Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	**Estimates of the Horizon Distance at 3.5 and 10.5 GHz**
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Re:	Coexistence pfd Simulation Estimates in Support of 802.16a System Design
Abstract	This document estimates the horizon distance at both 3.5 and 10.5 GHz. It identifies the distance limits for which coordination may be required between system operators. The conclusions are specific to the system parameters selected. Other system model parameters may modify the distance coordination requirements.
Purpose	This document is provided for consideration and inclusion in the amended Coexistence Practice Document for PMP systems operating below 11 GHz (P802.16.2a).
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Estimates of the Horizon Distance at 3.5 and 10.5 GHz

1.0 Introduction

In [1], Table 12 identifies the radio horizon distance for EHF frequencies assuming relative antenna elevations from 10 m to 90 m. The table assumed normal refractive index parameters (K = 4/3) and only involved the geometry for a spherical earth given relative antenna elevations. This is valid for EHF frequencies since, for the very small Fresnel zone sizes involved, you are either LOS or blocked.

However for sub-11 GHz transmission, Fresnel zone sizes are much larger and there is thus some finite value of diffraction loss beyond the horizon. So, one might realistically ask - just where in heck is the horizon? This contribution estimates diffraction loss for 10/90 m antenna heights at separation distances of 60, 70 and 80 km.

2.0 Estimation Method

For a radio signal ray tangent to the surface of a spherical earth, there are three field strength regions. These are:

- The interference region above the signal ray tangent where LOS transmission applies.
- The near vicinity of the signal ray tangent known as the "intermediate region (see Note 1).
- The well beyond the horizon distance diffraction loss region (see Note 2).

This contribution examines only diffraction based on the CCIR empirical equation methods given in [2]. The computations exclude the influence of the electrical characteristics of the surface of earth on diffraction loss (surface admittance). Strictly speaking, they thus apply only to horizontal polarization where the admittance factor is quite small.

3.0 Estimation Results

Tables 1 through 3 summarize the computational results for 3.5 GHz diffraction loss at link distances of 60, 70 and 80 km. As indicated by the tables, the combinatorial values for antenna elevation’s range from 10 to 90 m. Tables 4 through 6 illustrate the results for 10.5 GHz.

The diffraction loss results are expressed as the excess loss to be expected relative to the LOS free space loss to be expected at some given link distance. For some combinations of antenna heights, the empirical equations tend to "blow up" and indicate that the field strength would be greater than LOS. For such combinations, the diffraction loss entries have been just set to zero.

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	63.5	55	49	44	40	36	32.5	29	26
20	55	47	40.5	35.5	31.5	27.5	24	21	18
30	49	40.5	34.5	29.5	25	21.5	18	14.5	11.5
40	44	35.5	29.5	24.5	20.5	16.5	13	10	6.5
50	40	31.5	25	20.5	16	12	8.5	5.5	2.5
60	36	27.5	21.5	16.5	12	8.5	5	1.5	0
70	32.5	24	18	13	8.5	5	1.5	0	0
80	29	21	14.5	10	5.5	1.5	0	0	0
90	26	18	11.5	6.5	2.5	0	0	0	0

Table 1. Diffraction Loss at 3.5 GHz (Di = 60 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	77	68.5	62.5	57.5	53.5	49.5	46	42.5	39.5
20	68.5	60.5	54	49	45	41	37.5	34.5	31
30	62.5	54	48	43	39	35	31.5	28	25
40	57.5	49	43	38	34	30	26.5	23	20
50	53.5	45	39	34	29.5	25.5	22	19	16
60	49.5	41	35	30	25.5	22	18.5	15	12
70	46	37.5	31.5	26.5	22	18.5	15	11.5	8.5
80	42.5	34.5	28	23	19	15	11.5	8.5	5
90	39.5	31	25	20	16	12	8.5	5	2

Table 2. Diffraction Loss at 3.5 GHz (Di = 70 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	90.5	82	76	71	67	63	59.5	56	53
20	82	74	67.5	62.5	58.5	54.5	51	47	44.5
30	76	67.5	61.5	56.5	52.5	48.5	45	41.5	38.5
40	71	62.5	56.5	51.5	47.5	43.5	40	36.5	33.5
50	67	58.5	52.5	47.5	43	39	35.5	32.5	29.5
60	63	54.5	48.5	43.5	39	35.5	32	28.5	25.5
70	59.5	51	45	40	35.5	32	28.5	25	22
80	56	47	41.5	36.5	32.5	28.5	25	22	18.5
90	53	44.5	38.5	33.5	29.5	25.5	22	18.5	15.5

Table 3. Diffraction Loss at 3.5 GHz (Di = 80 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	81.5	70.5	62	55	49	43.5	38.5	34	29.5
20	70.5	59	51	44	38	32.5	27.5	22.5	18
30	62	51	42.5	35.5	29.5	24	19	14.5	10
40	55	44	35.5	28.5	22.5	17	12	7.5	3
50	49	38	29.5	22.5	16.5	11	6	1.5	0
60	43.5	32.5	24	17	11	5.5	.5	0	0
70	38.5	27.5	19	12	6	.5	0	0	0
80	34	22.5	14.5	7.5	1.5	0	0	0	0
90	29.5	18	10	3	0	0	0	0	0

Table 4. Diffraction Loss at 10.5 GHz (Di = 60 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	101.5	90	82	75	69	63.5	58.5	53.5	49
20	90	79	70.5	63.5	57.5	52	47	42.5	38
30	82	70.5	62	55.5	49	44	38.5	34	29.5
40	75	63.5	55.5	48.5	42.5	37	32	27	22.5
50	69	57.5	49	42.5	36.5	31	25.5	21	16.5
60	63.5	52	44	37	31	25.5	20.5	15.5	11
70	58.5	47	38.5	32	25.5	20.5	15	10.5	6
80	53.5	42.5	34	27	21	15.5	10.5	6	1.5
90	49	38	29.5	22.5	16.5	11	6	1.5	0

Table 5. Diffraction Loss at 10.5 GHz (Di = 70 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	121	110	101.5	94.5	88.5	83	78	73.5	69
20	110	98.5	90.5	83.5	77.5	72	67	62	57.5
30	101.5	90.5	82	75	69	63.5	58.5	54	49.5
40	94.5	83.5	75	68	62	56.5	51.5	47	42.5
50	88.5	77.5	69	62	56	50.5	45.5	40	36.6
60	83	72	63.5	56.5	50.5	45	40	35.5	31
70	78	67	58.5	51.5	45.5	40	35	30.5	26
80	73.5	62	54	47	40	35.5	30.5	25.5	21.5
90	69	57.5	49.5	42.5	36.5	31	26	21.5	17

Table 6. Diffraction Loss at 10.5 GHz (Di = 80 km)

4.0 Comments

In a number of prior boundary coexistence simulations, it has been found that coordination between operators would be required up to the distance where diffraction loss reduces the interference levels so that they apply to only a small percentage of interference exposures. In these contributions, it has been "alluded to" that the horizon is "somewhere between" 60 to 80 km. So, we are back to the initial question - just where is the horizon?

Well, the answer would seem to be - take your pick! If we assume a typical CS antenna elevation to be 60 m and a typical TS elevation to be between 10 and 30 m, then the diffraction loss is a minimum of 21 dB at 3.5 GHz at a separation distance of 60 km. However, if we were to pessimistically assume that we have two CS antennas, both at a 90 m elevation, then we need a separation distance of 80 km to obtain a diffraction loss of 15 dB at 3.5 GHz.

We could go on and on, and assume that one of the terminals is located on top of the CN or Sears towers. But, such assumptions require that we engineer to the extreme tail of the diffraction loss estimates. These extreme situations should be dealt with on a case by case basis. Hence, it is concluded that 80 km is a rational practical distance to establish for coordination between operator boundaries.

Readers should note that the reference separation distance D employed in prior simulations does not necessarily conform to the boundary distance employed by regulatory agencies. D is always set to be the distance between base stations. Critical pfd values are identified relative to the interference link distance Di, as is their relationship to C/N or C/I. If we think in terms of two cells of radius R, one of which just touches at the boundary, then the distance relationships are as given by Table 7. Table 7 assumes a boresight alignment of the interference link and TS locations at cell edge.

TS to CS or CS to TS Interference Distance Di	CS to CS Interference Distance Di	Regulatory Distance from Cell Center to Boundary
D + R	**D**	**D-R**

Table 7. Distance Relationships for Cells Centers Separated by Distance D

5.0 Notes

Note 1: Reference [3] provides an interesting discussion of the intermediate region.

Note 2: Reference [2] does not appear in the current listing of ITU-R.P active recommendations. It may be masquerading under a different name. Another frequently cited reference on diffraction loss is reference [4] however, it would seem to be long out of print.

6.0 References

[1] IEEE Standard 802.16.2 (Coexistence of Fixed Broadband Wireless Access Systems), Sept. 10, 2001.

[1] Propagation by Diffraction, CCIR Rec. 526-1 (Report 715-2).

[2] L. V. Blake, Radar Range-Performance Analysis, Artech House, 1986.

[3] P. L. Rice et al., Transmission Loss Predictions for Tropo Scatter Communication Circuits, NBS Technical Note 101, 1965.