Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Coexistence Co-Channel Boundary pfd Simulations at 10.5 GHz (Inbound). Revision 1.**
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Re:	Coexistence pfd Simulation Estimates in Support of TG3 System Design
Abstract	This document examines inbound pfd requirements at 10.5 GHz. It identifies the distance limits for which coordination may be required between system operators. The conclusions are specific to the system model selected. Other system model parameters may modify the distance coordination requirements. This revision corrects text and Figure errors identified in the original contribution. Coordination via cross polarization reassignment has been added.
Purpose	This document is provided to TG2a for consideration and inclusion in the amended Coexistence Practice Document for PMP systems operating below 11 GHz.
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Coexistence Co-Channel pfd Boundary Simulations at 10.5 GHz (inbound)

1.0 Introduction

This document examines inbound power flux density interference levels (pfd), and related distance requirement separations, that may be required for coordination between PMP service operators who operate in an adjacent area/same frequency environment. Using Monte Carlo simulation techniques, a computational analysis is developed to identify the percentage of inbound link exposures that may require coordination between operators who operate co-channel in adjacent geographical areas.

For any radio systems engineering design, all things flow from the transmission link budget. Thus, this report is required to make assumptions with respect as to what are expected to be *typical* equipment parameters. As well, this report is required to make assumptions as to what is an acceptable objective for link availability, and hence, what are the *constraints* that must be assigned to the operational channel propagation model. Different assumptions should be expected to result in different conclusions.

2.0 Simulation Channel Model

At 10.5 GHz, there are many propagation parameters that can factor into the system analysis. Atmospheric Rayleigh multipath must be considered even for paths of modest length. If transmission links are diffracted or experience excess loss from man made or natural obstacles, then an excess loss beyond LOS must be accounted for. If transmission paths are just above, or penetrate, the urban foliage canopy, then it should be expected that a Rician fading component must be included in the transmission availability analysis.

TG3 have identified a baseline availability objective of 99.99% @ BER=10^{-6}. The corresponding TG3 link distance for these objectives is a maximum cell radius of R = 7 km.

Designing diffracted 10.5 GHz transmission links can be quite risky. It requires a very accurate estimate of topographical obstacle height and a hope that the vegetation will not grow. It is therefore excluded from the link analysis. Based on what are concluded to be *cost effective* equipment transmission parameters, the link budget also does not allow for any Rician fading. If the link analysis was to assume any significant magnitude of excess path loss, and then victim links would be expected to experience significant delay spread and hence ISI from minimum and non-minimum phase echoes. As the channel model assumes clear LOS propagation, hence a relatively strong primary signal strength, it is assumed that echo signals are minimal, and hence delay spread can be ignored. Victim links are therefore assumed to be clean LOS up to R = 7 km.

Interference TS to CS links are also assumed to be LOS up to R =7 km. Beyond this distance, they are assumed to have a propagation distance loss exponent (d^{-x}) of:

$-d^{-2}$: LOS all the way.

$-d^{-2}$ to 7 km, d^{-4} beyond.

-d^{-2} to 7 km, random assignment of d^{-2} or d^{-4} beyond.

All three-channel models for pfd interference estimates are considered in the following simulation analysis.

3.0 Simulation Transmission Parameters

For coexistence simulation estimates, it is necessary to identify what might be assumed to be "typical equipment and system parameters" and subsequently identify interference levels that would impact on a victim link performance availability. These are summarized as follows:

Propagation Models:	as per section 2
Atmospheric Multipath Model:	Vigants-Barnett (annual - 2 way)
Rician Fading Model:	Erceg (TG3 - 2 way)
Rain Fade Model:	ITU, Rain Region K
Maximum Cell Radius:	7 km
Channel Bandwidth:	5 MHz
TS TX Power:	+20 dBm
CS TX Power:	+26 dBm
TS Antenna Gain:	+25 dBi
CS Antenna Gain:	+16 dBi
Receiver Noise Figure:	5 dB
TX/RX RF Losses:	3 dB at each end
Link Availability:	99.99% @ BER=10^{-6}
Modulation Index Options:	4/16/64 QAM
Receiver C/N Threshold:	12 dB/18 dB/24 dB for the respective modulation indices

The preceding are incorporated into an inbound link budget for 4-QAM (Table 1). Based on the parameter assumptions, link budget estimates indicate that the modulation index is limited to 16-QAM outbound and 4-QAM inbound. As discussed in Section 2, the link budget cannot support excess diffraction loss, nor can it cater to excess loss or Rician fading resulting from foliage penetration. All victim links are therefore assumed to be LOS up to 7 km.

PARAMETER	NAME		V-POL	H-POL	UNITS
Location	**New York**				
Modulation	mod4	4 QAM			
Symbol Rate	fs	4			
Noise Figure	nf	5			dB
Frequency	f0	10.5			GHz
Path Length	r0	7			km
CCIR .01% Rain Rate	rr01ccir	42			mm/hr
Rice Factor	Kr	20			dB
TX Pwr/Cxr (clear sky)	ptx		20.00	20.00	dBm
Power Control	pcr		0.00	0.00	dB
TX Transmission Line Loss			0.00	0.00	dB
TX Branching Network Loss			-3.00	-3.00	dB
TX Antenna Gain	gsub		25.00	25.00	dBi
EIRP (clear sky)			42.00	33.00	dBm
EIRP (rain)			42.00	33.00	dbm
FSL to Distance R0			-129.73	-129.73	dB
Excess Loss to edge of coverage Rmax			0.00	0.00	dB
Atmospheric Absorption	aabsorb		-0.10	-0.10	dB
Foliage Loss			0.00	0.00	dB
Structure Loss			0.00	0.00	dB
Rx Antenna Gain	gbase		16.00	16.00	dBi
RX RF Losses			-3.00	-3.00	dB
RX Signal Level (clear sky)			-74.83	-74.83	dBm
RX Noise Level	n0		-102.98	-102.98	dBm
C/N (clear sky)	cnrcsv/h		28.15	28.15	dB
Required C/(N+I) for BER=E-6	cnir_E6		12.00	12.00	dB
C/I (HPA Intermod -clear sky)	hpaim		100.00	100.00	dB
C/I (adj-channel)	ciadjcs		100.00	100.00	dB
C/I (co-channel)	cicocs		100.00	100.00	dB
C/I Total	citotalcsv/h		95.23	95.23	dB
C/(N+I) (clear sky)	cnircsv/h		28.15	28.15	dB
Allowed C/N at Threshold	cnthreshv/h		12.00	12.00	dB
Fade Margin (clear sky)	margincsv/h		16.15	16.15	dB
C/I (HPA Intermod -rain)	hpaim		100.00	100.00	dB
C/I(adj-channel) plus Rain XPD	ciadjr		100.00	100.00	dB
C/I(co-channel plus Rain XPD)	cicor		100.00		dB
C/I Total	citotalv/h		95.23	96.99	dB
C/(N+I) (rain)	cnirrv/h		28.15	28.15	dB
Allowed C/N at Threshold	cnthreshrv/h		12.00	12.00	dB
Fade Margin (rain)	marginrainv/h		16.15	16.15	dB
Annual Availability (clear sky)-2 Way	availcsv_a_		99.99548	99.99548	%
Annual Availability (rain)	availrv/h_a		99.99966	99.99933	%
Annual Availability (Rice)-2 Way	avail_rice		100.00000	100.00000	%
Total Annual Availability			99.99514	99.99481	%
Outage			0.42560	0.45421	hrs

Table 1. Inbound Link Budget for 4-QAM @ 10.5 GHz

Table 1 indicates that the defining constraint on link availability up to 7 km is atmospheric multipath fading. Excess path loss and Rician fading have been excluded. While rain attenuation can be a performance issue for long paths at 10.5 GHz, it has not been identified to be significant for paths as short as 7 km.

Table 1 essentially excludes any allowance for either intra-system or inter-system interference. This later item is addressed in subsequent sections of this document.

4.0 Antenna RPE

Estimates of inter-system interference levels are influenced by the antenna gain discrimination provided by the TS and CS antennas as a function of angular offset. Prior coexistence studies for LMCS/LMDS have indicated that this discrimination is not critical as long as the antenna RPE patterns are *respectable*. Figures 1 and 2 illustrate the azimuth RPE patterns from measured data for *representative* 10.5 GHz RPE patterns employed in this study. This subject is still under study by TG2a.

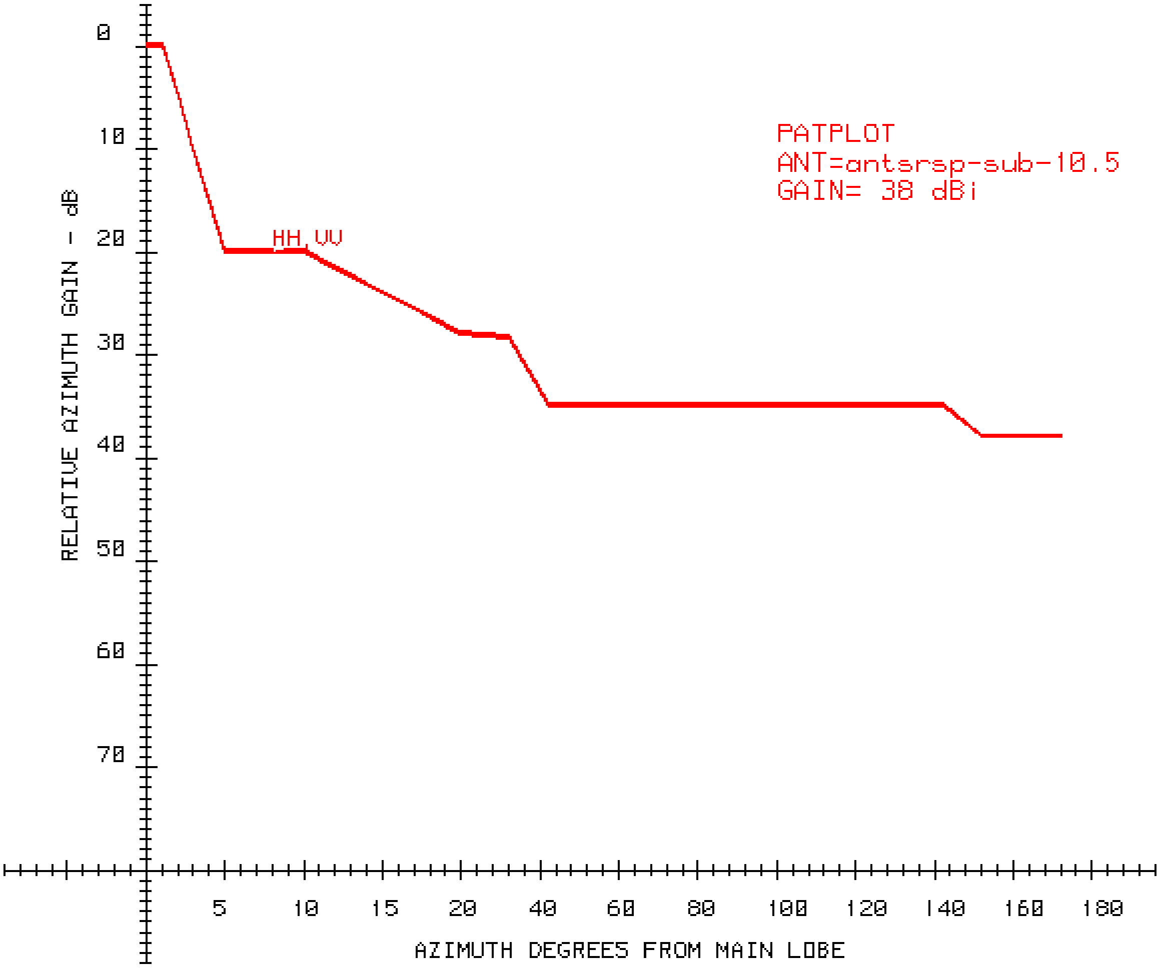

Figure 1. Representative TS Antenna RPE (corrected).

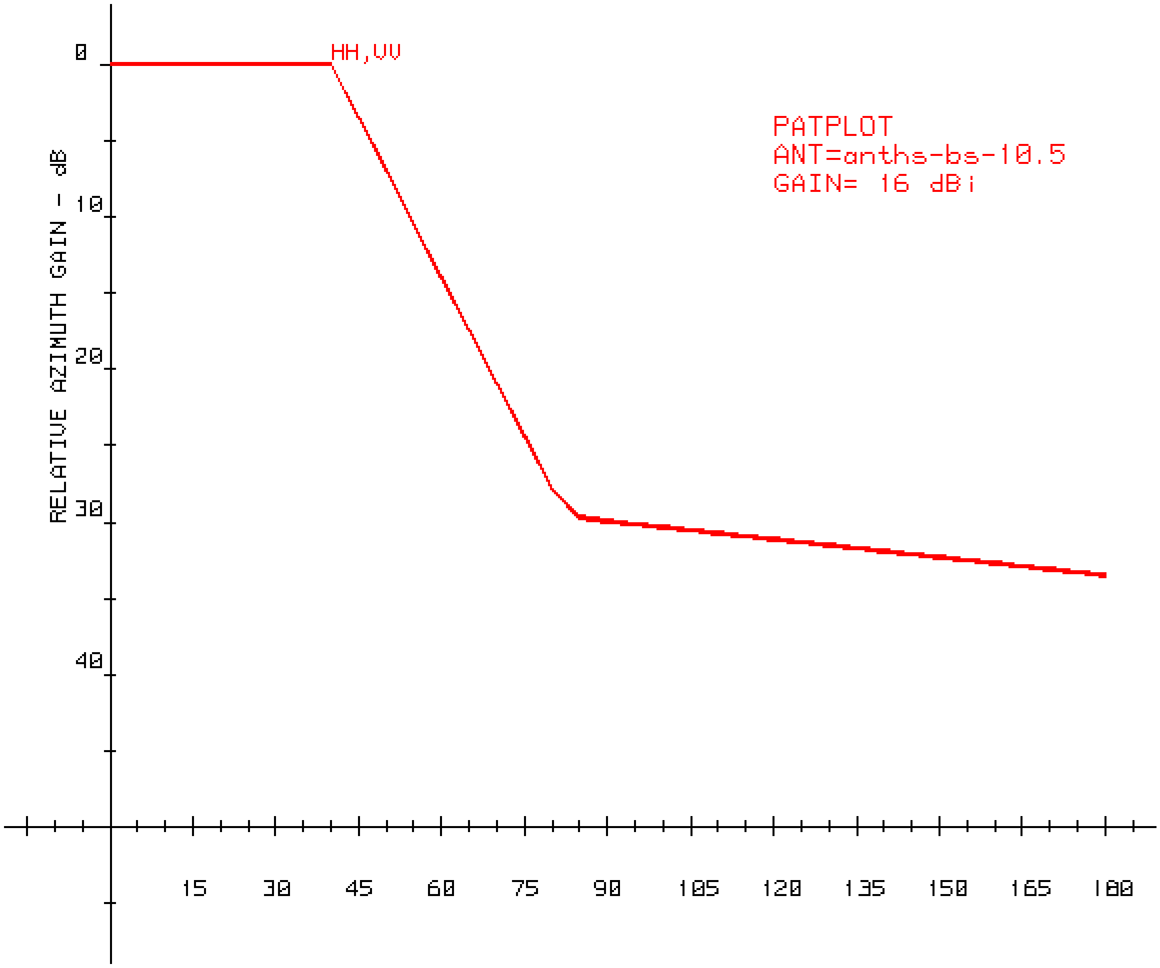

Figure 2. Representative CS Antenna RPE.

5.0 Limiting pfd Considerations

A major problem with identifying limiting pfd objectives is the difficulty of selecting what are *likely* to be transmitter EIRP values as opposed to what are *regulatory allowed* EIRP levels. These can often differ by one or more orders of magnitude. The choice of modulation index and channel bandwidth further compounds the problem due to the almost limitless number of combinatorial relationships that can be established. Never the less, we will just push on, based on a *rash* assumption that the *selected* link parameters are *reasonable*.

Hence, referenced to the link budget described in Table 1, it may be noted that there is a fade margin of FM=16 dB available up to the specified link availability limit. It is assumed that inbound links will employ inbound distance-proportional ATPC to resolve near/far signal level differentials. At cell edge, it would be expected that unfaded clear sky ATPC would be somewhere between 0 and 10 dB. Both limiting values are subsequently considered in the coexistence simulations.

It may be instructive to relate subsequent simulation pfd estimates to critical C/N and C/I values that have been identified in the link budget described in Table 1. These are summarized in Table 2. Please note that the relationships require developing an *equivalent* pfd for both desired signal and noise at the input to an isotropic receiver antenna. All numbers are rounded. From Table 2, it may be noted that critical pfd levels of interest fall - 117 dBW/m^2/MHz or greater. Note that these conclusions are coupled to the link budget assumptions.

Parameter	Value
$(C/N)_{threshold}$ QPSK	12 dB
pfd_sig_threshold	-99 dBW/m^2/MHz
$(C/N)_{unfaded}$ QPSK (FM=16 dB) - without ATPC	28 dB
pfd_sig_unfaded - without ATPC	-83 dBW/m^2/MHz
effective pfd_noise	-111 dBW/m^2/MHz
$(C/I)_{1\text{ dB threshold impairment}}$ (I/N=-6 dB)	18 dB
Pfd_int_1dB (I/N=-6 dB)	-117 dBW/m^2/MHz

Table 2. C/N, C/I and pfd Relationships (corrected).

6.0 Simulation Methodology and Results

Figure 3 illustrates the simulation model. Two co-channel sectors are exposed to each other across a boundary. To maximize pfd levels, TS locations are located on the periphery of the sectors. The distance between the CS locations is D and the distance from an interference TS to the victim CS is D_i. Twenty-randomly selected angular locations are set for the interference TS interference positions and each establish some angle φ relative to their boresight position and the victim CS. This establishes the TS antenna angular discrimination to be expected from a specific interference link.

As the operator assignments for sector location are assumed to be uncoordinated, the victim link CS boresight angle is set at some value α and the interference CS boresight is set at some value β. Angle α establishes the RPE antenna discrimination to be expected from the victim CS link.

To complete a simulation, both CS boresight angles are independently incremented in 5 degree spin intervals. For each spin, the worst C/I estimate is computed from the 20 interference locations and entered into a database. For each CS spin, the locations of the interference TS positions are modified by changing the random number seed. A simulation, parameterized against D, thus consists of 5184 interference level estimates. These values are sorted to provide a cumulative distribution function (CDF) estimate of pfd vs D.

As previously noted, the pfd estimates apply to levels to be expected at the interference CS, not at the boundary. Consequently, there is a pfd trigger discrepancy that reduces as D increases. If we consider the cells to just touch at the boundary, then D = 2R, R being the cell radius. For R = 7 km, D = 14 km which would be the minimum distance that could be considered. Under this condition, critical TS to CS boresight alignments are at approximately 3R = 21 km. At this distance, pfd levels are very excessive. Hence, the simulations restrict the coordination distance range from D=20 to 80 km. For two 90 m antennas, the horizon distance is 78 km [1].

Thus, 80 km would seem to be a reasonable distance at which to truncate the simulations. For a spherical earth and a typical K=4/3 earth radius, propagation loss beyond the horizon involves both a transition region followed by the tropo-scatter region. Additional interference transmission losses, and related distances in these regions, have not been considered in the following.

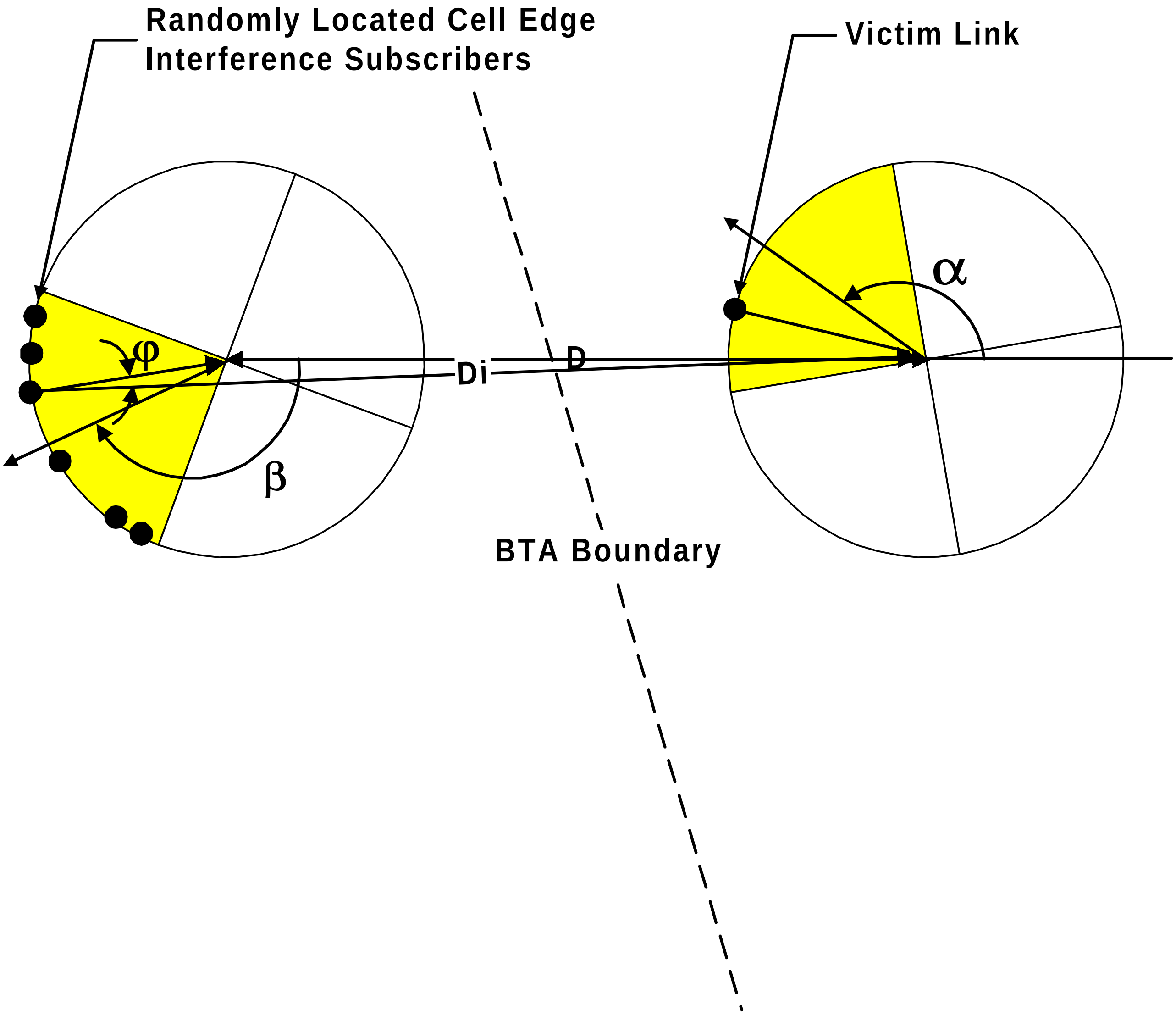

Figure 3. Interference Geometry.

Figure 4 illustrates a simulation for the case where all cell edge interference transmitters operate at full power without ATPC. The simulation also assumes that all interference paths are LOS and do not experience any excess path loss. For a 1 dB threshold impairment at -117 dBW/m^2/MHz, there is a 9-14 percent probability of distance dependent conflicts.

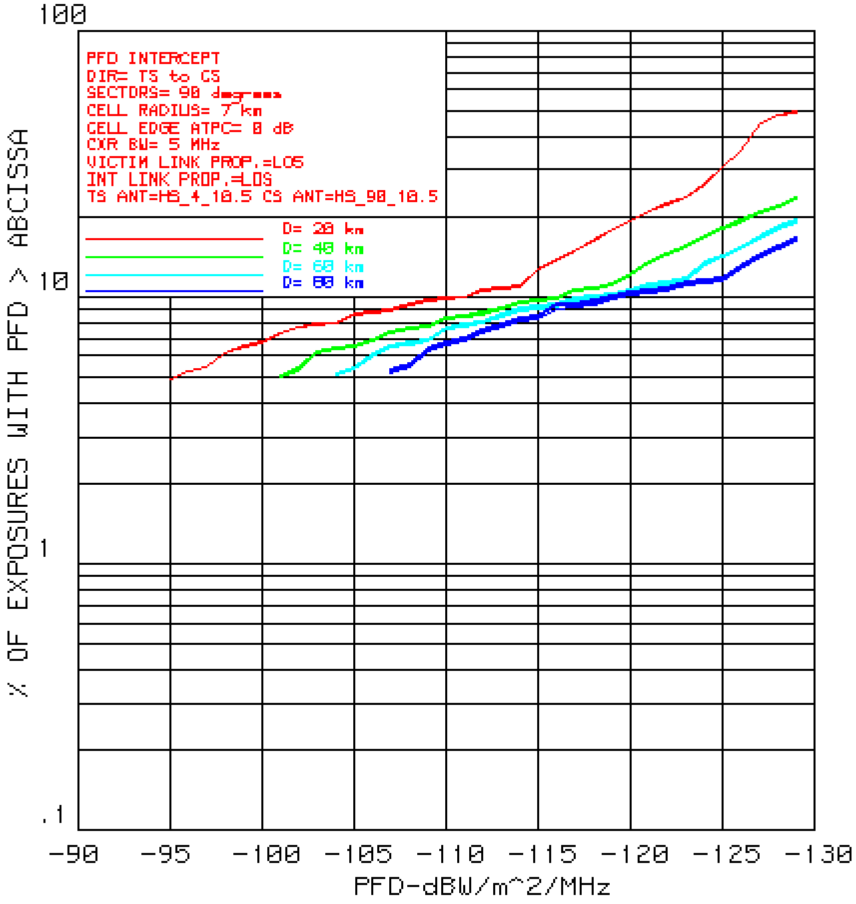

Figure 4. CDF Simulation Estimates for Full Power LOS Interference Vectors (corrected).

Figure 5 illustrates a comparable for LOS interference paths but with 10 dB cell edge ATPC applied to both the victim and interference vectors. As expected, pfd level estimates simply reduce by 10 dB and there are now no pfd levels greater than -117 dBW/m^2/MHz for D greater than approximately 60 km.

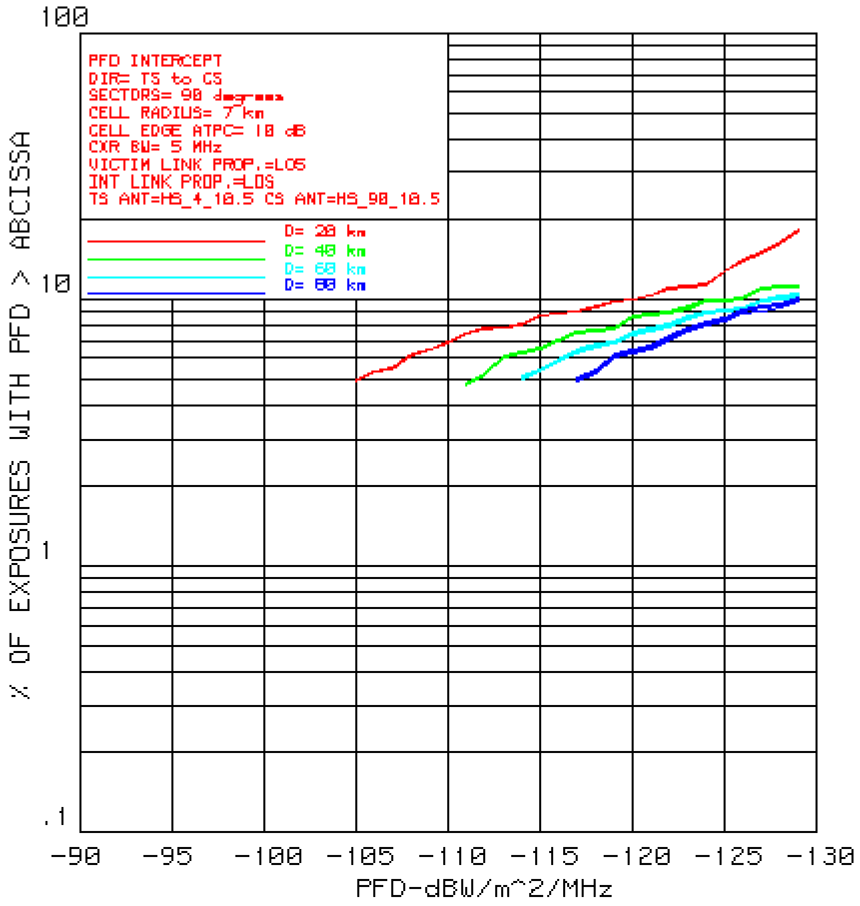

Figure 5. CDF Simulation Estimates for LOS Interference Vectors at ATPC = 10 dB (corrected).

Figure 6 illustrates a simulation for excess loss assigned to all interference paths. For this simulation, all interference vectors are set to operate at full power. Interference link path loss exponents are set to be d^{-2} up to 7 km and d^{-4} beyond 7 km. The impact of distance separation is now quite evident and the distance for an impact on critical pfd levels has been reduced to 40 km.

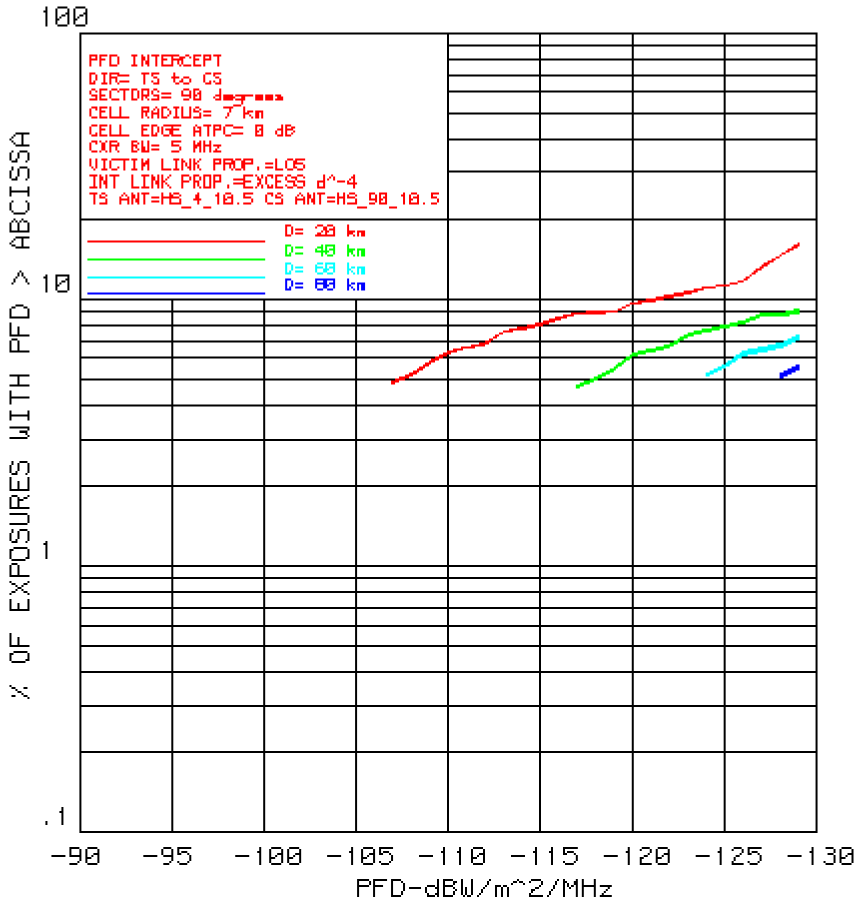

Figure 6. CDF Simulation Estimates for Full Power Interference Vectors with Excess Path Loss (corrected).

Figure 7 illustrates an additional simulation example. Here, all interference transmitters again operate at full power. However, interference vectors are randomly assigned to have a path loss exponent of d^{-2} for the full interference distance or to be d^{-4} beyond 7 km. The CDF results are only modestly improved referenced to Figure 4, indicating that a significant number of worst case exposures were randomly identified to have a LOS propagation exponent. Repeated simulations with different random seed assignments for loss exponents displayed only a marginal change in the CDF results.

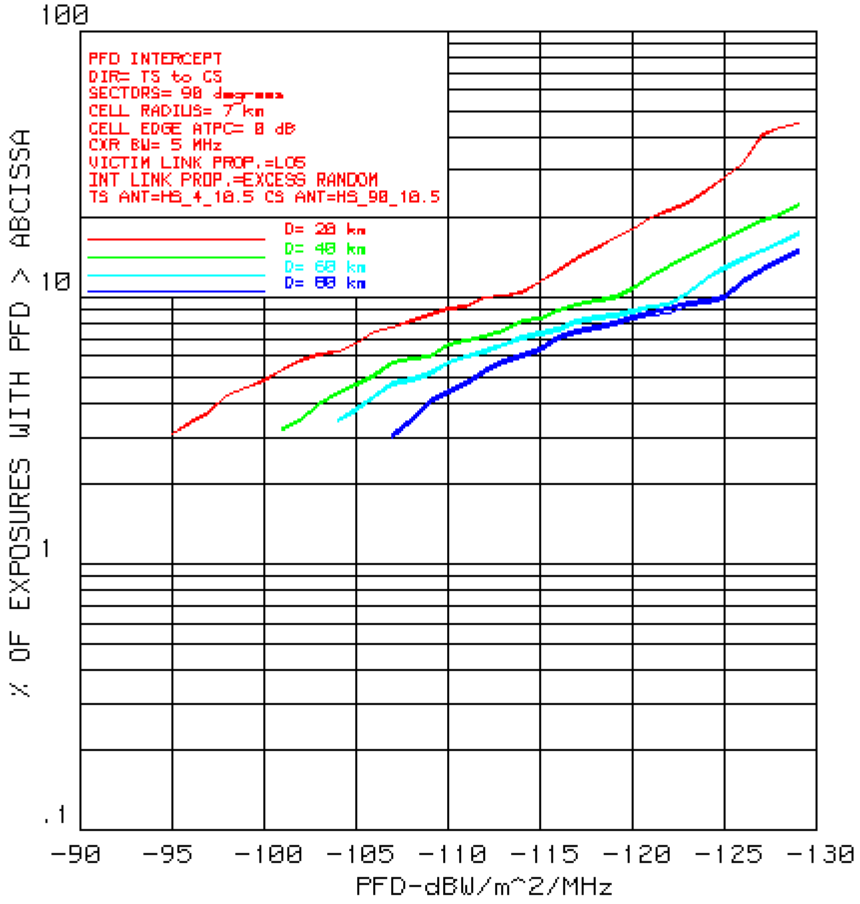

Figure 7. CDF Simulation Estimates for LOS Interference Vectors with Random LOS or Excess Path Loss (corrected).

Figure 8 illustrates one final simulation example. For this case we assume that, at time of deployment, one operator has some intra-system frequency re-use flexibility. So we will assume something as simple as a change of polarization. Typically, we might assume an XPD discrimination of the order of 25 dB. However, given the large interference link distances, and the potential transmission anomalies, let us assume that XPD is only 15 dB. As expected, and referenced to Figure 4, the pfd estimates just move to the right by 15 dB. But, it is interesting to now note, that the coordination requirements for a 1 dB threshold impairment, have now been reduced to approximately 40 km.

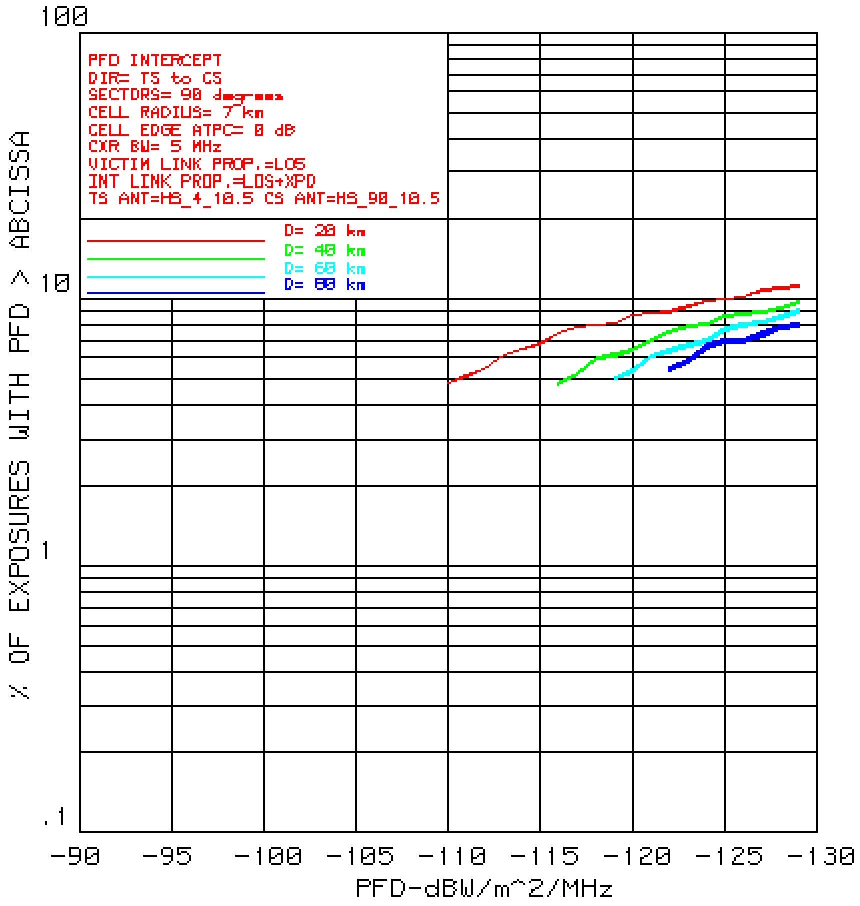

Figure 8. CDF Simulation Estimates for Full Power LOS Interference Vectors + XPD = 15 dB (added).

7.0 Summary Comments

The simulation results indicate that, even with a selection of relatively modest transmit power levels, there is a significant probability that inter-operator coordination will be required. While coordination requirements diminish with distance, they are potentially significant up to 80 km. Unless antenna elevations are exceptionally high, 80 km would likely represent the horizon distance limit for possible LOS propagation. Figure 7 dramatically illustrates the benefits of operator coordination, whereby coordination distance is reduced by a factor of 2, even under an assumption of full power LOS interference vectors and impaired XPD antenna discrimination.

8.0 References

[1] IEEE Std 802.16.2-2001