THE CHALLENGE OF DELIVERING
WIDE-AREA BROADBAND SERVICES
USING VHF/UHF WHITE SPACE SPECTRUM

WHITE SPACE: AN ALTERNATIVE TO MICROWAVE AND SATELLITE BACKHAUL

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OVERVIEW

The challenge of delivering wide-area terrestrial broadband services within high-vegetative areas like the developing Marcellus Shale region is daunting. Topographically, the terrain is some of the most rugged and harshest of global plays. Marcellus geography ranges from gently rolling hills to wetlands to steep vertical rock barriers, making line-of-sight microwave links a challenge along with wide-area sensor and SCADA networks. In addition, seasonal variation of natural ground clatter and obstructions can seriously affect signal reliability. Currently, nearly all play theater communications are supported through Satcom, licensed/unlicensed microwave, and where available, 4G/LTE broadband systems. This approach, while satisfying basic requirements for voice and data, constrains operational efficiencies by limiting reliable implementation of additional value-added requirements such as video, real-time streaming of well data and wide-area governmentally-mandated environmental monitoring data.

This article focuses on presenting the corporate communications engineer and IT professional with the benefits and advantages of using unlicensed White Space spectrum. White Space is a broadcast technology term for unused 6 MHz wide TV channels. This paper will conclude with basic deployment and use scenarios applicable to the ever-increasing, tetherless connectivity requirements of the entire oil and gas production stream.

Unlicensed White Space Spectrum
On September 23, 2010, the U.S. FCC opened for unlicensed regional secondary use, 293 MHz of new, idle prime VHF (54-60, 76-88 and 174-216 MHz) and UHF (470-602, 620-698 MHz) spectrum resulting from the transition in the U.S. from analog to digital TV broadcasting.

Table 1 shows the TV White Space bands in the U.S., along with available spectrum, and conservative estimate of digital payload bandwidth as a function of current practical technology. The FCC allocates available White Space channels geographically and sets rules to avoid interference with existing over-the-air TV reception. Available use channels are made available via FCC-certified database suppliers.

The link below to the iConectiv.com FCC-certified database provides White Space channels available on the basis of latitude, longitude or place name. As expected, the number of available White Space channels increases as distance from urban areas increases.

Figure 1 outlines the basic channel acquisition process for a fixed White Space station. Each White Space base station acts as a channel acquisition server querying an FCC-approved database for geographically available channels.

Unlicensed White Space Spectrum

Table 1. U.S. Unlicensed TV Band spectrum estimated payload bandwidth based on 4 bits per hertz payload coding rate

<table>
<thead>
<tr>
<th>White Space Band</th>
<th>North American TV Channels</th>
<th>Frequency Range (MHz)</th>
<th>Available Spectrum (MHz)</th>
<th>Estimated Payload Bandwidth * (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF- High Band</td>
<td>2,5,6</td>
<td>54-60, 76-88</td>
<td>18</td>
<td>72</td>
</tr>
<tr>
<td>VHF - Low Band</td>
<td>7-13</td>
<td>174-216</td>
<td>47</td>
<td>188</td>
</tr>
<tr>
<td>UHF</td>
<td>14-35, 37-51</td>
<td>470-602, 620-698</td>
<td>228</td>
<td>912</td>
</tr>
</tbody>
</table>

Table 1. U.S. Unlicensed TV band spectrum estimated payload bandwidth based on 4 bits per hertz payload coding rate

Intrinsic White Space Propagation Benefits

The core advantage of using White Space spectrum is superior propagation and structure penetration as compared to operating in the 900 MHz, 2.4 and 5.8 GHz bands. Additional benefits include minimizing equipment count required to extend operation into areas and supporting applications requiring costly satellite or public carrier transactionally-priced services.
The White Space Propagation Advantage

An end-to-end (point-to-point, or multi-point) wireless White Space communications system, operating in the VHF/UHF range versus microwave (1 GHz and higher) will have a marked advantage in operating range and ability to penetrate natural and man-made ground clutter. Current licensed, cellular LTE systems operating in the 470 and 700 MHz band in the U.S. and internationally, take advantage of improved UHF propagation physics in urban and rural areas to push through and establish viable communications in high rise, dense urban complexes, and extended range suburban/rural areas.

VHF/UHF Broadband operation provides the communication planner with three intrinsic system propagation benefits over microwave spectrum (900 MHz and above):
1. A 4-5X range extension over microwave
2. Superior clutter and structure penetration
3. Near and non line-of-sight capability, especially in the low and high VHF bands.

All of which make the use of White space spectrum a serious alternative propagation option in the environs of the Marcellus Shale Play and rugged terrain regions.

Network Example

To appreciate the inherent operational benefits of White Space spectrum in a varied topology we have constructed a broadband mesh network model interconnecting five (5) actual production pads in mid-central Clinton County, PA. The basic model shown in Figure 2 contains 10 viable pad-to-pad broadband links; each link providing a payload bandwidth of 4-6 DS1s. Tables 2 and 3 below present the results of each link evaluated (using a Longley-Rice Propagation Model in an 80% forested region) for sustained reliability on the basis of Rx signal level, fade margin and spectrum availability. For example, in Figure 3, Link 1-2 between Pads 1 and 2, runs a 6.5 mile uphill stretch grazing about 1 mile of tree line. Using site antenna heights of 60 feet (20 m) and an antenna gain of 6 dBi at each site, each White Space band provides a broadband usable link with a 10 dB fade margin. Table 2 below shows, in comparison, that unlicensed operation in the 2.4 to 8 GHz spectrum presents a margin deficit which would require taller antennas and/or higher gain antennas, or a diversity system to overcome inherent path loss to achieve equivalent operation, thus increasing capital and labor deployment costs.

Figure 2. Five production pads in Clinton PA interconnected in a broadband mesh network operating over non and near line-of-sight paths using available White Space VHF and UHF spectrum.

Figure 3. 10 km grazing path between Pads 1 and 2 @ 174-216 MHz

Figure 4. Non-Line-of-Sight path between Pads 2 and 3 @ 174-216 MHz

Figure 4 illustrates inherent capability of VHF and low end UHF transmissions to tolerate reasonable path obstructions. The path between Pads 2 and 3 is obscured by gently rolling hills spanning approximately .5 Km or .3 miles obscuring an otherwise line-of-sight path. Path analysis shows that the combined VHF ground-wave and air-wave provide a potential 16.4 dB fade margin, sufficient for sustainable high payload bandwidth operation.
Tables 2 and 3 summarize the available White Space channels at each pad and RF propagation performance between each pad contrasting VHF/UHF and microwave performance.

<table>
<thead>
<tr>
<th>Link #</th>
<th>Node-to-Node</th>
<th>Range (km)</th>
<th>Range (miles)</th>
<th>Propagation Mode</th>
<th>White Space Band Signal Margin (dB)</th>
<th>Microwave Spectrum Margin (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LO-Band</td>
<td>Hi-Band</td>
</tr>
<tr>
<td>1</td>
<td>1-2</td>
<td>10.34</td>
<td>6.45</td>
<td>Grazing</td>
<td>22.9</td>
<td>15.4</td>
</tr>
<tr>
<td>2</td>
<td>1-3</td>
<td>9.30</td>
<td>5.80</td>
<td>LOS</td>
<td>25.6</td>
<td>19.3</td>
</tr>
<tr>
<td>3</td>
<td>1-4</td>
<td>8.34</td>
<td>5.20</td>
<td>LOS</td>
<td>40.0</td>
<td>27.1</td>
</tr>
<tr>
<td>4</td>
<td>1-5</td>
<td>8.49</td>
<td>5.29</td>
<td>LOS</td>
<td>37.2</td>
<td>24.7</td>
</tr>
<tr>
<td>5</td>
<td>2-3</td>
<td>2.13</td>
<td>1.33</td>
<td>NLOS</td>
<td>37.6</td>
<td>17.2</td>
</tr>
<tr>
<td>6</td>
<td>2-4</td>
<td>3.86</td>
<td>2.41</td>
<td>LOS</td>
<td>32.9</td>
<td>20.7</td>
</tr>
<tr>
<td>7</td>
<td>2-5</td>
<td>2.08</td>
<td>1.30</td>
<td>Grazing</td>
<td>39.5</td>
<td>27.8</td>
</tr>
<tr>
<td>8</td>
<td>3-3</td>
<td>2.70</td>
<td>1.68</td>
<td>LOS</td>
<td>41.6</td>
<td>36.8</td>
</tr>
<tr>
<td>9</td>
<td>3-4</td>
<td>4.84</td>
<td>3.02</td>
<td>LOS</td>
<td>38.4</td>
<td>34.1</td>
</tr>
<tr>
<td>10</td>
<td>4-5</td>
<td>2.14</td>
<td>1.33</td>
<td>LOS</td>
<td>44.6</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Table 2. Clinton PA White Space network showing usable inter-pad links, propagation mode and point-to-point signal design margin. RED TEXT INDICATES MARGIN DEFICIT.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lat</th>
<th>Long</th>
<th>LO-Band</th>
<th>Hi-Band</th>
<th>UHF</th>
<th>Total Available Spectrum (MHz)</th>
<th>Potential Payload Bandwidth (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pad 1</td>
<td>41.19814</td>
<td>-77.66617</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>138</td>
<td>552</td>
</tr>
<tr>
<td>Pad 2</td>
<td>41.21552</td>
<td>-77.78767</td>
<td>3</td>
<td>6</td>
<td>17</td>
<td>156</td>
<td>624</td>
</tr>
<tr>
<td>Pad 3</td>
<td>41.19802</td>
<td>-77.77731</td>
<td>3</td>
<td>7</td>
<td>17</td>
<td>162</td>
<td>648</td>
</tr>
<tr>
<td>Pad 4</td>
<td>41.23701</td>
<td>-77.75148</td>
<td>3</td>
<td>5</td>
<td>16</td>
<td>144</td>
<td>576</td>
</tr>
<tr>
<td>Pad 5</td>
<td>41.22001</td>
<td>-77.76347</td>
<td>3</td>
<td>6</td>
<td>17</td>
<td>156</td>
<td>624</td>
</tr>
</tbody>
</table>

Table 3. Clinton PA Pad coordinates along with available White Space channels and potential internode network payload rate.

Potential payload capacity (in megabits per second) should be used as a guide of potential capability of each link, based on total available White space spectrum at each pad.
Deploying the Network and Building a Bandplan

Today, each of these pads is in the production stage. For now, let us assume we are commencing a multi-well development process which will require, as well site development progresses, a suite of value-added voice, data and video services. Table 4 below presents the Payload Bandwidth estimation required to sustain multiple plays in various stages of development. Our goal here is to show that when backhaul White Space wireless systems are integrated with third-party communications services, i.e. satellite, common carrier (4G/LTE), point-to-point microwave and fiber, the White Space advantage provides the bridge integrating edge devices into a unified infrastructure solution.

Completing the physical design of the network we will need to determine which TV channels are available at each pad. This can be done by accessing one of several FCC-certified databases. The iConectiv database previously cited is used to determine available channels at each pad entering coordinates from Table 3; the iConectiv database will return available channels, normally at the zip code center of the target county. See Table 5 for available channels at Pad 1. Figure 1 summarizes the deployment concept of broadband mesh network interconnection in five (5) pad sites over a 222 square mile area. As a rule of thumb, the lower channels were chosen for meeting the near and non line-of-sight critical paths; higher UHF channels for near or clear line-of-sight and/or tree level paths.

<table>
<thead>
<tr>
<th>WELL SITE DEVELOPMENT STAGE</th>
<th>COMMUNICATION SERVICE REQUIREMENTS</th>
<th>NEXT GENERATION ESTIMATED MINIMUM BANDWIDTH REQUIRED (Mbps)</th>
<th>USE PERIOD</th>
<th>WHITE SPACE CHANNELS REQUIRED</th>
</tr>
</thead>
</table>
| Site Selection, Well Pad Preparation and Drilling | Drilling pad coverage area may range from 2-10 acres  
Broadband internet with support for:  
- Security Video  
- Voice connectivity  
- Corporate networking  
- Contractor networking; wire trucks, man camps, etc.  
- Independent Cell Coverage | 2-8 DS1s | 1-12 Months | TWO(2)-THREE(3) |
| Well Completion             | Pad Coverage  
- Video, Sensor Security  
- Smart Phone  
- Secure Unlicensed Wireless for PC and Tablets | 1-2 DS1s | 4-12 Months | 1 |
| Production                  |  
- Cell Coverage  
- Secure PC/Tablet Coverage  
- Security | 1-2 DS1s | Up to 40 years | 1 |
| Aqua Renew                  |  
- Cell Coverage  
- Environmental Monitoring | 1-DS1 | 3 Months | 1 |
| Well Site Reclamation       |  
- Continuous sensor monitoring | < 1-DS1  
1.544 mbps | 6 months | 1 |
Wide-Area Long Distance Coverage

White Space spectrum also provides for superior reach-out in point-to-multi-point applications. For servicing multiple locations from a common central point, e.g. Wi-Fi range extension, SCADA and VoIP and video. Figure 5 clearly shows the advantage of VHF/UHF propagation. There is a montage of WiFi unlicensed radial spectrum available in the play area example from low band VHF to 5.8 GHz. The wide-area coverage provided by the low and high VHF/UHF channels provides superior coverage over 900 MHz, 2.4 and 5.8 GHz systems allowing reach out to lowlands and terrain depressions, covering greater range and terrain variations.
SUMMARY
The additional availability of nearly 300 MHz of unlicensed spectrum and equipment will provide every sector of the energy industry, in general, and the oil and gas sectors specifically, with the resources to enhance the security and operational effectiveness of each link of the production chain. In addition, low cost, high resolution, wide-area sensor coverage, and wide-area environmental coverage will provide a quantitative basis to address uncertainty in watershed monitoring.

REFERENCES

AGENCIES AND RELATED LINKS

• U.S. Federal Communications Commission/ www.fcc.gov

• FCC CDBS (Consolidated Database System) https://licensing.fcc.gov/prod/cdbs/forms/prod/cdbs_ef.htm

• FCC ULS (Universal Licensing System) uls-gis.fcc.gov

• FCC EAS (Equipment Authorization System) (“white” list) https://apps.fcc.gov › FCC E-filing

Temporary BAS (Broadcast Auxiliary Service) links:

• https://www.google.com/get/spectrumdatabase/

• http://iconectiv.com/spectrum-mgmt/white-spaces

• http://spectrumbridge.com/tv-white-space/

• https://www.federalregister.gov/articles/2003/03/17/03-4176/broadcast-auxiliary-service-rules

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