IEEE 802.22 Wireless Regional Area Networks (WRAN)
Removing Digital Divide and Enabling Rural Broadband Access Using Cognitive Radio Technology

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Muito obrigado por me dar esta oportunidade de falar na frente de um público tão estimado
Outline

• Digital divide: Today’s problem and its solution
• Television Whitespace (TVWS): A New Hope
• Overview of regulatory rules in various countries
• IEEE 802.22 Standard
• Conclusions
Problem: Digital Divide Exists Today

• Today, more than half the population in the world live in rural areas with hardly any access to broadband.
• It is expensive to lay fiber / cable in rural and remote areas with low population density. Wireless is the only solution.
• Backhaul / backbone internet access for rural areas is very expensive (50% of the cost)
• Traditional wireless carriers have focused on urban areas with high populations density (faster Return on Investment) using licensed spectrum
• America: About 28 percent of rural America, lack access to Internet with speeds of three megabits per second or faster, compared with only 3 percent, in non-rural areas, according to an FCC report titled "Bringing Broadband to Rural America."
• India: In India, a country with more than 1.2 Billion people, more than 500 Million people have cell phones but less than 0.75% of the population has access to high speed internet access
• Brazil: In Brazil, less than 4% population has access to high speed internet access.
• This has created a DIGITAL DIVIDE
Solution to Reduce Digital Divide

- **Govt. Initiative and Vision**
  - e.g. US Second Memorandum Opinion and Order (Sept. 2010) allowing licensed-exempt operation in Television Whitespaces

- **Suitable regulations and incentives**
  - Policy regulations (license-exempt, lightly licensed, licensed), provide incentives to companies that provide rural broadband

- **Viable business model**
  - Technical Regulations
    - Ensure that the correct spectrum is allocated to deploy large Regional Area Networks (RAN) with adequate transmit power.
    - Requirements on spectrum sensing, access to geolocation database, spectrum mask, transmitter and receiver height etc.

- **Research, development, innovations and novel applications**
  - Low Cost – Low cost of spectrum, low cost of equipment and Govt. incentives
<table>
<thead>
<tr>
<th>License-exempt</th>
<th>Light Licensing</th>
<th>Licensed</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g., TVWS in United States</td>
<td>e.g., TVWS in Canada</td>
<td>e.g., 700 MHz and 800 MHz bands in USA and Canada</td>
</tr>
<tr>
<td>Low start-up costs resulting in rapid deployment to markets without technology bias</td>
<td>Low start-up costs resulting in rapid deployment to markets if appropriate technology is developed</td>
<td>Higher start-up and infrastructure costs. Cost of spectrum transferred to the users.</td>
</tr>
<tr>
<td>Can proliferate in rural and under-served areas due to low spectrum cost and lower equipment cost.</td>
<td>Facilitates proliferation in rural and under-served areas due to lower spectrum costs and guaranteed spectrum use without interference.</td>
<td>Rural areas with low population densities are yet to experience true broadband wireless access due to higher infrastructure cost.</td>
</tr>
<tr>
<td>Spurs innovation since it requires additional features for co-existence</td>
<td>May or may not spur innovation</td>
<td>Legacy systems and solutions may not result in innovative approaches. Technology bias of the regulators may hinder innovation.</td>
</tr>
<tr>
<td>Service and spectrum is not guaranteed but innovative approaches can fuel R&amp;D that can fill that gap</td>
<td>Service and spectrum guaranteed over certain regions and periods of time.</td>
<td>Service is guaranteed but Quality of Service is not guaranteed due to lack of competition.</td>
</tr>
<tr>
<td>Unlikely to result in corrupt practices within the Govt.</td>
<td>Unlikely to result in corrupt practices within the Govt.</td>
<td>May result in corrupt practices within the Govt.</td>
</tr>
</tbody>
</table>
Relative Cost and Complexity of Various Technologies for Rural and Regional Area Broadband Service

- Fixed broadband at lower frequency
- Mobile broadband
- Satellite
- ADSL
- Optical fiber
- Cable modem

FCC Definition of ‘Rural’

Credits:
- Courtesy: Gerald Chouinard: gerald.chouinard@crc.ca

www.crc.ca
Choice of Spectrum: Optimum frequency range for large area Non-Line-of-sight Broadband Access

![Graph showing frequency vs. relative complexity/cost for various factors such as Ground wave reach, Antenna aperture, Ionospheric reflection, Industrial noise, and more.](image-url)

Courtesy: Gerald Chouinard: [gerald.chouinard@crc.ca](mailto:gerald.chouinard@crc.ca)
Choice of Spectrum: Optimum frequency range for large area Non-Line-of-sight Broadband Access

Optimum frequency range for large area Non Line of Sight (NLoS) operation falls within the TV Band spectrum.
High Range and NLoS Operation are Necessary

- **Range**: VHF/ UHF Bands and Television Whitespaces with appropriate transmit / receive power allowance are ideally suited to deploy large Regional Area Networks (RANs) due to favorable propagation characteristics.

![Diagram showing high range and NLoS operation](image.png)
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Television Whitespaces: A New Hope

Southern Ontario Canada

Legend
Available TV channels
None
1
2
3
4
5
6
7
8
9
10 and +

Sparse Spectrum Usage

Rural Areas

Urban Areas

TV Channel Availability for Broadband

- TV Channels in VHF / UHF bands have highly favorable propagation characteristics.
- Analog TV will be transitioned to Digital TV world-wide. One analog TV channel allows up to 5 standard definition DTV signals to be transmitted.
- Excess spectrum is called the **digital dividend** and it can be used to provide broadband access while ensuring that no interference is caused to primary users.
- In some administrations like the United States, **opportunistic license-exempt usage** of the spectrum used by the incumbents is allowed on a non-interfering basis using **cognitive radio techniques**.
The Digital Dividend

Rural Broadband
(e. g. 802.22)
What can Television Whitespaces do?

Wireless Regional Area Networks such as IEEE 802.22 systems using TV Whitespaces can connect rural areas in emerging markets.

- Television Whitespaces (TVWS) will allow broadband wireless access to regional, rural and remote areas under Line of Sight (LoS) and Non Line of Sight (NLoS) conditions.
- Other Applications:
  - Smart grid
  - Cheap backhaul using multi-profile RAN stations
  - Triple play for broadcasters (e.g. video, voice and data),
  - Off-loading cellular telephony traffic to un-licensed spectrum,
  - Distance learning, civic communications, regional area public safety and homeland security, emergency broadband services,
  - Monitoring rain forests, monitoring livestock, border protection,
  - Broadband service to multiple dwelling unit (MDU), multi tenant unit (MTU), small office home office (SoHo), campuses, etc.
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United States TVWS Regulations
United States TVWS Regulations


• **2004**: IEEE 802 commented on the NOI and authorized the launch of the 802.22 Working Group Project


• **2011** – IEEE 802.22-2011 Standard was published in July 2011.
United States RF Spectrum Allocation and Television Whitespaces

**Fixed TV Band Device**

Usable TV channels: Channels 2, 5, 6, 7-13, 14-20, 21-36, 38-51

VHF: 2 (54-60 MHz), 5,6 (76-88 MHz), 7-13 (174-216 MHz)

UHF: 14-20 (470-512 MHz except in major markets), 21-36, 38-51 (512-698 MHz)

**Personal/portable TVBD**

Usable TV channels: TV Channels 21-36, 38-51

UHF: 21-36, 38-51 (512-698 MHz)

Source: [www.fcc.gov](http://www.fcc.gov)
Cognitive Radio based Dynamic Spectrum Access in TV White Space is One Approach (USA)

- New cognitive radio technology can sense the spectrum using spectrum sensing or accessing a geolocation database service
- Access the spectrum
- Use the spectrum
- Release it if not needed or co-exist with other services

Reference: IEEE 802.22-2011 Standard

Courtesy – Carl Stevensen – WK3c Wireless and Presentation – Samsung Electronics
USA TV White Space device types

• **Fixed TVBD**
  – Maximum EIRP= 4 W (12.2 dBm/100 kHz). Allows for channel bonding.
  – Chaining of fixed device allowed
  – Geolocation capable or professional installer (Accuracy +/- 50 m)
  – Secure access to TV Database with device Id. Check database every 24 hours. Operation can continue for 48 hours even if connection to database is lost
  – Usable TV channels:
    • VHF: 2, 5, 6, 7-13
    • UHF: 14-20 (except in major markets), 21-36, 38-51
    • Maximum antenna height: 30 m AGL and 76 m HAAT (limiting factor)

• **Mode II Personal/portable TVBD**
  – Maximum EIRP= 100 mW (20 dBm), 40 mW (16 dBm) when adjacent to incumbent
  – Geolocation: +/- 50 m, check database daily
  – Secure access to TV Database with device Id
  – Usable TV channels:
    • UHF: 21-36, 38-51
USA TV White Space device types (cont’d)

• **Mode I Personal/portable TVBD (Slave Device)**
  – Maximum EIRP= 100 mW, 40 mW when adjacent to incumbent
  – Must obtain available channels from Mode II or Fixed TVBD. Can not act as a master for another Mode I.
  – Channel availability must be checked every 60 seconds
  – Usable TV channels:
    • UHF: 21-36, 38-51

• **Sensing-only Personal/portable TVBD**
  – Maximum EIRP= 50 mW (17 dBm), 40 mW (16 dBm)) when adjacent to incumbent
  – Usable TV channels:
    • UHF: 21-36, 38-51
    • Must sense for incumbents prior to channel use
  – Detection thresholds:
    • ATSC digital TV= -114 dBm over 6 MHz (0 dBi antenna and 0 dB loss) (-19 dB SNR. This was a challenge but progress is being made to meet the goal)
    • NTSC analog TV= -114 dBm over 100 kHz at NTSC carrier
    • Auxiliary and microphone= -107 dBm over 200 kHz
  – Sense for 30 seconds before transmit
  – In-service monitoring every 60 seconds
  – Channel release time= 2 seconds
United States TV Whitespaces – Database Service Implementation

- **Total of 10 companies are involved:** Google, Microsoft, Spectrum Bridge, Key Bridge, Telcordia, Neustar, Comsearch, WSdB, LS Telecom, Frequency Finder

Reference: Spectrum Bridge response to the TV Band Database Management Proposal – FCC ET Docket # 04-186
Kinsley, Kansas, USA

TV Channel Availability
Rural Town, Moderate Density

 Courtesy: Spectrum Bridge:
 http://spectrumbridge.com/whitespaces.aspx
Ithaca, New York, TV Channel Availability

Urban University Town, Moderate Density

The table shows all the 6 MHz TV channels between channels 2 and 51 that are potentially available for secondary use by White Space radios (i.e., TV Band Devices or TVBDS).

Available Channels

<table>
<thead>
<tr>
<th>Fixed TVBD &lt; 10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAAT: 212.63 meters</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel</th>
<th>TVBD &lt; 10m</th>
<th>TVBD &lt; 30m</th>
<th>TVBD &lt; 100mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>6</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>8</td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>9</td>
<td>✓</td>
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<td></td>
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<tr>
<td>10</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>11</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>14</td>
<td>✓</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td></td>
<td>✓</td>
<td></td>
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<tr>
<td>16</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Channel Map Legend

- ✓ Your location is within the service area of a TV station or other licensed user and this channel cannot be used by a TVBD.
- This channel is vacant in your location, and can potentially be used by your TVBD.
- This channel is vacant in your location, and can potentially be used by your TVBD, but personal portable devices may not be used on channels 2-20.
- This channel is reserved for wireless microphone use.
- Warning: Height Above Average Terrain (HAAT) exceeds 76m. White Space Devices cannot be used at this location.

Manhattan, New York TV Channel Availability

Urban City with very high population density

Canada Remote Rural Rural Broadband Service TVWS Regulations
Canada TVWS Regulations – Remote Rural Broadband Service

- Frequency range: 512-608 MHz and 614-698 MHz (TV Channels 21 to 51 except channel 37)
- Type of operation: Fixed wireless access for subscriber-based broadband applications (in-band backhaul for broadband access is also permitted)
- Light licensing: first-come, first served exclusive license
- TDD over one 6 MHz channel and FDD over two 6 MHz channels allowed, (exceptionally, two contiguous 6 MHz channels can be used)
- Minimum distance of CPEs from protected contours

<table>
<thead>
<tr>
<th>Co-channel</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>N+/-1</td>
<td>0.5 km</td>
</tr>
<tr>
<td>N+/-2</td>
<td>0 km</td>
</tr>
</tbody>
</table>

- BSs and CPEs can operate inside the protected contours for N+/-3 and beyond (operation on N, N+/-1 and N+/-2 is not permitted inside the protected contours)

Canada TVWS Regulations

- Transmitter specifications:
  - Minimum bandwidth = 500 kHz
  - Maximum bandwidth = 6 MHz (and exceptionally 12 MHz)
  - Carrier frequency stability = +/-10 ppm
- Subscriber equipment:
  - Maximum transmit power = 1 W conducted, 4 Watts radiated
  - Maximum transmit power spectral density = -7 dBW/100 kHz
- Base equipment:
  - Maximum transmit power = 125 W
  - Maximum transmit power spectral density = 14 dBW/100 kHz

<table>
<thead>
<tr>
<th>Distance to DTV/NTSC Protected Contour</th>
<th>RRBS Base Station HAAT (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>≤ 7 km</td>
<td></td>
</tr>
<tr>
<td>≥ 7 km</td>
<td>2.5</td>
</tr>
<tr>
<td>≥ 10 km</td>
<td>20</td>
</tr>
<tr>
<td>≥ 15 km</td>
<td>100</td>
</tr>
<tr>
<td>≥ 20 km</td>
<td>305</td>
</tr>
<tr>
<td>≥ 25 km</td>
<td>305</td>
</tr>
<tr>
<td>≥ 30 km</td>
<td>305</td>
</tr>
<tr>
<td>≥ 40 km</td>
<td>305</td>
</tr>
</tbody>
</table>
UK OFCOM TVWS Regulations
## UHF Bands IV and V – United Kingdom Plan

<table>
<thead>
<tr>
<th>Channel</th>
<th>Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>566-574</td>
</tr>
<tr>
<td></td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>854-862</td>
</tr>
</tbody>
</table>

- **112 MHz of cleared spectrum (14 × 8 MHz)**
- **Channel 36** (currently used for airport radar, but plans published for clearing radar use)
- **Channel 69** (used for PMSE but to be allocated as part of Upper cleared award to aligning with CEPT band plan)
- **256 MHz of spectrum retained for DTT (32 × 8 MHz but interleaved capacity available within this)**
- **Channel 38** (currently used for radioastronomy but now to be dedicated channel for PMSE)
- **Channels 39, 40** (new DTT allocations as part of proposals for alignment with CEPT band plan)
- **Channels 61, 62** (to be allocated as part of Upper cleared award to align with the CEPT band plan)
Interleaved spectrum available across the UK

Available MHz:
- 0-25
- 26-50
- 51-100
- 101-150
- >150

Courtesy: Andy Gowans (OfCom), UK OfCom
Update on Digital Dividend -
https://mentor.ieee.org/802.18/dcn/09/18-09-0091-00-0000-ofcom-update-on-the-digital-dividend-cognitive.ppt

Outdoor

Indoor
UK OFCOM TVWS Regulations

- OFCOM concluded to enable both RF detection and geolocation/database access and allow stakeholders to determine which approach they prefer. Both approaches could also be amalgamated.

- Proposed system parameters:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum transmit power</td>
<td>17 dBm (50 mW) 4 dBm (2.5 mW) (to operate on adjacent channels)</td>
</tr>
<tr>
<td>Transmit power control</td>
<td>Required</td>
</tr>
<tr>
<td>Out-of-band performance</td>
<td>&lt; -46 dBm</td>
</tr>
<tr>
<td>Sensitivity assuming 0 dBi antenna and 0 dB loss</td>
<td>-120 dBm in 8 MHz (DTV) -126 dBm in 200 kHz (wireless microphones)</td>
</tr>
<tr>
<td>Time between sensing</td>
<td>&lt; 1 second</td>
</tr>
</tbody>
</table>
Comparisons of the Spectrum Mask

- RF Mask
  - Should be based on a balance between out-of-band TV receiver rejection performance and out-of-band broadband transmitter emission

0.7 dB maximum Rx desensitization at edge of coverage due to co-channel interference (FCC OET Bulletin 69)
Other Countries
TVWS Regulations Around the World

Canada Regulations completed – Total 288 MHz freed up (Sept 2010) for lightly licensed operation.

USA Regulations completed – Total 288 MHz freed up (Sept 2010) for license-exempt operation. Geolocation database, sensing driven.

Brazil – DTV transition on-going. Realizes the importance of broadband for rural (e.g. Res. 558, Operation in 450 – 470 MHz)

UK Final Rules to be released this year – License-exempt database driven approach

EU (CEPT) Discussions on-going – license-exempt, collaborative sensing, database approaches considered. Variable transmit power based on device capabilities, microphone protection beacon

Egypt – Participating in IEEE 802.22

ITU – Several study groups are discussing cognitive radio based operation. TVWS will be a discussion topic in 2015 WRC. IEEE 802 is providing inputs

India Discussions on-going – 368 – 380 MHz for rural. 470 MHz – 585 MHz for fixed and mobile. Further discussions in 2015 time-frame

Japan (MIC) Discussions on-going Final rules before 2015. 10 WS projects under way – WS Test Area to be allocated

Singapore Testing devices on-going (IDA) – Final rules before 2015. 12 channels for testing. May allow bonding of up to 8 channels. Sensing, database required
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IEEE Standards Association Hierarchy

IEEE

IEEE Standards Association (IEEE-SA)

Standards Board

IEEE 802
Sponsor Executive Committee

Board of Governors

Review Committee (RevCom)

New Standards Committee (NesCom)

Patent Committee (PatCom)

802.11
WLAN

802.15
WPAN

802.22
WRAN

Courtesy, Paul Nikolich, Chair, IEEE 802
IEEE 802.22 WG on Wireless Regional Area Networks

IEEE 802.22 WG is recipient of the 2011 IEEE SA Emerging Technology of the Year Award

IEEE 802.22 Standard – Wireless Regional Area Networks: Cognitive Radio based Access in TVWS: Published in July 2011

Member copy:

- 27 Voters,
- 8 Aspirants,
- 18 observers

- 802.22.1 – Std for Enhanced Interference Protection in TVWS: Published in Nov. 2010
- 802.22.2 – Std for Recommended Practice for Deployment of 802.22 Systems: Expected completion - Dec 2012
- 802.22 RASGCIM – Regional Area Smart Grid and Critical Infrastructure Monitoring Study Group

www.ieee802.org/22
802.22 Unique Proposition

- *First* IEEE Standard for operation in Television Whitespaces
- *First* IEEE Standard that is specifically designed for rural and regional area broadband access aimed at removing the digital divide
- *First* IEEE Standard that has all the Cognitive Radio features
Today, more than half the population in the world resides in rural areas with hardly any access to true broadband. IEEE 802.22 connects rural areas in emerging markets

- IEEE 802.22 will Provide Broadband Wireless Access to Regional, Rural and Remote Areas Under Line of Sight (LoS) and Non Line of Sight (NLoS) Conditions using Cognitive Radio Technology (without causing harmful interference to the incumbents).
- Cognitive Radio technology added to a simple and optimized OFDMA waveform (similar to the OFDMA technology used in other broadband standards)
- Meets all the regulatory requirements such as protection of incumbents, access to the database, accurate geolocation, spectrum mask, control of the EIRP etc.
- Large regional area foot can allow placement of the Base Station closer to the area with cheaper internet backhaul / backbone.
IEEE 802.22 Website

IEEE 802.22 Working Group on Wireless Regional Area Networks
Enabling Rural Broadband Wireless Access Using Cognitive Radio Technology in TV Whitespaces

**IEEE 802.22 Charter**

The charter of IEEE 802.22, the Working Group on Wireless Regional Area Networks ("WRANs"), under the PAR approved by the IEEE-SA Standards Board is to develop a standard for a cognitive radio-based PHY/MAC/air interface for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service.

The approved PARs for 802.22, 802.22.1, and 802.22.2 can be viewed by clicking on their respective links.

**On-going Projects**

- IEEE P802.22 (Base Standard) Sponsor Ballot Draft v1.0 is available for [download (Members Only)]

- IEEE P802.22.2 (Standard for Recommended Practice for Installation and Deployment of 802.22 Systems) Draft v1.0 is available for [download (Members Only)]

**Completed Projects**

- IEEE 802.22.1 Standard for the Enhanced Interference Protection of the Licensed Devices was Published as an Official IEEE Standard on November 1st 2010. [Download here (Members Only)]

**Contact Information**

- Working Group Chair: Apurva N. Mody, Ph. D.
- Working Group Vice Chair: Gerald Chouinard
- BAE Systems
- Communications Research Center, Canada

[www.ieee802.org/22](http://www.ieee802.org/22)
Other Use Cases: IEEE 802 Standards for Smart Grid and Machine to Machine Communications

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring -
IEEE 802.22 Other User Cases

- TVDB = (TV Database)
- LC-CPE = Low Complexity CPE

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring
IEEE 802.22 Other User Cases

- TVDB = (TV Database)
- LC-CPE = Low Complexity CPE

Environment monitoring – e.g. monitoring deforestation

Critical infrastructure and hazard monitoring

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring
IEEE 802.22 Other User Cases

- **TVDB** = (TV Database)
- **LC-CPE** = Low Complexity CPE

Homeland Security

Smart traffic management

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring
IEEE 802.22 Other User Cases

- TVDB = (TV Database)
- HC-CPE = Higher Complexity CPE

Emergency Broadband Infrastructure

Remote medical service

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring
IEEE 802.22 Other User Cases

- TVDB = (TV Database)
- HC- CPE = Higher Complexity CPE

Archipelago and marine broadband service.
Servicing oil rigs

Triple play (Bi-directional Video, Voice and Data) for traditional TV Broadcasters

C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring
IEEE 802.22 Other User Cases

- Cheap backhaul
- Broadband service extension – integrated smart grid and other applications
Overview of the IEEE 802.22 Standard

- **Core Technology** - Cognitive radio technology used to co-exist with and protect the primary users (incumbents).
- **Representation** – Commercial industry, Broadcasters, DoD, Regulators, and Academia
- **Membership** – 30 on an average (over 5 years)
- **CONOPS** - VHF and UHF band operation allows long range propagation and cell radius of 10 – 30 km, exceptionally extensible to 100 km in favorable conditions.
- **PHY** - Optimized for long signal propagation distances and highly frequency selective fading channels (multipath with large excess delays).
- **MAC** – Provides compensation for long round trip delays to provide service to up to 100 km.
- **Unique features** introduced for Cognitive Radio based operation: spectrum sensing, spectrum management, incumbent protection, coexistence, geo-location and security
- **Portability** – IEEE 802.22 allows portability (nomadic use). In case the rules do change, IEEE 802.22 PHY is designed to support mobility of up to 114 km/h (no hand-off is included in the current version).
IEEE 802.22 CONOPS

- Operation in the VHF / UHF Whitespaces.
- Network Topology – Point-to-Multipoint (PMP)
- Max EIRP and Cell Radius – Fixed BS and Fixed Subscribers using 4W EIRP, Cell Radius 10 – 30 km, exceptionally extensible to 100 km under favorable conditions. 802.22 protocol has been Optimized for long signal propagation distances. (Higher power BS allowed in countries outside the USA)
- Portable Subscribers Supported.
- 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,
- Sensing antenna requires horizontal and vertical polarization sensitivities to sense TV and microphone signals, and omni-directional pattern.
- Geo-location - GPS based geo-location is mandatory, and high resolution terrestrial geo-location (triangulation) is embedded in the standard
IEEE 802.22
Cognitive Node: Reference Architecture

IEEE 802.22 Provides Three Mechanisms for Incumbent Protection
- Sensing
- Database Access
- Specially Designed Beacon

Security Sub-layers are introduced to protect non-cognitive as well as cognitive functions

Cognitive Plane is used to control the Cognitive Radio Operation. Security Sublayer 2 is introduced for protection against Cognitive Threats
IEEE 802.22 – Cognitive Radio Capability

Spectrum Manager

Channel Set Management

Subscriber Station Registration and Tracking

Policies

Self Co-existence

Spectrum Sensing

Incumbent Database Service

Geo-location

Incumbent Database

TV Channel
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 downstream (DS) sub-frame, upstream (US) sub-frame, and the Co-existence Beacon Protocol (CBP) burst
- Lengths of DS and US sub-frames can be adjusted.
- Self-coexistence Window (SCW): BS commands subscribers to send out CBPs for 802.22
  - Self-coexistence – CBP bursts contain information about the backup channel sets, sensing times, SCW scheduling, contention information
  - terrestrial geo-location and
  - whitespace device identification as required by the regulatory domain rules.
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 Upstream.

- **Modulation** - QPSK, 16-QAM and 64-QAM supported

- **Coding** – Convolutional Code is mandatory. Either Turbo, LDPC or Shortened Block Turbo Code can be used for advanced coding.

- **Pilot Pattern** - Each OFDM / OFDMA symbol is divided into sub-channels of 28 subcarriers of which 4 are pilots. Pilot carriers are inserted once every 7 sub-carriers. Pilots cycle through all 7 sub-carriers over 7 symbol duration. No frequency domain interpolation is required because of low Doppler spread in TV bands.

- **Net Spectral Efficiency** - 0.624 bits/s/Hz – 3.12 bits/s/Hz

- **Spectral Mask** - IEEE 802.22 PHY flexible to meet Spectral Mask requirements in various countries

---

**PHY Transport**

- **TV channel bandwidth (MHz)**: 6, 7, 8
- **Total number of subcarriers, \( N_{\text{FFT}} \)**: 2048
- **Number of guard subcarriers, \( N_{G} \) (L, DC, R)**: 368 (184, 1, 183)
- **Number of used subcarriers, \( N_{T} = N_{D} + N_{P} \)**: 1680
- **Number of data subcarriers, \( N_{D} \)**: 1440
- **Number of pilot subcarriers, \( N_{P} \)**: 240
- **Signal bandwidth (MHz)**: 5.6240625, 6.5625, 7.494375

**Data Rates in NLOS Conditions**

<table>
<thead>
<tr>
<th>PHY capacity</th>
<th>Mbit/s</th>
<th>bit/(s*Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mod.</strong></td>
<td><strong>Rate</strong></td>
<td><strong>CP= 1/8</strong></td>
</tr>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>3.74</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>4.99</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>5.62</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>6.24</td>
</tr>
<tr>
<td>16QAM</td>
<td>1/2</td>
<td>7.49</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>9.98</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>11.23</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>12.48</td>
</tr>
<tr>
<td>64QAM</td>
<td>1/2</td>
<td>11.23</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>14.98</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>16.85</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>18.72</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>
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<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 (160 ms)
  - Subscribers stations can alert the BS of the presence of incumbents in a number of ways. Dedicated - Urgent Co-existence Situation (UCS) messages or lower priority MAC messages
  - BS can ask one or more subscribers to move to another channel in a number of ways using the 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>

**QoS Application**

- **UGS** (Unspecified Guaranteed Service)
- **rtPS** (Real-time Polling Service)
- **nrtPS** (Non-real-time Polling Service)
- **BE** (Best Effort)

**Diagram**

- Intra-frame quiet period scheduling
- Inter frame quiet period scheduling
IEEE 802.22 – Spectrum Sensing

TV and Wireless Microphone Protection Using Spectrum Sensing - Several blind and signal specific feature-based sensing schemes have been proposed and **thoroughly evaluated** using TV Broadcaster supplied over-the-air collected signals

- Spectral correlation based sensing,
- Time domain cyclostationarity,
- Eigen value based sensing,
- FFT – based pilot sensing,
- Higher order statistics based sensing, etc.

**Wireless Microphone Protection Using Beacon**

- 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 according to the manufacturers)

- **802.22** has designed a beacon signal which will be transmitted from wireless microphone operations with up to 250 mW (as compared to 10 mW for microphones). These beacon signals consist of repeated pseudo-noise (PN) sequences and occupy a bandwidth of 78 kHz.

- Security features are provided for beacon authentication

---

**DTV Detection Results based Cyclostationary Feature Detection**

\[ P_d = 99.9\%, \ P_f = 10\% \]

**Wireless Microphone Beacon Sensing Results**

- Sensing threshold (dBm)
  - Minimum sensing time (ms)
  - TG1 certificate
  - TG1 signature
  - TG1 information (FEC encoded)
  - Sync and index
  - 8-chip spreading sequence

\[ -114 \text{ dBm} \]
IEEE 802.22 – Geo-location

Satellite-based geo-location
- Requires GPS antenna at each terminal
- NMEA 0183 data string used to report to BS

Terrestrially-based geo-location:
- A new scheme has been included in the 802.22 Standard 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 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
- 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)

Super-frame N (16 Frames)

Super-frame N+1 (16 Frames)

TV Channel X

Cell 1 | Cell 2 | Cell 3

Cell 3 | Cell 1 | Cell 2 | Cell 1 | Cell 1 | Cell 2 | Cell 3

Data Frames

Coexistence Beacon Windows

IEEE 802.22 – Self Co-existence

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

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

Primary user appears

Self-coexistence window (SCW) does not have to be allocated at each frame.

Number x – represents operating channel
Number y – represents backup channel
Number z (double underline) – represents candidate channel
IEEE 802.22 – Security Sub-layer 1 (Non-Cognitive)

- 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.
IEEE 802.22 – Additional Features

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>802.22 (WRAN)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1. **Regulatory Domain Specific Switches** – Allows 802.22 features to be switched ON or OFF based on regulatory domain specifications. E. g. Spectrum Sensing can be turned OFF in the US.

2. **Access to the Incumbent Database** – IEEE 802.22 WG has gone to great lengths to define the messaging format, techniques, and timers to access the incumbent database. We even recommend the technology for secure access to the database.

3. **Portability** - The IEEE 802.22 standard supports portable devices. Messaging has been added that sends an update to the Base Station if the device has moved by +/- xx meters based on the regulatory domain requirements. The BS then acts as a proxy and refreshes the available channel information.

4. **Ensuring that Regulatory Domain EIRP Requirements are not exceeded**: IEEE 802.22 ensures that the regulatory domain specifications for the EIRP are not exceeded.

5. **Accurate Indoor NLOS Geolocation**: Indoor NLOS geolocation has traditionally been very difficult. IEEE 802.22 provides ways to perform accurate indoor NLOS geolocation.
Formation of the Whitespace Regional Area Networks (WRAN) Alliance

A specification alone does not create ROI
– Need stake in the ground for other companies to rally around

Ecosystem ‘brand’ is required-
– 802.11 >> WiFi
– 802.15.4 >> ZigBee
– 802.16 >> WiMAX

Brand is formed and developed by multiple industry participants to commercialize 802.22 specs and accelerate commercial realization
– Collaboration across technical, business and marketing fronts
– Solutions Development, awareness, outreach, marketing, education

Brand provides rapid realization of returns from 802.22 R&D investment

IEEE 802.22 Member Companies have formed Whitespace Regional Area Networks (WRAN) Alliance

www.wranalliance.org

R. Maley, WRAN Alliance Overview
WRAN Alliance Benefits

• **Neutral Participation Platform**
  – Involve all communities of interest under an open umbrella

• **Create a corporate veil/umbrella to shield, indemnify and protect individual and company participants**
  – Ad Hoc and ‘informal work together’ frameworks create exposure for participants

• **Ensure compliance with regulations specified by law**
  – Anti-trust, Anti-competitive

• **Define and enforce fair, inclusive participation platform**
  – Policies, practices and procedures

• **Funding for required programs**
  – Annual Dues

• **Management and ownership of key deliverables:**
  – Specification(s), Reference Architectures, Implementation Guidelines, Test Suites; Market Messaging/Positioning; Trademarks; Certification Logos; Etc.
The WRAN Alliance will create the environment and technical foundation for development and delivery of wireless broadband solutions in rural and remote areas while ensuring protection for the incumbents.

By working in an open and neutral forum, WRAN Alliance participants will gain the ability to collectively educate and seed the market for WRAN solutions and services and generate RoI for their investments.

www.wranalliance.org
Outline

• Digital divide: Today’s problem and its solution
• Television Whitelspace (TVWS): A New Hope
• Overview of regulatory rules in various countries
• IEEE 802.22 Standard
• Conclusions
Conclusions (1)

- **Spectrum**: Television Whitespaces are ideal for providing wireless broadband access service to rural and remote areas (better signal propagation at lower frequencies).
- **Innovation**: TVWS deployment is likely to spur innovation and help reduce the digital divide that exists today.
- **Fixed vs Mobile**: Fixed wireless broadband access can reach larger areas than mobile broadband (i.e., optimized modulation, user terminal antenna gain and higher antenna height). Basic problem needs to be solved first.
- **Cost Sensitivity**: Rural broadband access is highly cost sensitive and can better succeed if spectrum is lightly licensed and/or license exempt.
Conclusions (2)

• **Govt Role:** The Governments around the world should encourage deployment of broadband wireless access technologies to rural and hard-to-reach remote areas, by creating regulatory framework that is encouraging and promoting technologies that are best suited for this type of large area coverage.

• **Regulations:** Regulations should not be too aggressive such that there would be a need for breakthrough technology driving up the cost and making the business case unfeasible.

• **Product Roadmap:** Countries where rural and remote broadband access is needed should identify their potential need in equipment so that an aggregation of the potential worldwide market could be made to attract industry’s interest toward volume production of equipment best suited for such large coverage.
Conclusions (3)

- **IEEE 802.22 is the First** IEEE Standard for operation in Television Whitespaces
- **IEEE 802.22 is the First** IEEE Standard that is specifically designed for rural and regional area broadband access aimed at removing the digital divide
- **IEEE 802.22 is the First** IEEE Standard that has all the Cognitive Radio features
- **Emerging Breakthrough Technology**: IEEE 802.22 Working Group is the recipient of the 2011 IEEE SA Emerging Technology of the Year Award
- **Brazil Participation**: We urge countries such as Brazil to participate, adopt, and develop IEEE 802.22 based solutions and make a difference.
## References

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