C Spire Rural Broadband Consortium Update

TVWS Testing: Power & Morphology Analysis

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Introduction

The C Spire Rural Broadband Consortium continues to evaluate TV White Spaces (TVWS) by studying the effects of transmission power and morphology (clutter, terrain, etc.). TVWS spectrum is located within the TV broadcast band (below 700 MHz), making it shared spectrum with TV stations the primary users.

Using low frequencies typically enables signals to travel over long distances and penetrate terrain, walls, trees, and other obstacles better than higher frequency bands. The expectation is that TVWS radios can send and receive signals up to 10 miles in rural areas. [1] However, testing in various locations in Mississippi has not produced these results to date. Line-of-site (LOS) service has only been observed to about 2 miles, while non-LOS (NLOS) service can be challenging at shorter distances. One cause is the unexpectedly noisy environments experienced in the markets under test [2,3]; another cause is low transmit power.

Power and Frequency

As with other unlicensed bands (e.g. 2.4 GHz and 5.8 GHz – bands where Wi-Fi typically operates), the FCC specifies a lower allowable maximum transmission power for TVWS operations. The FCC often specifies maximum power as EIRP (Effective Isotropic Radiated Power) for each frequency band. EIRP is primarily the sum of a radio's transmitted power and antenna gain specified in dBi. The following are the maximum EIRP allowed for several bands as specified by (or calculated from) the United States Code of Federal Regulations (CFR):

- TVWS: 36 dBm (per 6 MHz) maximum EIRP (47CFR§15.709)[1]
- 2.4 GHz & 5.8 GHz: 36 dBm maximum EIRP (47CFR§15.247)[2]
- 600 MHz cellular: 62.15 dBm per MHz maximum EIRP (47CFR§27.50)[3]

As can be seen, unlicensed bands have a severe disadvantage in allowable power compared to licensed, cellular bands. In addition, unlicensed bands operate in an uncoordinated manner, which can result in interference from other nearby transmissions as a band gets more crowded, reducing overall capacity and user experience. If there is enough noise and/or interference, even transmissions with good signal levels can have poor connectivity and very low throughput. This is because many technologies need a good signal-to-noise ratio (SNR) or signal-to-interference-plus-noise ratio (SINR) to operate well. Poorly

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[1] In more congested areas, at certain co-channel and adjacent channel separation distances, with above ground and above average terrain transmit antenna height limits. 40dBm allowed for less congested areas.
[2] Calculated based on regulated conducted power and 6 dBi antenna gain. If used for fixed, point-to-point service, more antenna gain is allowed, with some limits on conducted power for 2.4 GHz, none for 5.8 GHz.
[3] Calculated from ERP regulations for height above average terrain ≤305m; 3dB higher ERP allowed in rural areas.

designed or heavily congested networks in licensed bands can also result in excessive interference and poor performance.

The Free Space Path Loss formula [4] can be used to compare the difference in propagation between bands, all else being equal. In terms of frequency alone, 600 MHz has a 12 dB advantage over 2.4 GHz. However, transmission power, environmental noise, access technologies (LTE, Wi-Fi, etc.), and multi-antenna techniques all play a part in the overall range of a signal and its ability to transmit through objects. Because unlicensed bands are required to transmit at much lower powers than licensed bands, TVWS has a much shorter range and can penetrate fewer objects than 600 MHz cellular transmissions, even though the path loss for the two bands is nearly identical for closely spaced channels.

Table 1 illustrates the difference that EIRP makes by calculating received signal strength at different distances for each band (for a 6 MHz channel). The calculations were made using the maximum allowed EIRP as listed above combined with the free space path loss formula at mid-band.[4] Signal levels need for basic connectivity and broadband speeds ultimately depend on technology, bandwidth, noise or interference, and receiver characteristics, though signals around -70 dBm and higher can generally be considered "good."

	0.5 mile	1 mile	2 miles	5 miles
600 MHz cellular	-17	-23	-29	-37
TVWS	-49	-55	-61	-69
2.4 GHz	-62	-68	-74	-82
5.8 GHz	-70	-76	-82	-90

Table 1: Received signal level (in dBm) at various distances for FCC maximum allowed EIRP

As Table 1 indicates, higher power and lower bands result in a longer range and thus a larger coverage area. Not reflected in the table is that fixed point-to-point systems using 2.4 GHz and 5.8 GHz can also transmit at higher power, which increases the range of those two bands for that type of deployment. TVWS likewise is allowed a 4 dB power increase in less congested areas.

Morphology

The free space calculation assumes a perfect LOS world with nothing blocking the signal and nothing adding to the signal (multi-path, diffraction, multiple antennas, etc.). Although a wide-open, very flat field will come close to the free space formula, most locations have clutter (trees, buildings, etc.) and terrain variation (hills and valleys). Clutter and terrain create NLOS conditions while adding loss to a signal path; those losses typically increase for higher frequencies, making NLOS operation more challenging for higher frequencies.

TVWS base stations were installed in two locations in Mississippi: Maben and Liberty. These two areas are not completely flat but not mountainous, varying less than 200 feet in elevation between the base stations and the test locations. The average elevation in Maben is around 213 feet with clutter consisting primarily of trees scattered throughout the area. As for Liberty, the average elevation is around 82 feet with clutter consisting primarily of trees with a few buildings scattered throughout. A

[4] Note that the antenna gain of the receiver also impacts received signal strength; mobile devices can have a negative gain while fixed outdoor-mounted devices have a much higher positive gain.

mix of evergreen and deciduous trees populate the area at these two locations. With respect to foliage, the maximum tree height in Liberty is 92 feet while in Maben foliage reaches to 53 feet. In Maben, clutter is typically closer to the base station within the first 1640 feet, while in Liberty, clutter is typically closer to the test point, consisting of a cluster of trees or higher terrain.

Measurements

The TVWS equipment under test has a maximum EIRP that is 4 dB less than the maximum allowed by the FCC (7 dB less than what is allowed in less congested areas). The equipment uses multi-antenna techniques and has a high-gain antenna at the receiver. Multiple downlink and uplink measurements were made at distances up to 3 miles from the base stations at Maben and Liberty. Locations LOS and NLOS to the TVWS base stations were tested for coverage and throughput. Both vertical and horizontal antenna polarizations were measured, resulting in different received signal strength for each polarization.[3] While Maben and Liberty had some of the cleaner spectrum scans and the most available channels of the six markets measured, both markets are impacted by morphology. This is reflected in the differences in received signal strength between test points that were LOS to the TVWS base station and those that were NLOS.

With the TVWS base station antennas in Maben mounted at 235 feet, seven LOS and NLOS locations from 0.2 to 2.1 miles were able to connect. NLOS test locations at 2.3 and 2.5 miles failed to connect and signal strength was not measured. In Liberty, the base station antennas were mounted at 220 feet, and eight LOS and NLOS locations were tested from 0.3 miles out to 2.5 miles from the base station. All LOS test locations connected out to 2.3 miles, but the only NLOS test point that was able to connect was at 0.3 miles. NLOS test locations at 1.3 miles and farther failed to connect.

Figure 1 compares the theoretical LOS received signal strength of the TVWS test equipment (using the free space path loss model and maximum receiver antenna gain) to the measured signals at test locations in Liberty and Maben. 520 MHz was used in the free space formula to approximate what was transmitted in both markets. The received signal strengths in the figure are a blended average of all vertical and horizontal measurements made within the distance ranges shown.

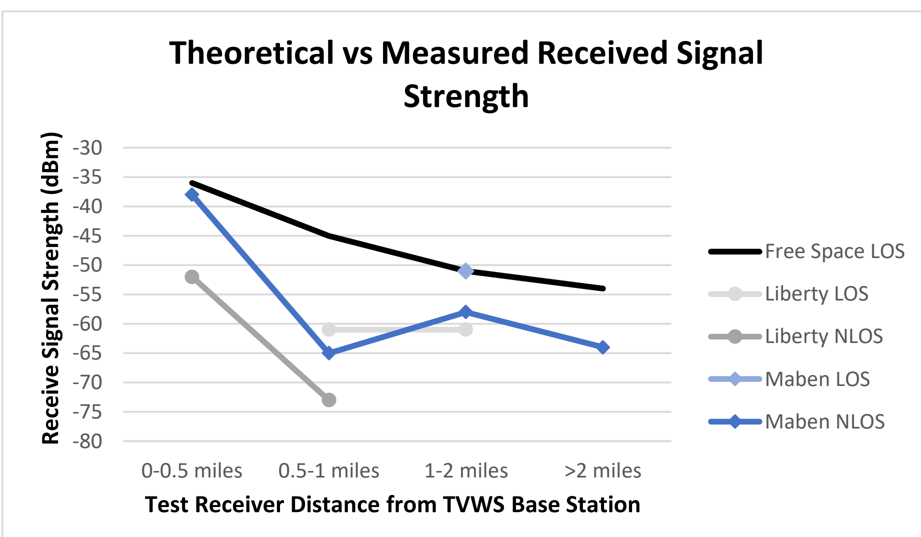

Figure 1: Theoretical and Measured Received TVWS Signal Levels Averaged at Various Distances

Maben's (limited) LOS signals are close to theoretical LOS, while Liberty's signals are significantly lower. Maben's NLOS measured signals are higher than Liberty's NLOS measurements. Given Liberty's overall lower measurements, this would indicate that Liberty is a more challenging environment in terms of morphology. This is likely due to additional terrain features that impair signals. With clutter closer to Liberty's test receiver locations, even LOS signals can be impacted. Overall in these test locations, signals less than -70 dBm prove to have problems connecting and thus providing service.

In conclusion the lower dB values for the NLOS test points results in a reduced chance of successfully receiving a transmission. The tree density and terrain in both Maben and Liberty made even TVWS signals around 520 MHz challenging to receive. While service in Maben appears to have better coverage and service at longer ranges than at Liberty, there are few potential users located within two miles of the Maben tower.

Final Thoughts

After analyzing theoretical capabilities and the realities of the test environments of Liberty and Maben, MS, one thing is becoming clear; there is more noise and clutter in those areas than low-power TVWS test equipment can overcome to achieve NLOS service out to 10 miles. TVWS does appear to be more viable out to 2 miles in those markets, depending on market morphology. While the Consortium believes there is a place for TVWS in the portfolio of rural broadband technology options, more powerful equipment and better database information would improve the chances of achieving broadband service at longer distances.

In the meantime, however, careful consideration and study of the environment, both spectrum (noise) and terrain/clutter (market profile) is necessary in order to use TVWS effectively. Some suggestions for improving the identification of usable spectrum have already been discussed [3], and it appears that using higher transmit power could help improve SNR and thus the range of TVWS.

The good news is that new TVWS radios with many advanced features, including channel aggregation, integrated CPE antennas and end to end network planning tools will be available in the next month, and the FCC has agreed to propose higher powered TVWS signals (https://www.telecompetitor.com/fccs-pai-proposes-higher-power-and-antennas-for-tv-white-spaces-broadband/), all of which will work together to improve this radio technology.

References

[1] https://blogs.microsoft.com/uploads/prod/sites/5/2018/12/MSFT-Airband_InteractivePDF_Final_12.3.18.pdf

[2] "Early TV White Space Testing," C Spire Rural Broadband Consortium bulletin, Oct. 2019.

[3] "TVWS Database vs. Environment: Spectrum Analysis," C Spire Rural Broadband Consortium bulletin, Jan. 2020.

[4] https://en.wikipedia.org/wiki/Free-space_path_loss