) frame structure
- **Super-frame**: 160 ms, **Frame**: 10 ms
  - Each frame consists of **downlink** (DL) sub-frame, **uplink** (UL) sub-frame, and the **Co-existence Beacon Protocol (CBP)** burst
  - Lengths of DL and UL sub-frames can be adjusted.
- **Self Co-existence Window**: BS commands subscribers to send out **CBPs** for 802.22
  - self co-existence – **CBP** bursts contain information about the backup channel sets and sensing times
  - terrestrial geo-location and
  - whitespace device identification as required by the regulatory domain rules.

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**Diagram Notes**:
- **Co-existence Beacon Protocol (CBP) burst** used for 802.22 self co-existence and terrestrial geo-location
- **Self-coexistence Window** (5 symbols)
- **Time buffer**
- **Ranging / BW request / UCS notification**
- **Burst**
- **DS Sub-frame**
- **US Sub-frame**
- **Frame Preamble**
- **FCH**
- **US-MAP**
- **US-MAF**
- **UCD**
- **DCD**
- **Burst 1**
- **Burst 2**
- **Burst 3**
- **More than 7 OFDMA symbols**
- **Time buffer**
- **TS**
- **60 subchannels**
- **Co-existence Window (5 symbols) when scheduled**
- **Time buffer**
- **CBP**
- **A**
- **B**
IEEE 802.22 – PHY Features

- **PHY Transport** - 802.22 uses Orthogonal Frequency Division Multiplexing (OFDM) as transport mechanism. Orthogonal Frequency Division Multiple Access (OFDMA) is used in the UL.
- **Modulation** - QPSK, 16-QAM and 64-QAM supported.
- **Coding** - Convolutional Code is Mandatory. Turbo, LDPC or Shortened Block Turbo Code are Optional but recommended.
- **Pilot Pattern** - Each OFDM / OFDMA symbol is divided into sub-channels of 28 sub-carriers of which 4 are pilots. Pilot symbols are inserted once every 7 sub-carriers. Pilots cycle through all 7 sub-carriers over 7 symbol duration. No frequency domain interpolation is required.
- **Net Spectral Efficiency** - 0.624 bits/s/Hz – 3.12 bits/s/Hz.
- **Spectral Mask** - 802.22 has adopted the Spectral Mask requirements proposed by FCC. (200 tap FIR filter may be needed for implementation).

<table>
<thead>
<tr>
<th>TV channel bandwidth (MHz)</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of subcarriers, $N_{FFT}$</td>
<td>2048</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of guard subcarriers, $N_g (L, DC, R)$</td>
<td>368 (184, 1, 183)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of used subcarriers, $N_f = N_g + N_p$</td>
<td>1680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of data subcarriers, $N_d$</td>
<td>1440</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pilot subcarriers, $N_p$</td>
<td>240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal bandwidth (MHz)</td>
<td>5.6240625</td>
<td>6.5625</td>
<td>7.494375</td>
</tr>
</tbody>
</table>

**PHY capacity**

<table>
<thead>
<tr>
<th>Mod.</th>
<th>Rate</th>
<th>Mbit/s</th>
<th>bit/(s*Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>3.74</td>
<td>0.624</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>4.99</td>
<td>0.832</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>5.62</td>
<td>0.936</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>6.24</td>
<td>1.04</td>
</tr>
<tr>
<td>16QAM</td>
<td>1/2</td>
<td>7.49</td>
<td>1.248</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>9.98</td>
<td>1.664</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>11.23</td>
<td>1.872</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>12.48</td>
<td>2.08</td>
</tr>
<tr>
<td>64QAM</td>
<td>1/2</td>
<td>11.23</td>
<td>1.872</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>14.98</td>
<td>2.496</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>16.85</td>
<td>2.808</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>18.72</td>
<td>3.12</td>
</tr>
</tbody>
</table>

**PHY performance: SNR (dB)**

<table>
<thead>
<tr>
<th>Mod.</th>
<th>Rate</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>8.1</td>
</tr>
<tr>
<td>16QAM</td>
<td>1/2</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>14.8</td>
</tr>
<tr>
<td>64QAM</td>
<td>1/2</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>19.7</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>20.9</td>
</tr>
</tbody>
</table>

Note: includes phase noise: -80dBc/Hz at 1 kHz and 10 kHz and -105 dBc/Hz at 100 kHz.
IEEE 802.22 – MAC Features

- **Connection-oriented MAC**, establishes connection IDs and service flows which are dynamically created
- **QoS** – Various types of QoS services are supported (See below). ARQ supported. Uni-cast, Multi-cast and broadcast services are supported.
- **Cognitive functionality** –
  - Dynamic and adaptive scheduling of quiet periods to allow the system to balance QoS requirements of users with the need to quiet down the network to support spectrum sensing. Quiet periods range from 1 symbol (approx. 1/3 ms) to one super-frame
  - Subscribers can alert the BS, the presence of incumbents in a number of ways. Dedicated - Urgent Co-existence Situation (UCS) messages or low priority MAC messages
  - BS can ask one or more subscribers to move to another channel in a number of ways using Frame Control Header (FCH) or dedicated MAC messages

<table>
<thead>
<tr>
<th>QoS</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>UGS</td>
<td>VoIP, T1 / E1</td>
</tr>
<tr>
<td>rtPS</td>
<td>MPEG video streaming</td>
</tr>
<tr>
<td>nrtPS</td>
<td>FTP</td>
</tr>
<tr>
<td>BE</td>
<td>E-mail</td>
</tr>
<tr>
<td>Contention</td>
<td>BW request etc.</td>
</tr>
</tbody>
</table>
IEEE 802.22 – Cognitive Radio Capability

Channel Set Management

Policies

Subscriber Registration and Tracking

Incumbent Database Service

Geo-location

Spectrum Manager

Self Co-existence

Incumbent Database

Spectrum Sensing

Geo-location

Cell 1
Cell 2
Cell 3

Super-frame N (16 Frames)

Coexistence Beacon Windows

Data Frames

TV Channel X

May 2010

Apurva N. Mody, BAE Systems
Many studies have suggested that FCC R&O target for wireless microphones is not sufficient to protect wearable microphones. (where body attenuation of as much as 27dB is possible)

802.22 has designed a beacon signal which will be transmitted from wireless microphone base stations with 250 mW EIRP (as compared to 50 mW EIRP of microphones). These beacon signals consist of repeated pseudo noise (PN) sequences and occupy a bandwidth of approximately 78 kHz.

Security features are provided for beacon authentication.
### Satellite-based geo-location

- Requires GPS antenna at each terminal
- NMEA 0183 data string used to report to BS
- Poor accuracy in Northern hemispheres.

### Terrestrially-based geo-location:

- A new scheme has been proposed requiring no additional hardware and using the characteristics and capabilities of the 802.22 standard.
- Normal BS-CPE ranging process: provides coarse ranging to an accuracy of 147.8 ns (44.3 m)
- Extended BS-CPE ranging process: augments the accuracy of the ranging process to 1 ns (0.3 m) by a more accurate scheme using the complex channel impulse response received at the CPE (Vernier-1) and at the BS (Vernier-2)
- Extended CPE-CPE ranging process: new scheme using the preamble of the CBP burst transmitted by a CPE and captured by another CPE in the surrounding area to acquire the distance between CPEs with a high level of accuracy (Vernier-3)
- Off-line geo-location calculation: All the information acquired at the CPEs is transmitted to the BS which can delegate the calculation of the CPE geo-location to a server. Calculation is based on usual triangulation using some CPEs as waypoints.
Spectrum Etiquette
(Enough channels available)

On Demand Frame Contention
(Two or more cells need to co-exist on the same channel)

Number x – represents operating channel
Number y – represents backup channel
Number z (double underline) – represents candidate channel

Requires that information on operating, backup and candidate channels of each cell is shared amongst WRAN cells: exchanged by CBP bursts.

Primary user appears

Self-coexistence window (SCW) does not have to be allocated at each frame.
Confidentiality and Privacy – AES (128) GCM is used for encryption and authentication.

Network Authorization - RSA and ECC based X.509 certificates are used for mutual authentication / network entry authorization.

Integrity – AES-GCM is used to compute Integrity Check Vector (ICV). PN sequence numbers are appended to each packet.

Authentication – Signals such as wireless microphone beacon and CBP are authenticated using ECC based digital signatures. No encryption is provided for these packets.

Key Management - Secure Control and Management Protocol is used for key management.

Management Messages – All management messages except for the broadcast, initial ranging and basic CID are protected.

Device Security - Trusted Computing Group, Trusted Platform Module specifications are recommended to enable tamper-proof capability for hardware and software.
IEEE 802.22 – Security Sub-layer 2 (Cognitive)

- Spectrum Availability -
  - Spectrum Sensing used to ensure spectrum availability for primary users.
  - Various types of signal specific and feature based sensing algorithms have been included into the standard
  - Standard recommends sensing algorithms to determine the signal type (Signal Classification)
- Collaborative Sensing - The group in general thinks that collaborative sensing will be useful. FCC R&O requires ‘OR’ rule based collaborative sensing.
- Correlation with Geo-location Information – Closely tied to collaborative sensing. It tries to cross check the spectral footprint of the detected signal based on location of the sensor

- Spectrum Access Authorization –
  - BS is capable of de-authorizing a subscriber at any time. Sensing and incumbent database service used for spectrum access authorization
  - Capability Check – The Spectrum Manager (SM) is capable of prohibiting a subscriber from registering if it does not have adequate sensing capabilities.

- Radio Behavior Control
  - IEEE 802.22 is policy driven. Policies are rule-based.
References

- Gerald Chouinard, Communications Research Center, 802.22 Overview presentation to the 802 Whitespaces Study Group [https://mentor.ieee.org/802-sg-whitespace/dcn/09/sg-whitespace-09-0058-00-0000-802-22-presentation-to-ecsg.ppt](https://mentor.ieee.org/802-sg-whitespace/dcn/09/sg-whitespace-09-0058-00-0000-802-22-presentation-to-ecsg.ppt)
- IEEE 802.22 Draftv3.0 – Members only Documents of the IEEE 802.22 Working Group ([www.ieee802.org/22](http://www.ieee802.org/22))
- Other Contributions to the IEEE 802.22 Standard ([www.ieee802.org/22](http://www.ieee802.org/22))