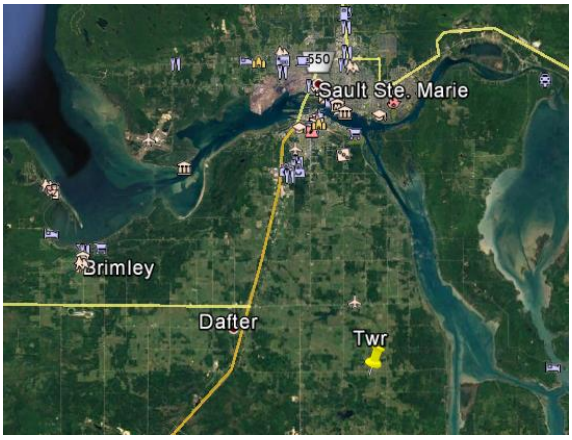
ASTREA

PROOF OF CONCEPT

Astrea (formerly Packerland/Lighthouse.net), based in Sault Ste. Marie, Michigan services the Upper Peninsula of Michigan; this service area is primarily deciduous and fir forests making it challenging to use line-of-site (LOS) unlicensed bands like 5.8GHz and 2.4GHz. To solve their non-line-of-site (NLOS) challenges they have traditionally used 900MHz spectrum. The new government requirement to provide 25Mbps downlink (DL) and 3Mbps uplink (UL) means that the 900MHz band cannot support this requirement due to the small amount of available spectrum (26MHz). So, another non-line-of-site band with more than 26MHz of spectrum needed to be considered, which opened the door for TV White Space (TVWS).



TVWS, which operates from 470MHz to 614MHz, can address the NLOS requirements and with a larger amount of available spectrum it meets the new government regulations of minimum DL and UL speeds. This band comes with its own set of challenges, but with some guidance from Redline, it can be determined if TVWS will work in your service area.

IDENTIFYING THE NEED

Astrea requires NLOS coverage 3 to 5 miles from each tower. This spectrum cannot interfere with the existing overused and noisy 900MHz spectrum but needs to complement the NLOS coverage and maybe even replace marginal 900MHz links.

The minimum downlink speed is 25Mbps and minimum uplink speed is 3Mbps.

PLANNING THE SOLUTION

Before any equipment is installed, there are basic steps that will help determine if TVWS is a good candidate for the service area.

TVWS CHANNEL AVAILABILITY

First, we perform a TVWS channel search using the TVWS database administrator, Nominet, to determine the number of available channels in the service area. Using the following link, https://usa.wavedb.com/, we enter the tower coordinates and the proposed antennas height. The maximum antenna height above ground level is 30m (100ft) and there is also a restriction on the height above average terrain of 250m (820ft).

Nominet Printout

Available Channels with Power Limits

Channel	TVWS Equipment		
	Fixed	Mode1	Mode2
2	32dBm	x	x
3	40dBm	x	x
4	40dBm	x	x
5	40dBm	x	x
6	40dBm	x	x
12	40dBm	x	x
13	40dBm	x	x
14	40dBm	20dBm	20dBm
15	32dBm	20dBm	20dBm
16	40dBm	20dBm	20dBm
17	40dBm	20dBm	20dBm
18	40dBm	20dBm	20dBm
19	40dBm	20dBm	20dBm
20	40dBm	20dBm	20dBm
21	40dBm	20dBm	20dBm
22	40dBm	20dBm	20dBm
23	40dBm	20dBm	20dBm
24	40dBm	20dBm	20dBm
25	40dBm	20dBm	20dBm
26	40dBm	20dBm	20dBm
30	40dBm	20dBm	20dBm
31	40dBm	20dBm	20dBm
32	40dBm	20dBm	20dBm
33	40dBm	20dBm	20dBm
34	40dBm	20dBm	20dBm
35	36dBm	20dBm	20dBm
36	36dBm	20dBm	20dBm
39	40dBm	20dBm	20dBm
40	40dBm	20dBm	20dBm
41	40dBm	20dBm	20dBm
42	40dBm	20dBm	20dBm
43	40dBm	20dBm	20dBm
47	40dBm	20dBm	20dBm
48	40dBm	20dBm	20dBm
49	40dBm	20dBm	20dBm
50	40dBm	20dBm	20dBm
51	40dBm	20dBm	20dBm
27	x	16dBm	16dBm
29	x	16dBm	16dBm
37	x	16dBm	16dBm
46	x	16dBm	16dBm

Nominet Printout with Unsupported Channels Removed

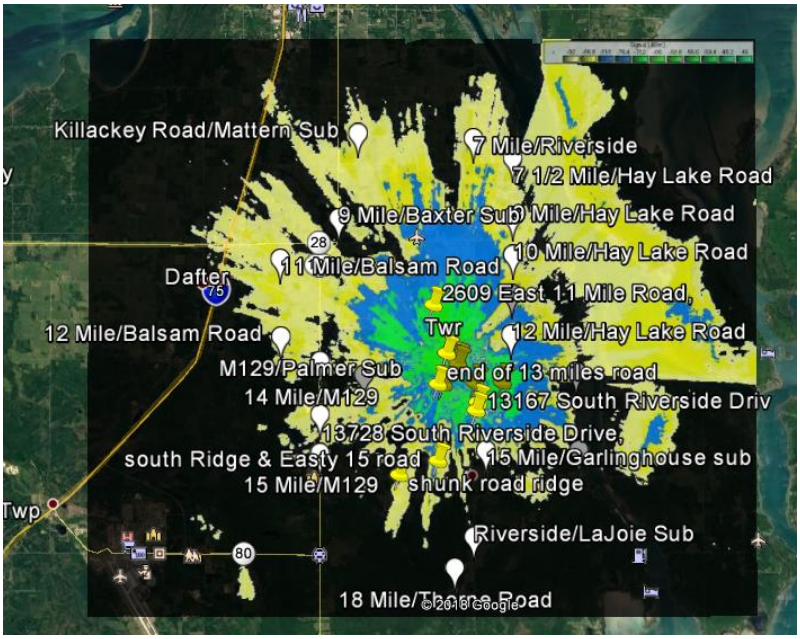
Available Channels with Power Limits

Channel	TVWS Equipment		
	Fixed	Mode1	Mode2
14	40dBm	20dBm	20dBm
15	32dBm	20dBm	20dBm
16	40dBm	20dBm	20dBm
17	40dBm	20dBm	20dBm
18	40dBm	20dBm	20dBm
19	40dBm	20dBm	20dBm
20	40dBm	20dBm	20dBm
21	40dBm	20dBm	20dBm
22	40dBm	20dBm	20dBm
23	40dBm	20dBm	20dBm
24	40dBm	20dBm	20dBm
25	40dBm	20dBm	20dBm
26	40dBm	20dBm	20dBm
30	40dBm	20dBm	20dBm
31	40dBm	20dBm	20dBm
32	40dBm	20dBm	20dBm
33	40dBm	20dBm	20dBm
34	40dBm	20dBm	20dBm
35	36dBm	20dBm	20dBm
36	36dBm	20dBm	20dBm

After adjusting the database printout to show just the supported channels that Redline TVWS radios support, the database channel search determined twenty fixed TVWS channels that are available in the service area. Although, having this many free channels does not guarantee that all channels are useable.

COVERAGE ESTIMATE

Coverage estimate is a heat map that shows receive signal levels that can be referenced to a downlink modulation level and downlink speed. Predetermined test points at the subscriber antenna test height were plotted on the map. Using this map as a guide, we can determine what estimated signal level can be received and with that information an estimated downlink modulation and speed can be determined. The map does not take noise into account; a high noise floor reduces coverage range.



FREQUENCY PLAN

Using the TVWS printout, we created a 12MHz TVWS frequency plan. The frequency plan below was adjusted after spectrum sweeps were completed.

Channel number - 6MHz	Center Frequency - 6MHz	F #	Channel Numbers - 12MHz	Center Frequency - 12MHz	Notes
14	473.00	F1	14 + 15	476	
15	479.00				
16	485.00	F2	16 + 17	488	Sector 4 - 100ft AGL
17	491.00				
18	497.00	F3	18 +19	500	
19	503.00				
20	509.00	F4	20 + 21	512	Sector 1 - 100ft AGL
21	515.00				
22	521.00	F5	22 + 23	524	
23	527.00				
24	533.00	F6	24 + 25	536	Sector 2 - 100ft AGL
25	539.00				
26	545.00	F7	26 + 27	548	
27	551.00				
28	557.00	F8	28 + 29	560	
29	563.00				
30	569.00	F9	30 + 31	572	Sector 3 - 90ft AGL
31	575.00				
32	581.00	F10	32 + 33	584	
33	587.00				
34	593.00	F11	34 + 35	596	
35*	598.50				

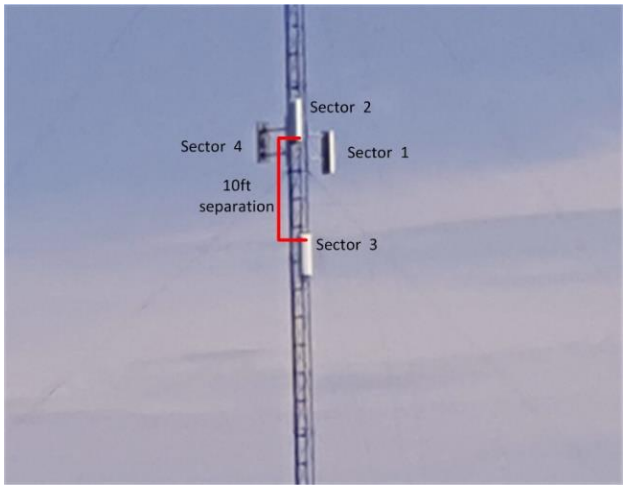
STAGING THE TVWS EQUIPMENT

We upgraded the software and pre-programmed all four base radios (Ellipses) and ten subscriber stations (Enterprise RF) with initial frequency plan and the IP plan provided by Astrea. We then ensured links could be established to each base radio and would pass data to all four base stations; each subscriber was testing against all four base radios.

After the spectrum sweeps were completed, the frequency plan was updated, and the base radio and subscriber station configurations were adjusted, as required.

DEPLOYING THE NETWORK

Sectors 1, 2 and 4 were installed at 100ft AGL with 6ft spacing. Sector 3 was installed at 90ft AGL to test adjacent and co-channel frequency plans.

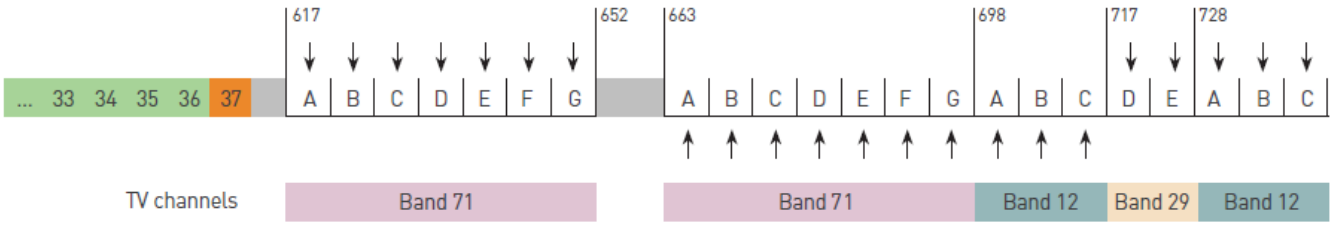


The subscriber antennas were mounted on a mast with 24” separation. This mast was then installed on a bucket truck that could go up to 30ft AGL.

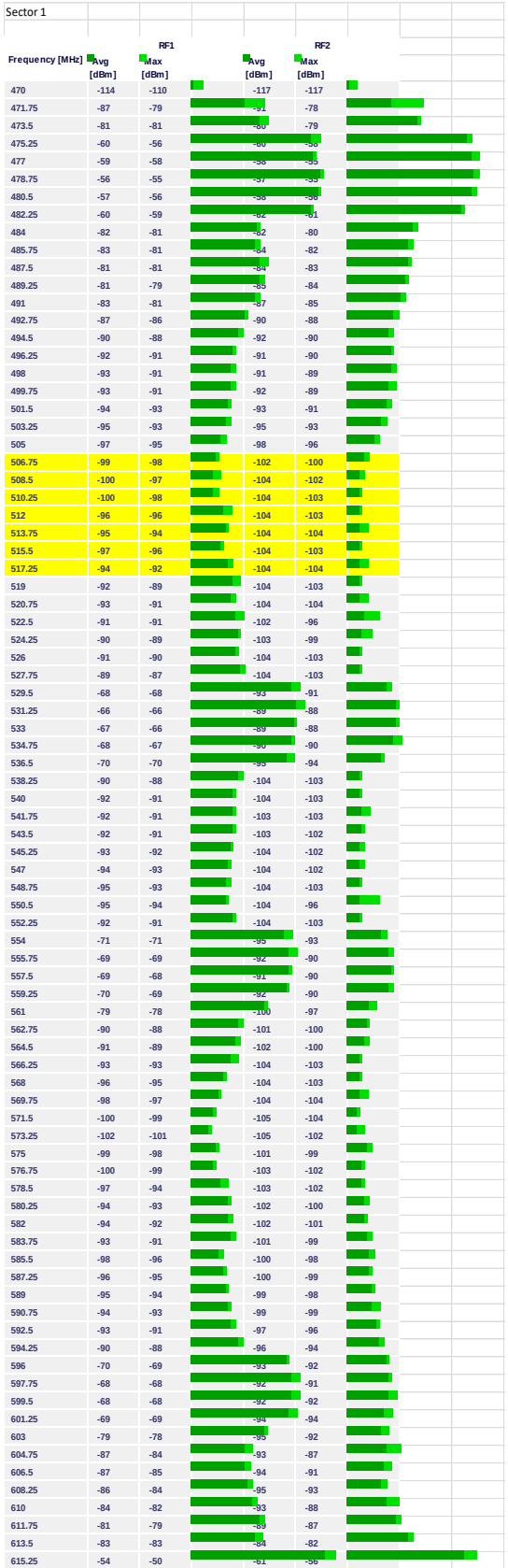
MEASURING THE SPECTRUM NOISE

Spectrum sweeps were completed after the base radios were installed on the tower using the base radio's spectrum sweep tool. The highlighted areas are where the base radios were tuned to. For actual center frequencies, please refer to the above frequency table.

We ensured the radios did not operate above channel 36 because channels 37 and higher have been allocated to the new LTE Band 71. For more information on the FCC ruling go to: http://www.spectrumgateway.com/600-mhz-spectrum.



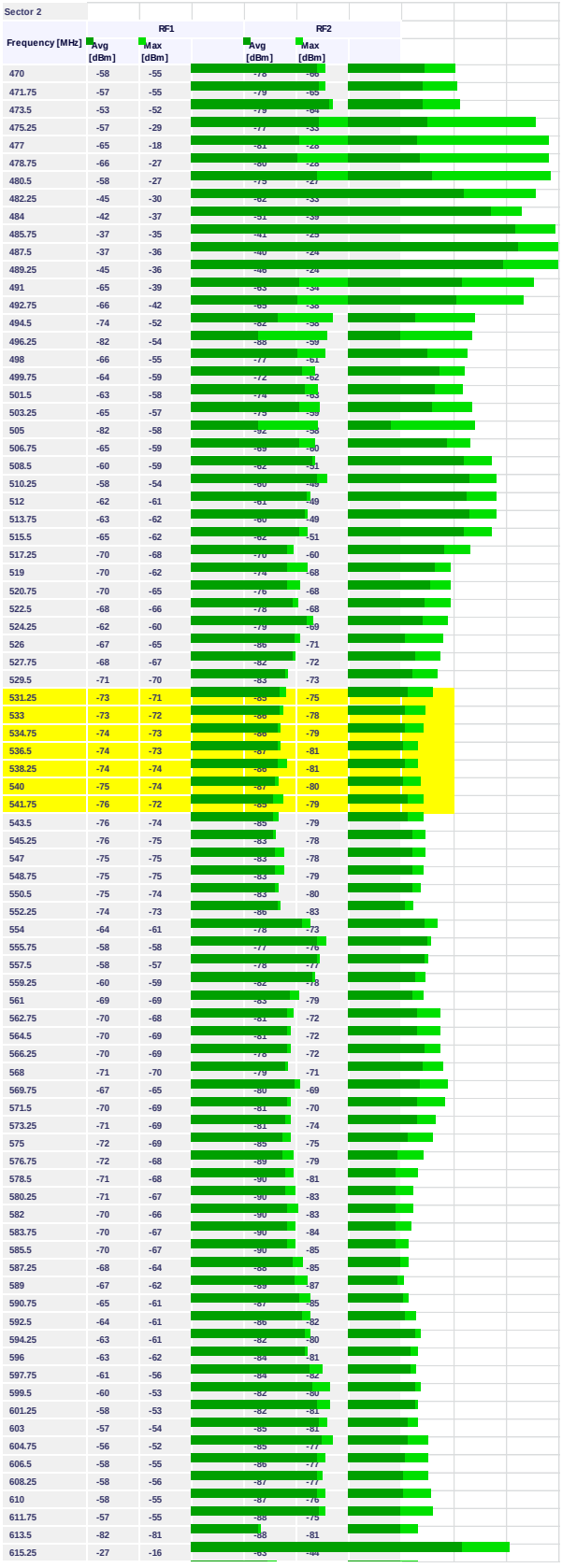
Sector 1



Sector 1

Frequency [MHz]	RF1 Avg [dBm]	RF1 Max [dBm]	RF2 Avg [dBm]	RF2 Max [dBm]
470	-114	-110	-117	-117
471.75	-87	-79	-91	-78
473.5	-81	-81	-80	-79
475.25	-60	-56	-80	-58
477	-59	-58	-58	-55
478.75	-56	-55	-57	-55
480.5	-57	-56	-58	-56
482.25	-60	-59	-82	-81
484	-82	-81	-82	-80
485.75	-83	-81	-84	-82
487.5	-81	-81	-84	-83
489.25	-81	-79	-85	-84
491	-83	-81	-87	-85
492.75	-87	-86	-90	-88
494.5	-90	-88	-92	-90
496.25	-92	-91	-91	-90
498	-93	-91	-91	-89
499.75	-93	-91	-92	-89
501.5	-94	-93	-93	-91
503.25	-95	-93	-95	-93
505	-97	-95	-98	-96
506.75	-99	-98	-102	-100
508.5	-100	-97	-104	-102
510.25	-100	-98	-104	-103
512	-96	-96	-104	-103
513.75	-95	-94	-104	-104
515.5	-97	-96	-104	-103
517.25	-94	-92	-104	-104
519	-92	-89	-104	-103
520.75	-93	-91	-104	-104
522.5	-91	-91	-102	-96
524.25	-90	-89	-103	-99
526	-91	-90	-104	-103
527.75	-89	-87	-104	-103
529.5	-68	-68	-93	-91
531.25	-66	-66	-89	-88
533	-67	-66	-89	-88
534.75	-68	-67	-90	-90
536.5	-70	-70	-95	-94
538.25	-90	-88	-104	-103
540	-92	-91	-104	-103
541.75	-92	-91	-103	-103
543.5	-92	-91	-103	-102
545.25	-93	-92	-104	-102
547	-94	-93	-104	-102
548.75	-95	-93	-104	-103
550.5	-95	-94	-104	-96
552.25	-92	-91	-104	-103
554	-71	-71	-95	-93
555.75	-69	-69	-92	-90
557.5	-69	-68	-91	-90
559.25	-70	-69	-92	-90
561	-79	-78	-100	-97
562.75	-90	-88	-101	-100
564.5	-91	-89	-102	-100
566.25	-93	-93	-104	-103
568	-96	-95	-104	-103
569.75	-98	-97	-104	-104
571.5	-100	-99	-105	-104
573.25	-102	-101	-105	-102
575	-99	-98	-101	-99
576.75	-100	-99	-103	-102
578.5	-97	-94	-103	-102
580.25	-94	-93	-102	-100
582	-94	-92	-102	-101
583.75	-93	-91	-101	-99
585.5	-98	-96	-100	-98
587.25	-96	-95	-100	-99
589	-95	-94	-99	-98
590.75	-94	-93	-99	-99
592.5	-93	-91	-97	-96
594.25	-90	-88	-96	-94
596	-70	-69	-93	-92
597.75	-68	-68	-92	-91
599.5	-68	-68	-92	-92
601.25	-69	-69	-94	-94
603	-79	-78	-95	-92
604.75	-87	-84	-93	-87
606.5	-87	-85	-94	-91
608.25	-86	-84	-95	-93
610	-84	-82	-93	-88
611.75	-81	-79	-89	-87
613.5	-83	-83	-84	-82
615.25	-54	-50	-61	-56

Sector 2



Sector 2

Frequency [MHz]	RF1 Avg [dBm]	RF1 Max [dBm]	RF2 Avg [dBm]	RF2 Max [dBm]
470	-58	-55	-78	-66
471.75	-57	-55	-79	-65
473.5	-53	-52	-79	-64
475.25	-57	-29	-77	-33
477	-65	-18	-81	-26
478.75	-66	-27	-80	-26
480.5	-58	-27	-79	-27
482.25	-45	-30	-62	-33
484	-42	-37	-51	-39
485.75	-37	-35	-41	-25
487.5	-37	-36	-40	-24
489.25	-45	-36	-46	-24
491	-65	-39	-63	-34
492.75	-66	-42	-69	-36
494.5	-74	-52	-82	-58
496.25	-82	-54	-88	-59
498	-66	-55	-77	-61
499.75	-64	-59	-72	-62
501.5	-63	-58	-74	-63
503.25	-65	-57	-75	-59
505	-82	-58	-92	-58
506.75	-65	-59	-69	-60
508.5	-60	-59	-82	-61
510.25	-58	-54	-80	-49
512	-62	-61	-81	-49
513.75	-63	-62	-80	-49
515.5	-65	-62	-82	-51
517.25	-70	-68	-70	-60
519	-70	-62	-74	-68
520.75	-70	-65	-76	-68
522.5	-68	-66	-78	-68
524.25	-62	-60	-79	-69
526	-67	-65	-86	-71
527.75	-68	-67	-82	-72
529.5	-71	-70	-83	-73
531.25	-73	-71	-83	-75
533	-73	-72	-86	-78
534.75	-74	-73	-86	-79
536.5	-74	-73	-87	-81
538.25	-74	-74	-88	-81
540	-75	-74	-87	-80
541.75	-76	-72	-83	-79
543.5	-76	-74	-85	-79
545.25	-76	-75	-83	-78
547	-75	-75	-83	-78
548.75	-75	-75	-83	-79
550.5	-75	-74	-83	-80
552.25	-74	-73	-86	-83
554	-64	-61	-78	-73
555.75	-58	-58	-77	-76
557.5	-58	-57	-78	-77
559.25	-60	-59	-82	-78
561	-69	-69	-83	-79
562.75	-70	-68	-81	-72
564.5	-70	-69	-81	-72
566.25	-70	-69	-78	-72
568	-71	-70	-79	-71
569.75	-67	-65	-80	-69
571.5	-70	-69	-81	-70
573.25	-71	-69	-81	-74
575	-72	-69	-85	-75
576.75	-72	-68	-89	-79
578.5	-71	-68	-90	-81
580.25	-71	-67	-90	-83
582	-70	-66	-90	-83
583.75	-70	-67	-90	-84
585.5	-70	-67	-90	-85
587.25	-68	-64	-88	-85
589	-67	-62	-89	-87
590.75	-65	-61	-87	-85
592.5	-64	-61	-86	-82
594.25	-63	-61	-82	-80
596	-63	-62	-84	-81
597.75	-61	-56	-84	-82
599.5	-60	-53	-82	-80
601.25	-58	-53	-82	-81
603	-57	-54	-85	-81
604.75	-56	-52	-85	-77
606.5	-58	-55	-86	-77
608.25	-58	-56	-87	-77
610	-58	-55	-87	-76
611.75	-57	-55	-88	-75
613.5	-82	-81	-88	-81
615.25	-27	-16	-83	-44

Sector 3

Sector 3

Frequency [MHz]	RF1 Avg [dBm]	RF1 Max [dBm]	RF2 Avg [dBm]	RF2 Max [dBm]
470	-66	-61	-76	-68
471.75	-66	-62	-82	-71
473.5	-59	-58	-79	-69
475.25	-34	-34	-48	-33
477	-31	-31	-44	-33
478.75	-31	-31	-42	-38
480.5	-31	-30	-42	-27
482.25	-34	-34	-45	-34
484	-84	-58	-73	-55
485.75	-76	-61	-74	-55
487.5	-69	-61	-70	-60
489.25	-68	-59	-72	-59
491	-65	-58	-72	-62
492.75	-79	-58	-78	-64
494.5	-77	-58	-81	-67
496.25	-73	-59	-79	-68
498	-78	-62	-82	-68
499.75	-77	-68	-87	-74
501.5	-71	-70	-82	-74
503.25	-72	-70	-80	-77
505	-73	-70	-83	-78
506.75	-72	-69	-78	-70
508.5	-68	-67	-71	-62
510.25	-65	-64	-66	-59
512	-68	-65	-67	-59
513.75	-68	-65	-68	-59
515.5	-74	-68	-76	-62
517.25	-72	-61	-75	-58
519	-74	-64	-80	-75
520.75	-74	-66	-83	-80
522.5	-69	-68	-82	-79
524.25	-66	-64	-66	-79
526	-69	-68	-83	-79
527.75	-73	-72	-86	-78
529.5	-72	-72	-83	-75
531.25	-58	-58	-83	-59
533	-53	-52	-80	-53
534.75	-52	-52	-80	-51
536.5	-52	-52	-80	-52
538.25	-52	-51	-80	-52
540	-54	-53	-82	-54
541.75	-71	-70	-83	-78
543.5	-71	-71	-82	-75
545.25	-72	-70	-86	-79
547	-75	-70	-83	-79
548.75	-73	-70	-85	-81
550.5	-72	-69	-84	-82
552.25	-71	-69	-83	-82
554	-61	-60	-78	-72
555.75	-58	-58	-77	-69
557.5	-58	-55	-78	-72
559.25	-59	-59	-81	-77
561	-68	-67	-82	-79
562.75	-71	-70	-83	-76
564.5	-71	-69	-82	-73
566.25	-70	-68	-79	-72
568	-73	-72	-83	-78
569.75	-68	-67	-84	-78
571.5	-72	-70	-87	-82
573.25	-78	-72	-88	-85
575	-79	-72	-89	-87
576.75	-78	-72	-89	-87
578.5	-78	-69	-90	-88
580.25	-77	-68	-90	-87
582	-76	-67	-86	-84
583.75	-75	-65	-85	-82
585.5	-74	-65	-84	-81
587.25	-73	-65	-86	-84
589	-71	-65	-86	-83
590.75	-68	-65	-84	-81
592.5	-67	-65	-82	-79
594.25	-66	-64	-83	-76
596	-64	-62	-79	-77
597.75	-62	-59	-81	-75
599.5	-61	-56	-78	-76
601.25	-61	-56	-81	-75
603	-61	-57	-84	-74
604.75	-63	-61	-86	-75
606.5	-65	-64	-87	-75
608.25	-67	-65	-87	-77
610	-62	-61	-86	-75
611.75	-63	-59	-86	-74
613.5	-83	-82	-85	-83
615.25	-28	-18	-56	-42

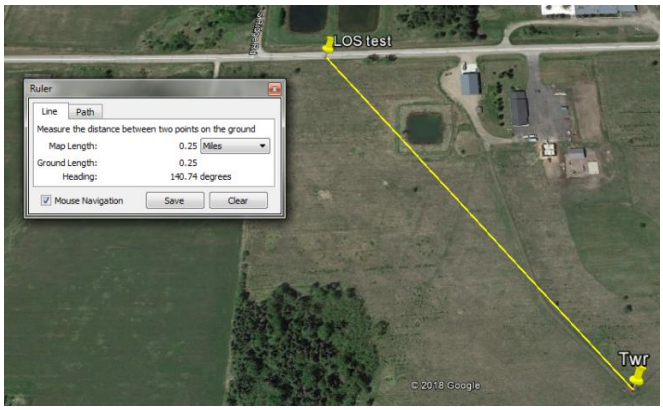
Sector 4

Sector 4

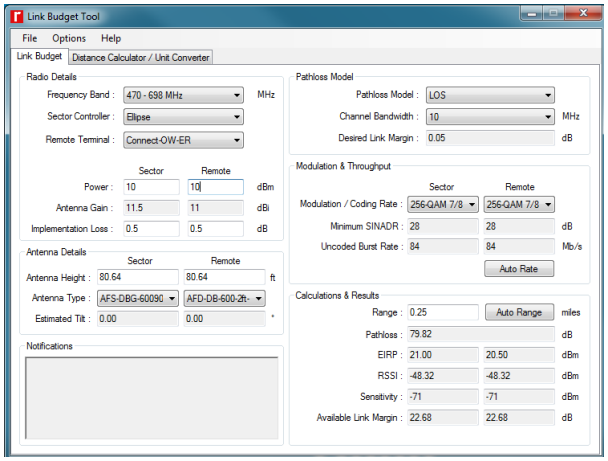
Frequency [MHz]	RF1 Avg [dBm]	RF1 Max [dBm]	RF2 Avg [dBm]	RF2 Max [dBm]
470	-82	-79	-87	-80
471.75	-77	-70	-83	-80
473.5	-78	-74	-80	-78
475.25	-53	-52	-61	-58
477	-51	-50	-57	-54
478.75	-51	-50	-56	-54
480.5	-51	-50	-57	-55
482.25	-54	-53	-63	-60
484	-79	-77	-80	-79
485.75	-78	-76	-81	-79
487.5	-81	-79	-82	-79
489.25	-82	-81	-85	-83
491	-81	-79	-84	-81
492.75	-80	-75	-82	-77
494.5	-80	-72	-81	-72
496.25	-78	-71	-78	-70
498	-77	-71	-78	-72
499.75	-77	-72	-77	-74
501.5	-76	-74	-79	-72
503.25	-75	-73	-74	-69
505	-71	-69	-74	-70
506.75	-54	-54	-52	-51
508.5	-44	-44	-41	-41
510.25	-42	-42	-39	-39
512	-42	-42	-40	-40
513.75	-41	-41	-39	-39
515.5	-43	-43	-41	-41
517.25	-53	-52	-52	-51
519	-71	-69	-75	-70
520.75	-75	-72	-74	-69
522.5	-76	-74	-76	-72
524.25	-78	-72	-78	-75
526	-78	-72	-78	-77
527.75	-79	-72	-79	-76
529.5	-62	-62	-82	-79
531.25	-59	-58	-82	-81
533	-59	-58	-84	-82
534.75	-60	-59	-86	-82
536.5	-65	-64	-82	-78
538.25	-82	-81	-81	-75
540	-81	-79	-82	-79
541.75	-80	-78	-82	-78
543.5	-79	-76	-84	-78
545.25	-79	-76	-82	-78
547	-79	-75	-84	-78
548.75	-80	-78	-82	-79
550.5	-83	-80	-76	-68
552.25	-80	-74	-75	-68
554	-78	-69	-77	-65
555.75	-75	-68	-80	-67
557.5	-75	-68	-82	-65
559.25	-76	-73	-82	-65
561	-83	-68	-82	-66
562.75	-85	-68	-82	-67
564.5	-84	-68	-81	-68
566.25	-84	-69	-83	-70
568	-85	-70	-86	-73
569.75	-86	-69	-84	-71
571.5	-86	-72	-83	-75
573.25	-81	-78	-83	-79
575	-81	-78	-83	-83
576.75	-82	-78	-87	-86
578.5	-79	-69	-90	-88
580.25	-79	-68	-93	-84
582	-79	-68	-86	-83
583.75	-75	-71	-79	-73
585.5	-76	-74	-78	-72
587.25	-79	-78	-81	-75
589	-83	-78	-84	-81
590.75	-83	-78	-87	-85
592.5	-81	-75	-90	-85
594.25	-81	-78	-91	-86
596	-72	-71	-90	-86
597.75	-70	-69	-85	-83
599.5	-69	-68	-81	-81
601.25	-70	-70	-79	-79
603	-77	-74	-78	-76
604.75	-79	-77	-78	-75
606.5	-81	-76	-79	-75
608.25	-80	-77	-80	-75
610	-80	-76	-82	-77
611.75	-85	-68	-84	-82
613.5	-84	-84	-85	-81
615.25	-44	-41	-74	-63

LINE-OF-SITE (LOS) TEST

Before starting any NLOS tests, a LOS test was performed to ensure the subscriber station set-up was working as expected. A LOS point was selected that had full view of the tower. See Google Earth diagram and picture of the tower with line-of-site below.



We use a Link Budget Tool calculate the expected DL and UL modulation. We lowered the transmit power to ensure the system was not overdriven. The test link was set up and measured RSSI within +/- 3dB of calculated RSSI. Once the LOS test was completed, the transmit power was returned to 20dBm per RF port.



CONNECTION ISSUES

When the NLOS tests were started, we encountered link connection issues. Initially we thought it was noise; however, during one of the tests, the following alarm in the system log file came up:

06/19/2018	20:39:53	1043 - ID "Sector1_15EFCA" (11) defined: OK
06/19/2018	20:39:53	1043 - ID "Sector1 Service_15EFCA" (167) defined: OK
06/19/2018	20:40:02	1074 - Link (11) [00:09:02:15:EF:CA]: UP
06/19/2018	20:59:39	2085 - Link (11) [00:09:02:15:EF:CA]: ERROR
06/19/2018	20:59:42	1047 - MAC Initialization: OK
06/19/2018	20:59:44	1035 - ID "Sector1 Service_15EFCA" (167) deleted: OK
06/19/2018	20:59:44	1035 - ID "Sector1_15EFCA" (11) deleted: OK

This link error message occurs when the base station is subjected to high interference. We determined the high interference was coming from the neighboring sector antennas. To correct this issue, all four sectors were changed to fixed frame and synced using the integrated GPS antenna in each sector antenna. The following fix frame settings, used on all four base stations, was 10msec frame size with a 75% downlink ratio. Also, we made sure “Max. Distance” and “Management MCS” was set the same on all base stations.

We determined that adjacent frequency plan between sector 3 and sectors 1, 2, and 4 worked fine as long as all sectors were running in fixed frame mode with GPS sync. The co-channel test did not work at all, even with fixed frame mode with GPS sync enabled. It was determined the sector antennas being used did not have enough side lobe isolation to support this type of channel plan.

LESSONS LEARNED

Enable fixed frame with GPS sync with multi-sector deployments.

Co-channel frequency plan is not recommended on the same tower with the available antennas on the market.

Perform spectrum analysis at height to determine any real life “noise” in the area beyond the database listing of unusable channels.

Subscriber connections need to be 16QAM minimum connectivity to maintain an acceptable margin of fade.

REALIZING A SUCCESSFUL OUTCOME

Once fixed frame with GPS sync was enabled, the issues with connecting to the base station radios were cleared. We successfully tested as far as 5 miles NLOS and were able to achieve downlink speeds from 25 to 35Mbps.

Astrea continued testing with friendly subscriber(s) sites and different subscriber antennas panels for another 3 to 4 weeks.

The TVWS system has moved from proof of concept to a commercial network. Astrea is planning to rollout Redline’s TVWS technology throughout their network.