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Title	Coexistence Simulation Documentation for BWA Systems	
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Re:	Coexistence Simulation Documentation.	
Abstract	This document provides a formal reference summary of coexistence simulation presentations made during IEEE 802.16.2 meetings at Sessions #7 and #8. These simulations examined adjacent area/same frequency TS to CS interference and same area/adjacent frequency CS to TS and TS to CS interference mechanisms.	
Purpose	This document is provided for reference informational purposes. As appropriate, the simulation methodology, results and conclusions may be included in the Coexistence Practice Document.	
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Coexistence Simulation Documentation for BWA Systems

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1.0 Introduction

This document summarizes coexistence simulations that were presented orally during IEEE 802.16 meetings #7 and #8. Using Monte Carlo techniques, the simulations address the adjacent area/same frequency TS to CS interference mechanism and the same area/adjacent frequency CS to TS and TS to CS interference mechanisms. As these interference scenarios are common to both FDD and TDD access techniques, they were concluded to be representative of interference modes that need to be examined in order to develop global estimates of interference susceptibility.

The prime objective of the simulation studies was to identify the significance of antenna RPE and transmitter out of band emission limits on interference levels. A variety of TS and CS antenna RPE mask specifications were examined [1], [2] however only a subset are presented herein. Emission limits were based on the ETSI mask (Type B) for 28 MHz carriers [3].

2.0 Simulation Transmission Parameters

A mid-band BWA transmission frequency of 26 GHz and a carrier bandwidth of 28 MHz have been employed in the simulations. Consequently, "typical equipment and system parameters" appropriate to 26 GHz are employed. These are:

Operating Frequency:	26 GHz
TX Power:	+24 dBm
TS Antenna Gain:	+34 dBi
CS Antenna Gain (90 Degree Sectors):	+19 dBi
Cell Edge Clear Sky ATPC:	15-20 dB
Cell Radius R (ITU Region K):	3.6 km
Fade Margin FM:	25 dB
Rain Cell Radius R_c :	1.2 km
C/I for 1 dB Threshold Impairment:	21 dB
Net Filter Discrimination: Co - Channel:	0 dB
1'st Adjacent Channel (0 Guard Band):	20 dB
2'nd Adjacent Channel (1 Guard Band):	49 dB

Net Filter Discrimination (NFD) is the transmission cascade of the out of band emissions mask [3] and the receiver Root-Nyquist filter. Excess filter bandwidth was assumed to be 15-25 % and numerical integration represents the values cited. NFD thus represents the interference protection to be expected at a given carrier flanking.

3.0 Correlated Rain Fading

In order to develop realistic estimates of global C/I statistics, it is necessary to establish some methodology to compute relative rain loss between a victim transmission path and a converging interference path. While the ITU rain loss and availability computation procedure [4] is frequently employed to develop rain loss and availability across a specific point to point transmission path, the procedure does not explicitly employ the dimensions of a rain cell.

To resolve this issue for multiple victim and interference transmission links, the simulation methodology assumes that some one-victim link in a cell experiences maximum rain loss up to the fade margin FM based on [4]. This is then equated to correspond to the rain loss across a uniform rain rate - circular rain cell of diameter $2R_c$. $2R_c$ is based on the computation procedure given in [5].

Given that $2R_c$ corresponds a rain loss of FM, the rain cell intersection distance of other randomly located victim links D_v is computed and assigned a rain loss value of $L_v = D_v / 2R_c \leftrightarrow FM$. Similarly, interference vectors that intersect the rain cell across a distance D_i are assigned a rain loss value of $L_i = D_i / 2R_c \leftrightarrow FM$.

Now, there is really so scientific justification to assume that a rain cell takes on any geometrical shape. It won't! But the methodology selected does allow for a somewhat equitable estimate of relative rain loss across randomly located victim and interference paths in a geographical area that is experiencing rain fading.

4.0 Antenna RPE

A major objective of the simulations has been to identify the significance of antenna RPE on coexistence. This is not to say that an antenna pattern that meets coexistence objectives will meet suitable intra-system C/I for arbitrary frequency re-use plans. This can be demonstrated to be the case for some aggressive re-use plans.

Current TS antennas under consideration by the IEEE coexistence committee are shown on Figure 1 and the CS 90 degree sectored antennas are shown on Figure 2.



Figure 1. Azimuth RPE for Proposed IEEE TS Antennas

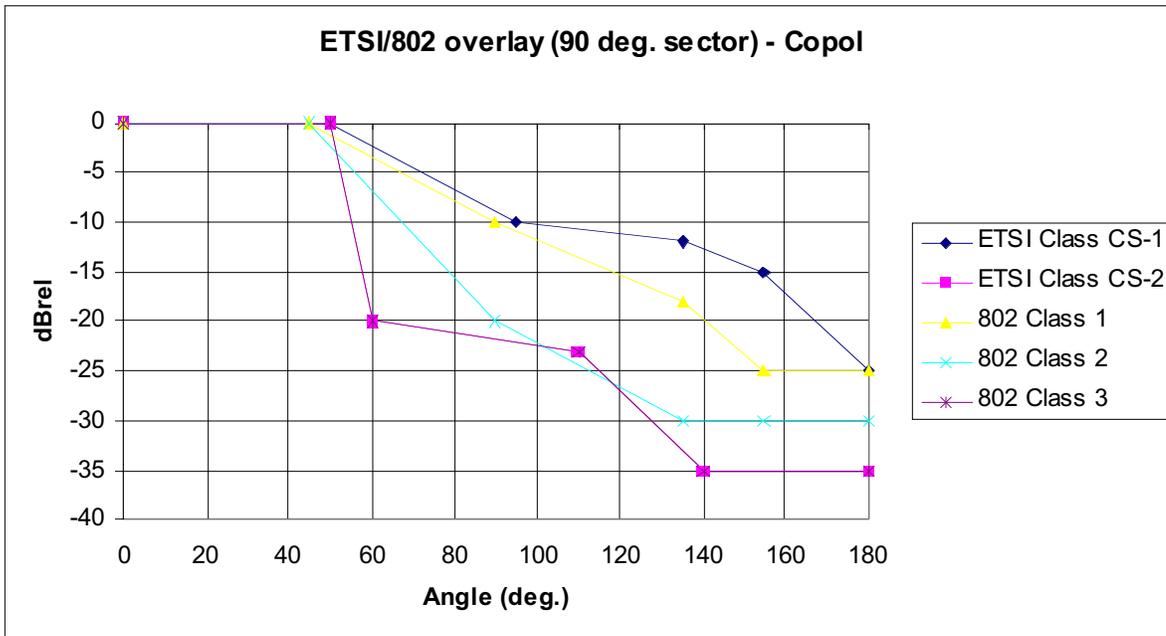


Figure 2 Azimuth RPE for Proposed IEEE CS Sector Antennas (90 degrees)

5.0 Simulation Methodology and Results

5.1 Adjacent Area/Same Frequency (TS to CS)

These simulations examine interference sensitivity across a service area or Business Trading Area (BTA) boundary. They examine the interference sensitivity between co-channel interference situations assuming an uncoordinated alignment of interference and victim sectors. Interference impairment is appropriately expressed in terms of power flux density (pfd) defined in terms of dBW/MHz/m².

In terms of coordination criteria, the Coexistence Practice Document will provide recommended pfd coordination trigger levels at the boundary. However these simulations have been developed based on expected pfd levels that can be estimated based on the separation distance between interference CS sites and victim CS sites. In this way, one can directly translate pfd levels to C/I estimates. The simulation estimates consider only a clear sky environment, as this is the trigger threshold on which operator coordination is recommended. The recommended boundary pfd trigger level for operator coordination is -114 dBW/MHz/m².

5.1.1 Simulation Model (TS to CS)

Figure 3 illustrates the simulation model. Two co-channel sectors are exposed to each other across a boundary. As is typical with cellular system engineering analysis, 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 R_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 a cell edge victim subscriber at 20 dB ATPC, then a victim link pfd is at -88.9 dBW/MHz/m². For interference and victim cells touching at the boundary, the interference link is at distance $3R$. Allowing for similar ATPC control on the interference link, this represents a worst case interference pfd of dBW/MHz/m² and consequently a worst case C/I = 10.3 dB.

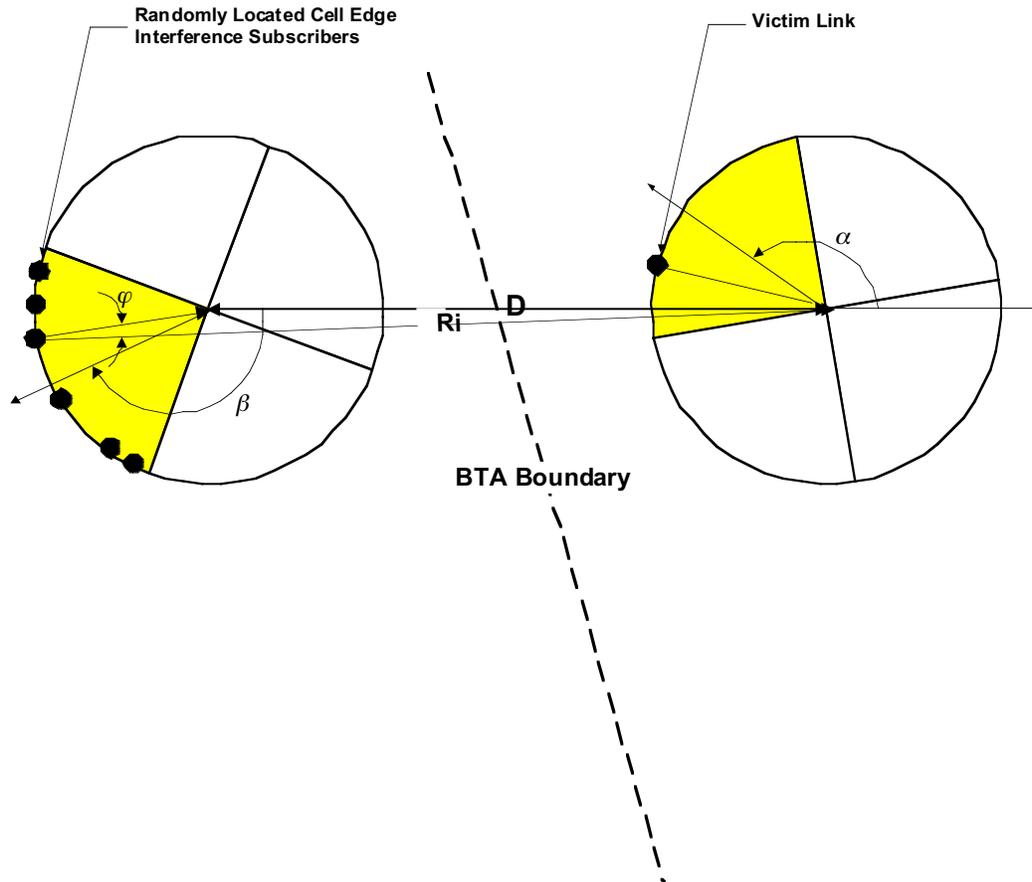


Figure 3. Interference Geometry

5.1.2 Simulation Results (TS to CS)

Figure 4 illustrates a simulation result employed as a reference as it utilizes the ETSI PMP TS1 and CS2 antennas. Distance D is parameterized between 7.2 km (cells just touching) and 60 km. It may be noted that for CS separation distances of less than 40 km, the simulation indicates that 7-10 % of deployments will require coordination. Beyond 40 km, there are no exposures that exceed the -114 dBW/MHz/m² pfd trigger threshold.

Simulations have been performed against all antenna combinations. As expected, improved antenna RPE results in reduced pfd. Figure 5 illustrates a simulation for the best antenna RPE combination (IEEE TS3/CS3). While an improvement in pfd may be noted, it is not sufficient to invoke usage of these antennas as a coexistence requirement. Simply stated, the simulation results demonstrate that the TS exposures that are "almost" bore sighted with the victim CS dominate worst case pfd performance. Hence, improved antenna RPE will not provide significant pfd improvement.

One exception to the low sensitivity of antenna RPE to pfd was found to be the proposed IEEE CS1 antenna. Figure 6 illustrates the simulation results for this antenna in conjunction with the ETSI TS1 antenna. It may be noted from Figure 6 that for $D < 40$ km, exposures that exceed the trigger pfd threshold range from 7 to 20 %. The explanation for this is the very slow roll off of the CS RPE side lobes. At 90 degrees, RPE suppression is only 10 dB. As a consequence, the range of the victim CS sector orientation that provides minimal RPE rejection is significantly increased. It has been recommended to the coexistence committee that this antenna be deleted from the proposed set of IEEE CS antennas. This would also rule out the ETSI CS1 antenna.

All of the simulations assumed a TS RPE beam width mask flat across +/- 2 degrees. To test the sensitivity of main lobe beam width to pfd, a TS4 mask was "fabricated" flat only across +/- 1 degree. Simulations indicated no meaningful improvement in pfd.

LOS transmission was assumed for all of the TS interference vectors. To examine the improvement that might be expected from terrain or man made structure blockage; a distance proportional random blockage algorithm was added to the simulation. An example simulation result for 80 % blockage at D = 60 km is shown on Figure 7. For this simulation, blockage reduces the pfd coordination requirement to be within approximately 2-4 % of exposures.

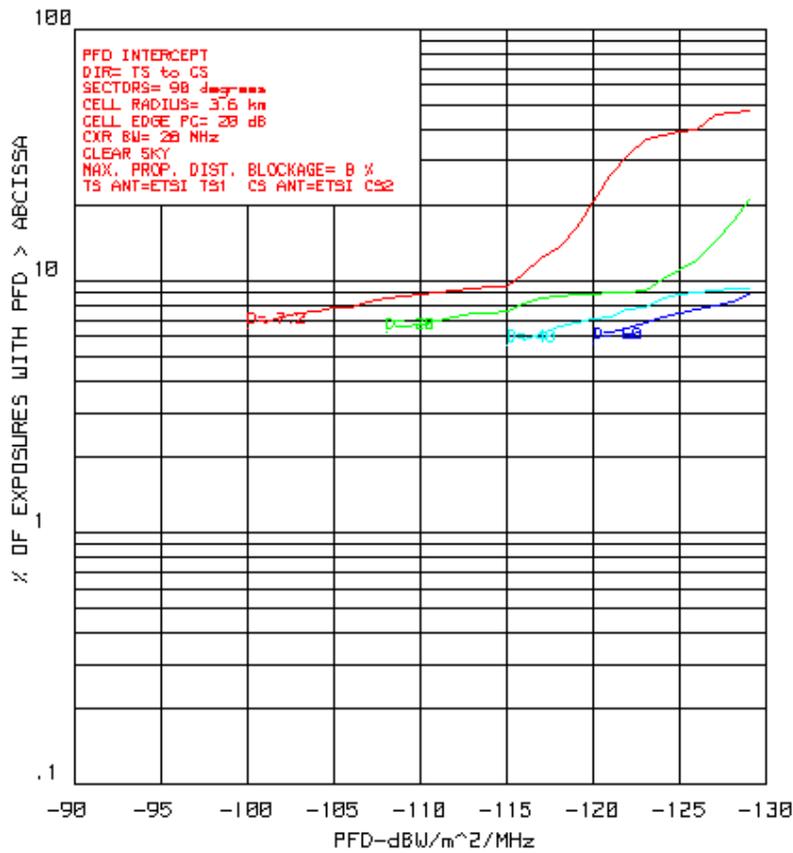


Figure 4 CDF Simulation Estimates for ETSI TS1 and CS2 PMP Antennas

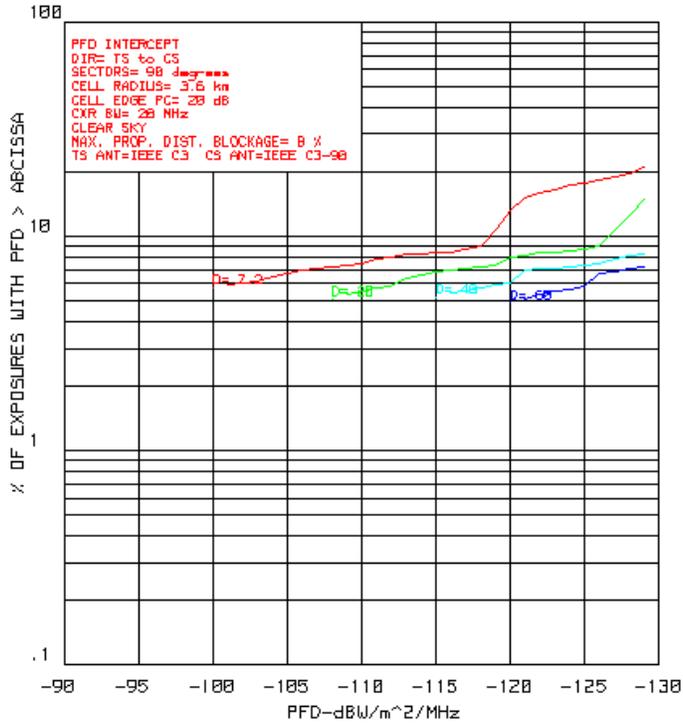


Figure 5 CDF Simulation Estimates for IEEE TS3 and CS3 Antennas

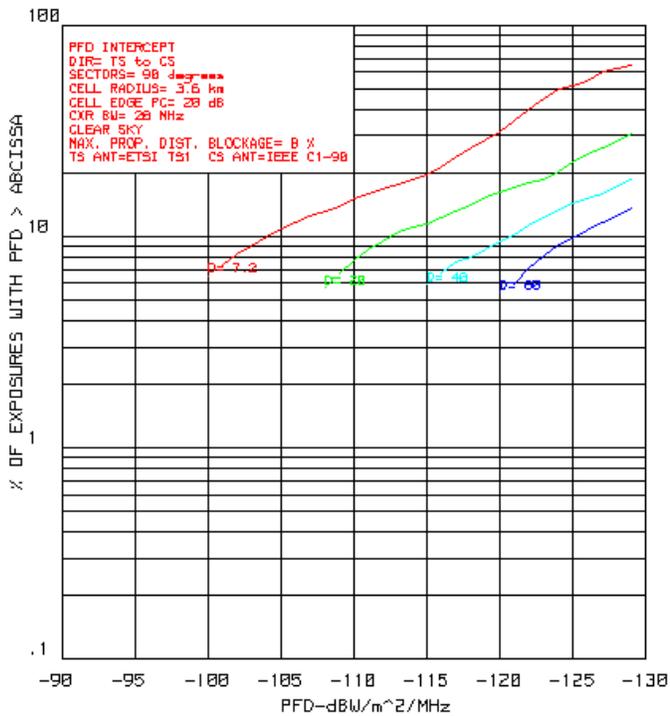


Figure 6 CDF Simulation Estimates for ETSI TS1 and IEEE CS1 Antennas

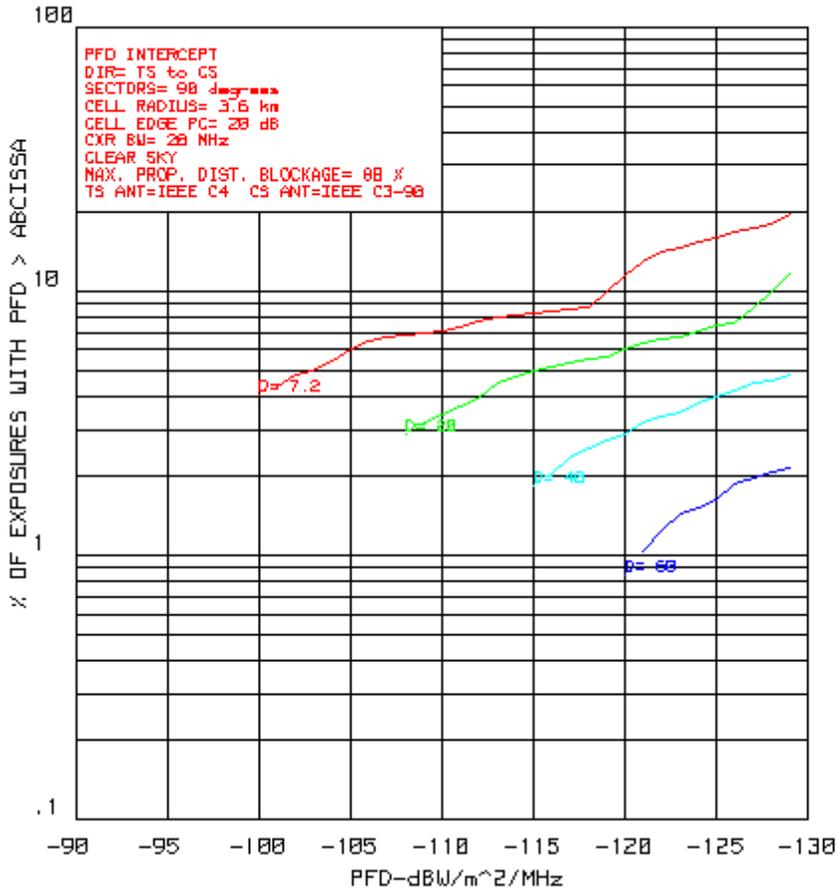


Figure 7 CDF Simulation Estimates for 80% Proportional Blockage @ 60 km

5.2 Same Area/Adjacent Frequency (CS to TS)

These simulations address the case of multiple operators deployed in a given geographical area that are employing adjacent frequencies. In this case, the most serious conflicts occur when two operators have adjacent carriers of the same polarization as illustrated by Figure 8. Worst case deployments are thus represented by cell overlays involving VB/VD or HB/HD. Dependent on an operator's ability to establish reserve carrier assignments there may or may not be a guard band(s). Hence, the NFD protection ratio may be either 20 or 49 dB as noted in Section 2.0.

The simulations assume that both operators employ the same carrier bandwidth (assumed as 28 MHz for the analysis). Also assumed are that both operators employ a comparable set of transmission as given in Section 2.0.

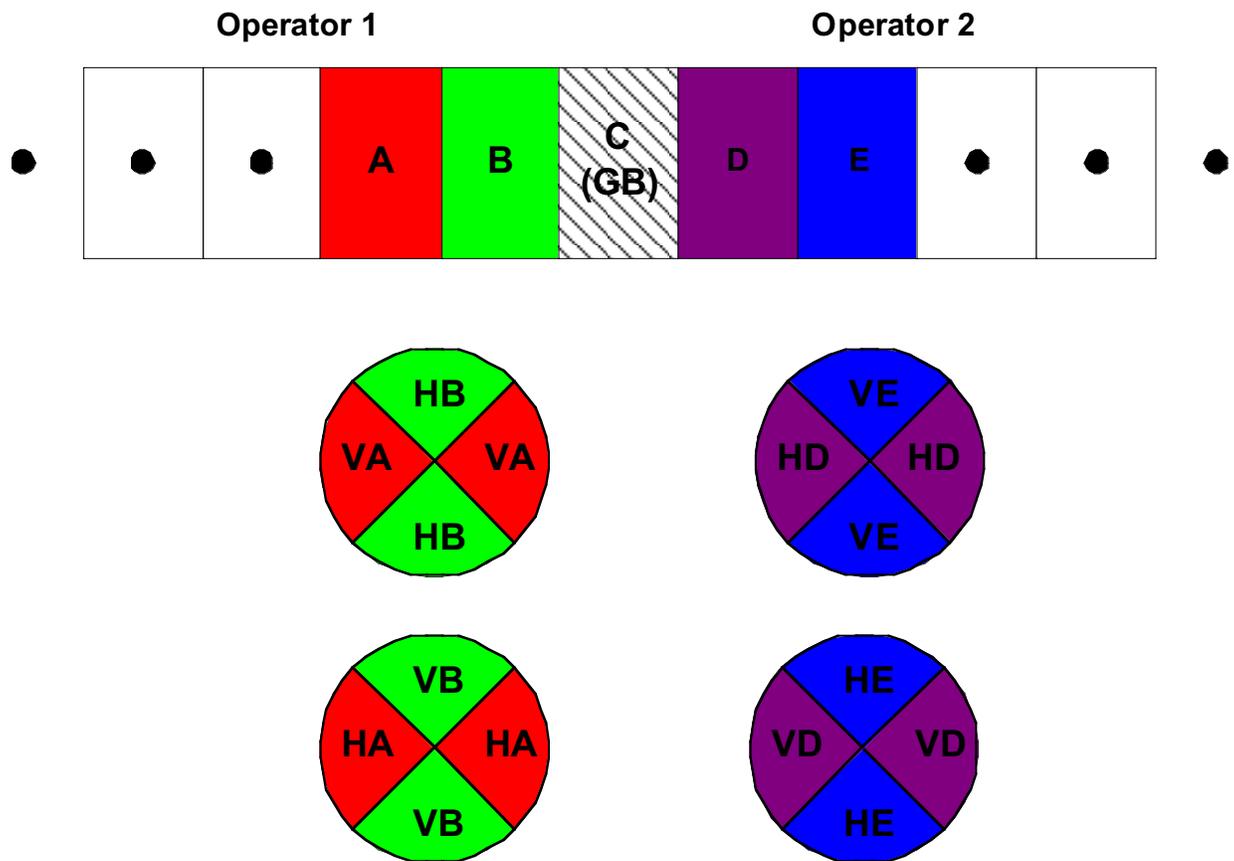


Figure 8 Frequency and Polarization Assignments

5.2.1 Simulation Model (CS to TS)

Figure 9 illustrates the simulation model. The interference CS is placed in the victim sector at some parameterized distance S between the hub centers. Relative angular position of the interference CS is set random for each rotational spin of sector alignments. As the interference CS is always deemed to be within the victim sector, only the sector alignment of the interference CS needs to be varied. Spin increments were taken at 5 degrees.

A rain cell of radius $R_c = 1.2$ km is positioned in the sector at some parameterized distance D_{rc} . To ensure that at least some one victim link experiences the full rain attenuation loss, D_{rc} is restricted to be within the range of 1.2 km to 2.4 km. A worst case value for D_{rc} would tend to be 1.2 km. At this distance, the rain cell just touches the victim sector, thus maximizing the number of victim TS locations that experience significant rain loss.

For each rotational spin of the interference CS, the angular position of the rain cell is randomized. Angular rotation is restricted to be within ± 45 degrees, thus ensuring that the full diameter of the rain cell is always within the victim sector.

Twenty victim subscribers are selected for each rotational spin. These are distance positioned on roughly an area proportional basis by first generating a random number μ in the range 0 to 1. Individual TS distance is then set as $R_0 = (1 - \mu^2)R$ where R is the cell radius. Hence it would be expected that 50% of the TS locations are at a distance $> 0.75R$ from the sector/cell center.

For each spin, the rain loss of interference and victim vectors is computed, based on the geometry and rain loss procedure described in Section 3.0. Victim signal levels are computed based on the transmission parameters, link distance and rain loss. Interference signal levels are similarly computed but with the inclusion of antenna angular discrimination, relative frequency polarization and NFD. A single interference computation accounts for the contribution of each of the four CS sectors and each spin represents 20 independent C/I estimates. Thus a simulation is represented by 1440 C/I estimates. These are sorted and employed to develop a CDF for C/I at given values for S and D_{rc} .

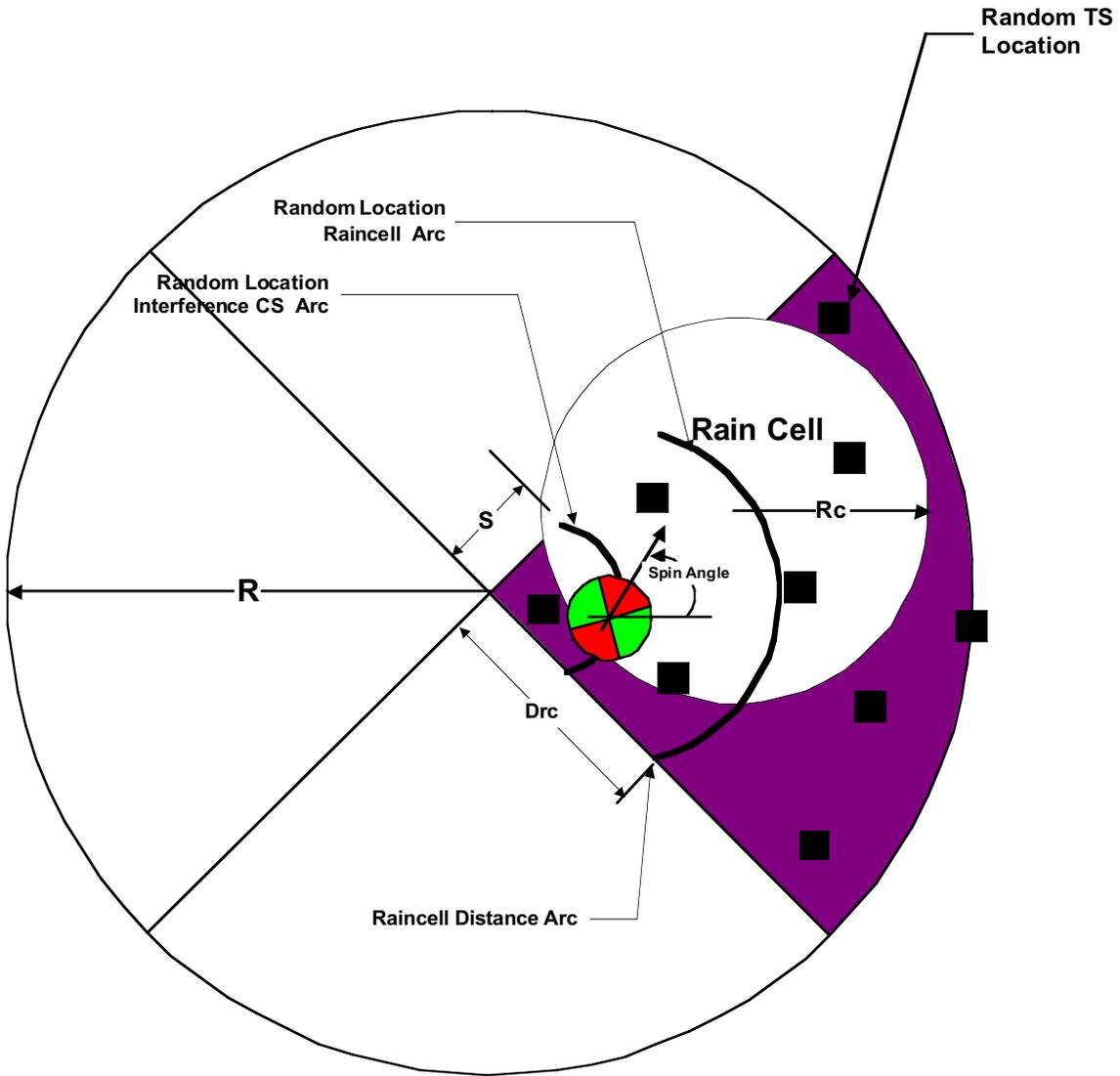


Figure 9 Interference Configuration for Rain Fading CS to TS Case

5.2.2 Simulation Results (CS to TS)

Figure 9 represents a one-guard band example simulation that employed ETSI PMP TS1 and CS2 antennas. Worst case CS separation distance is of the order of 0.6R. To test the significance of the TS antenna RPE, all combinations of IEEE antennas were examined. Figure 10 illustrates the combination of the IEEE TS3 and CS3 antennas. It is evident that relative antenna RPE is not a significant factor except for very large values of C/I.

Figure 11 illustrates a zero-guard band example for the ETSI antennas. IEEE antenna simulations have been found to give comparable results. It is evident that the reduction in NFD from 49 dB to 20 dB will not support the deployment of 1st adjacent co-polarized frequencies in the same geographical area.

Figure 12 illustrates one final simulation example, this being the clear sky case employing the best IEEE antennas and a zero-guard band. Here, as expected due to the geometry, the worst case CS separation distances correspond to small values of S. But here again, even clear sky deployment without a guard band seems problematic.

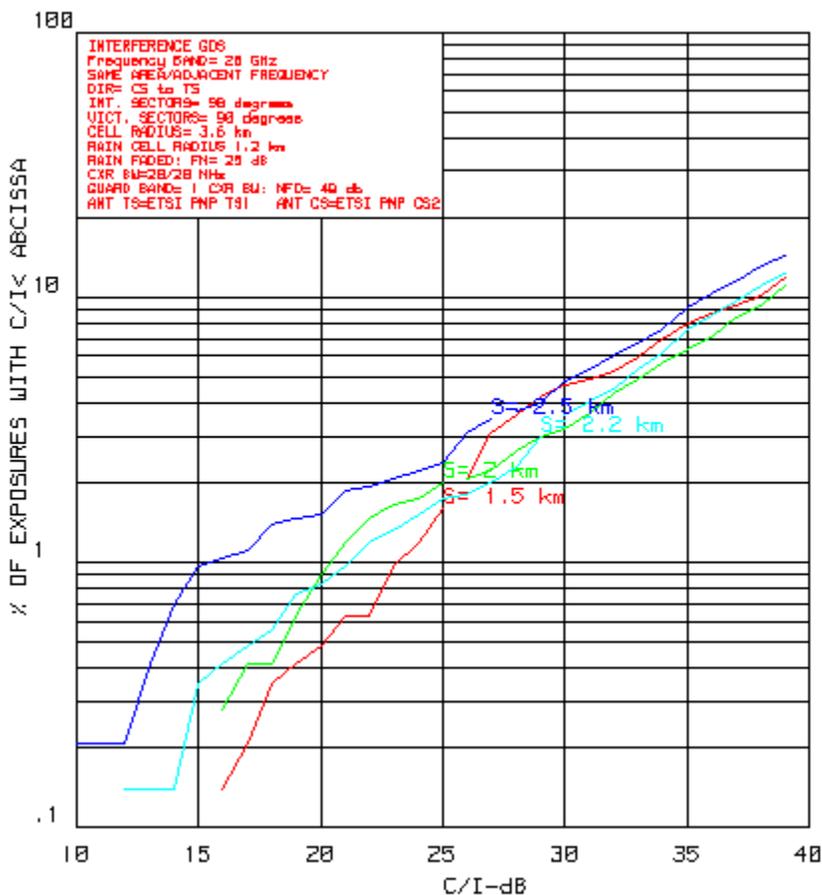


Figure 9 ETSI TS1 and CS2 Antennas; 1 Guard Band, Rain Faded

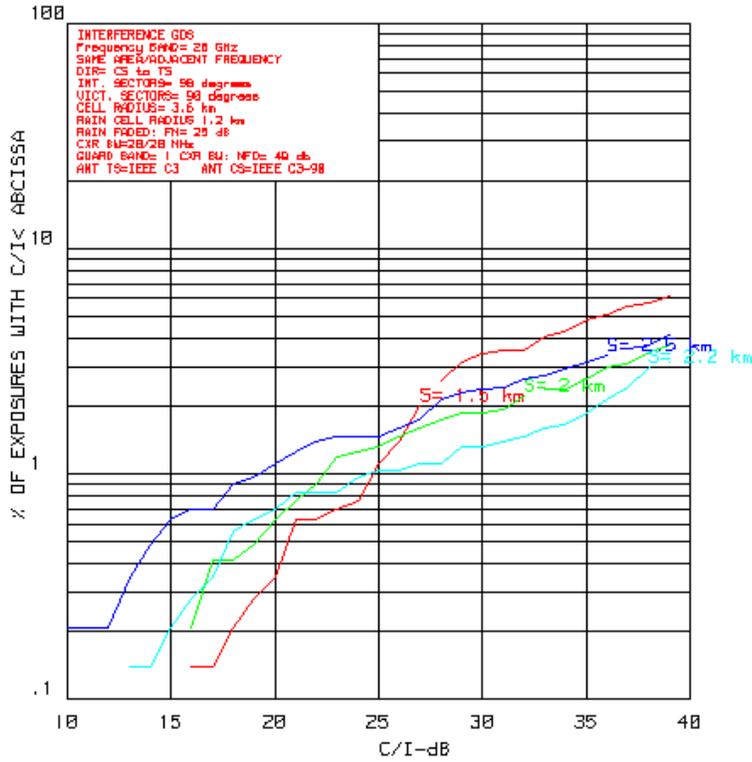


Figure 10 IEEE TS3 and CS3 Antennas; 1 Guard Band, Rain Faded

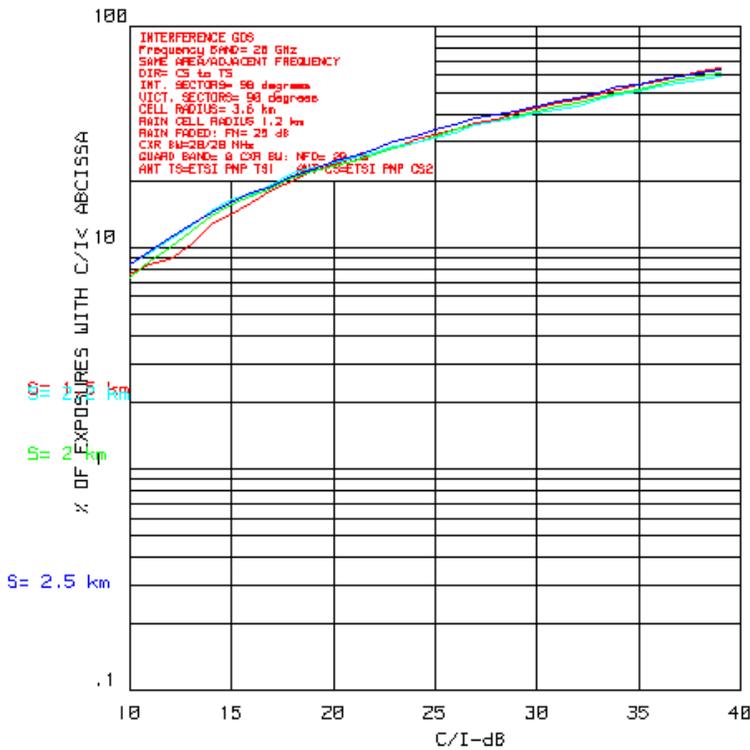


Figure 11 ETSI TS1 and CS2 Antennas; 0 Guard Band, Rain Faded

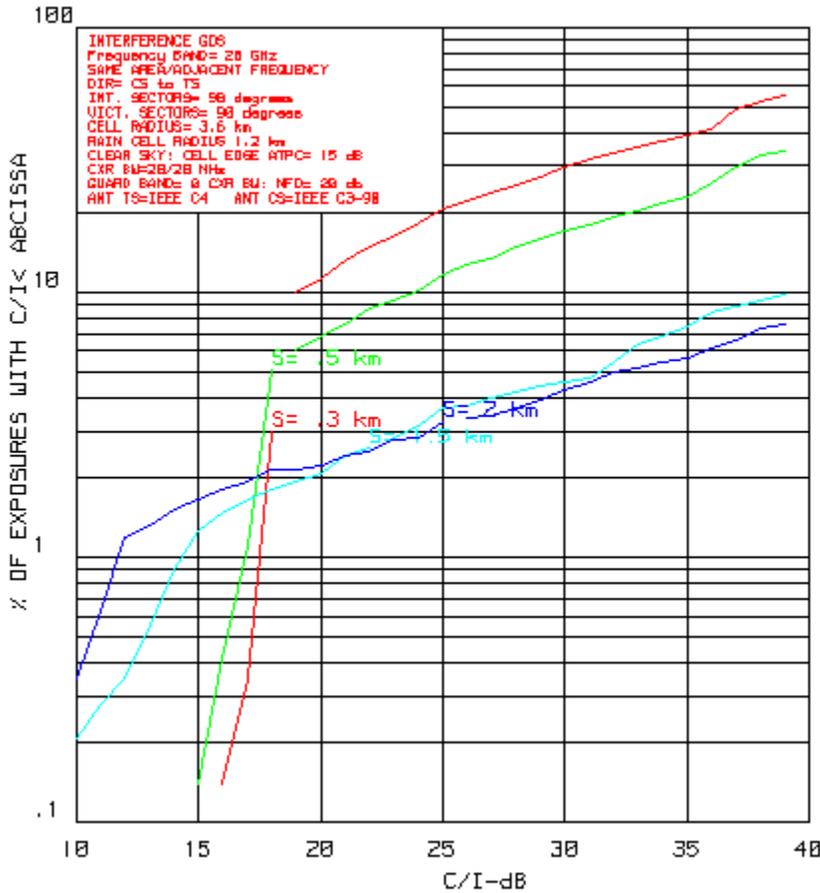


Figure 12 IEEE TS3 and CS3 Antennas; 0 Guard Band, Clear Sky

5.3 Same Area/Adjacent Frequency (TS to CS)

These simulations also address the case of multiple operators deployed in the same geographical area that employ adjacent carrier frequencies. However, in this case there are now two sets of TS carriers that need to be considered

and both uplink groups apply adaptive transmit power control (ATPC), dependant on the relative values of link distance and rain attenuation. In the CS to TS analysis examined in Section 5.2, both victim and interference CS transmitters operate without power control. Consequently, transmit EIRP was balanced. However in this case there could be a significant EIRP differential, dependant on distance and rain loss differential. This simulation analysis therefore attempts to identify if these system operational changes alter the conclusions reached in Section 5.2. There are now 3 transmission links for which different rain loss applies these being: TS/CS victim, TS/CS interference and TS/CS interference into victim.

The system frequency and polarization model is identical to that of Figure 8 and the simulation model employs the same methodology as described in Section 5.2.1 with ATPC now included.

5.3.1 Simulation Model (TS to CS)

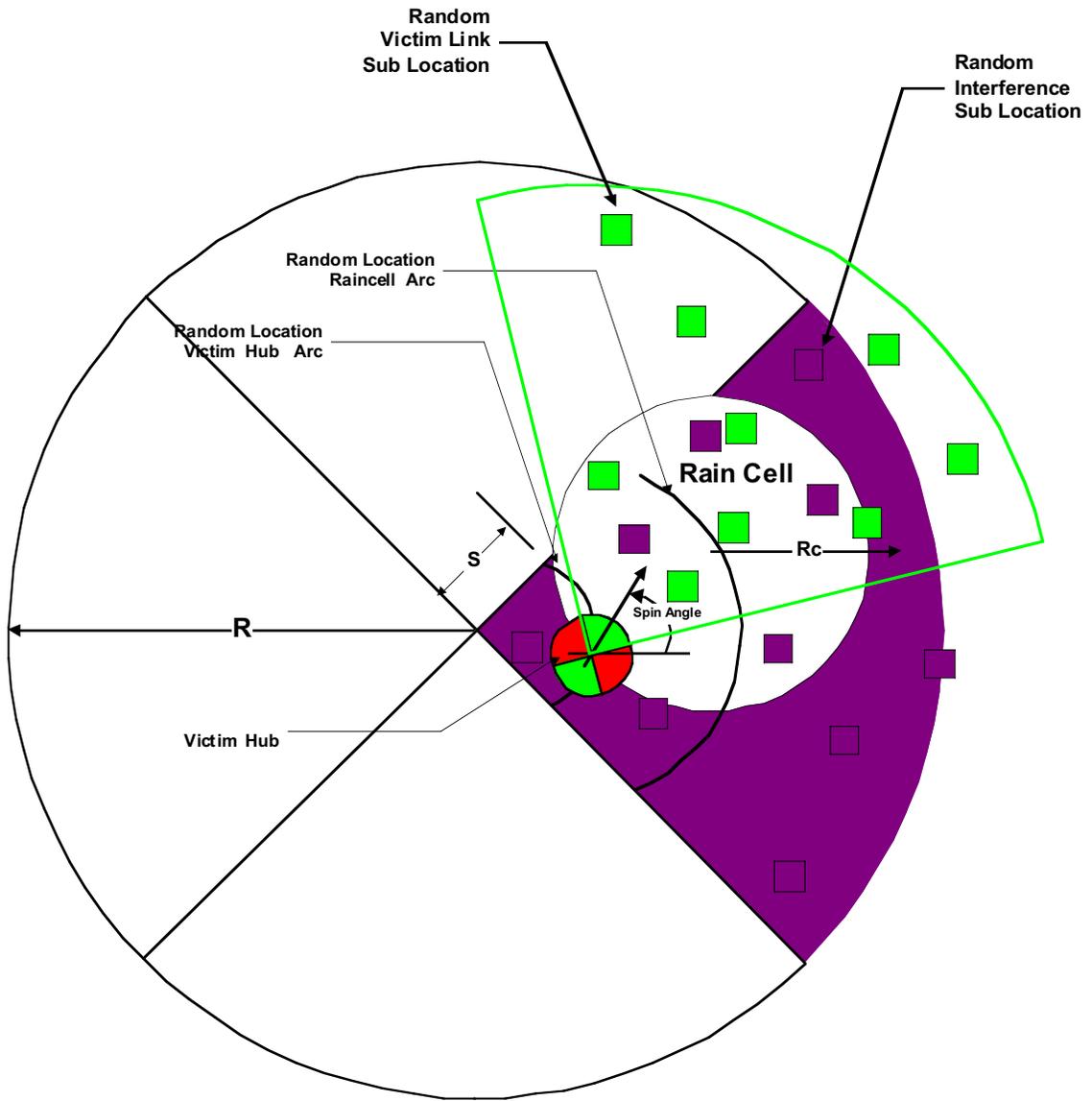
It is now convenient to consider the victim CS to be as illustrated on Figure 13. The rain loss of each of the 20 interference TS links is computed based on their exposure distance within the rain cell. The TX power of each interference TS is then ATPC adjusted to ensure that its combined distance and rain loss signal level suppression is such that it meets margin objectives.

For example, if the available fade margin is $FM = 25$ dB and cell edge ATPC = 20 dB, then each cell edge TS would operate with a 20 dB power reduction during clear sky conditions (a 5 dB margin). TS locations at reduced distances would operate at proportionally reduced TX power levels. Under rain fading conditions, the TX power of each interference TS is adjusted so that the 5 dB margin is maintained. If the margin cannot be met, then interference TS transmits at maximum power. This sets the ATPC adjusted TX power of each of the interference TS links. The signal level of each interference path into the victim CS is then computed based on the transmission criteria of the link.

To simplify the complexity of the analysis, it is assumed that victim TS locations are also area proportionally located. Hence, 50% of the victim subscribers are at a distance $>$ than $0.75R$ from the victim CS. An average victim rain loss is then computed by sampling the intersection of the victim hub with the rain cell across 5 degree increments as illustrated on Figure 14. Victim link rain loss is then set at this average and victim link transmission distance is referenced to $0.75R$. Victim link ATPC is then set accordingly.

This methodology ensures a 50% TS estimate accuracy for victim link rain loss. However, if the rain loss never exceeds the margin requirement, then all victim link received signals are at the margin requirement. This is the case for many simulation configurations and is guaranteed for clear sky conditions. In such cases, all victim TS signal vectors arrive at the victim CS at the margin RX signal level.

Figure 13 Interference Configuration for TS to CS Case



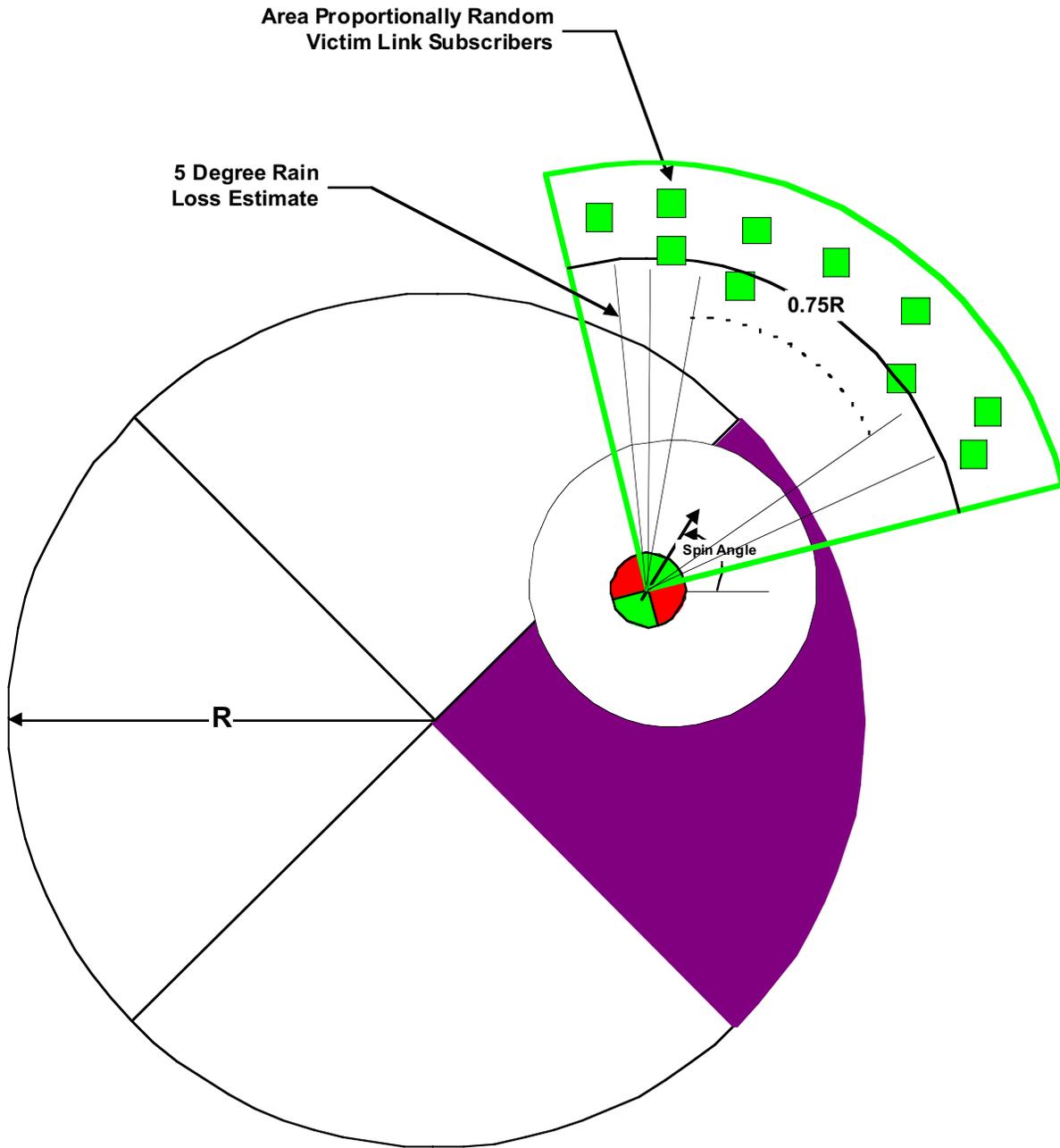


Figure 14 Victim Link Rain Loss Averaging

5.3.2 Simulation Results (TS to CS)

Figure 15 illustrates a rain faded simulation for a one-carrier guard band under rain fading conditions and with ETSI TS1 and CS2 PMP antennas. For this example the rain cell location just touches the interference cell center as $D_{rc} = 1.2$ km. Figure 16 illustrates a comparable simulation for $D_{rc} = 2.0$ km. Both simulations assume cell edge clear sky ATPC at 20 dB. The results are slightly better than the CS to TS grade of service performance reported on in Section 5.2.2. In spite of the possibility of an EIRP differential due to different ATPC transmit power levels, the averaged results indicate that there is a power averaging occurring between interference and victim links. This has been confirmed by examining specific interference C/I scenarios extracted from the simulation analysis. IEEE antennas would be expected to perform slightly better. Figures 15 and 16 indicate that there is only a modest difference in C/I vs separation distance S as the relative location of the rain cell is adjusted.

Figure 17 illustrates the simulation results for the case of ETSI PMP antennas and a zero-guard band. As with the CS to TS case, the results are disastrous.

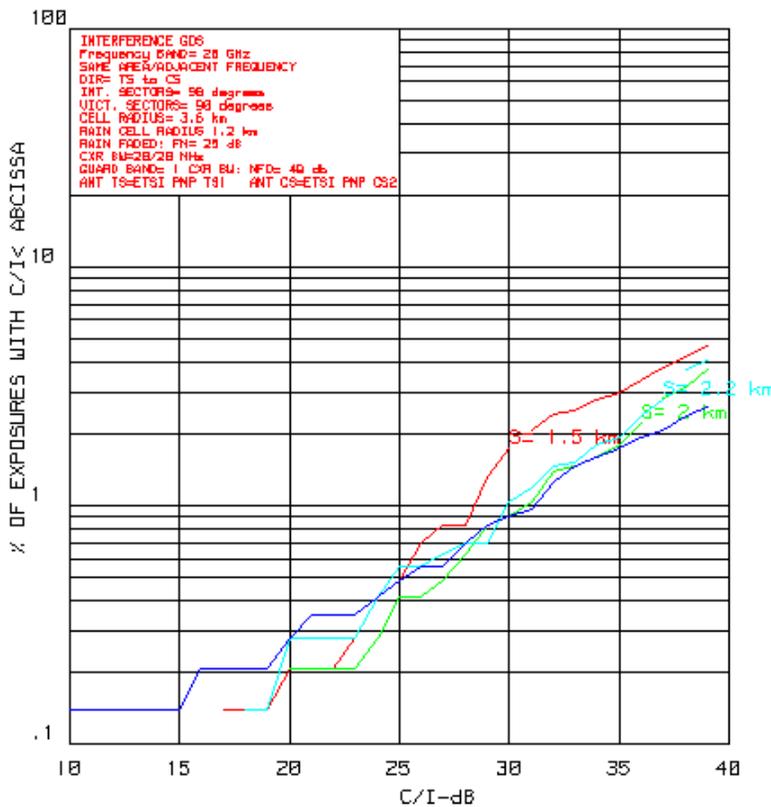


Figure 15 Simulation Example for $D_{rc} = 1.2$ km and One-Guard Band

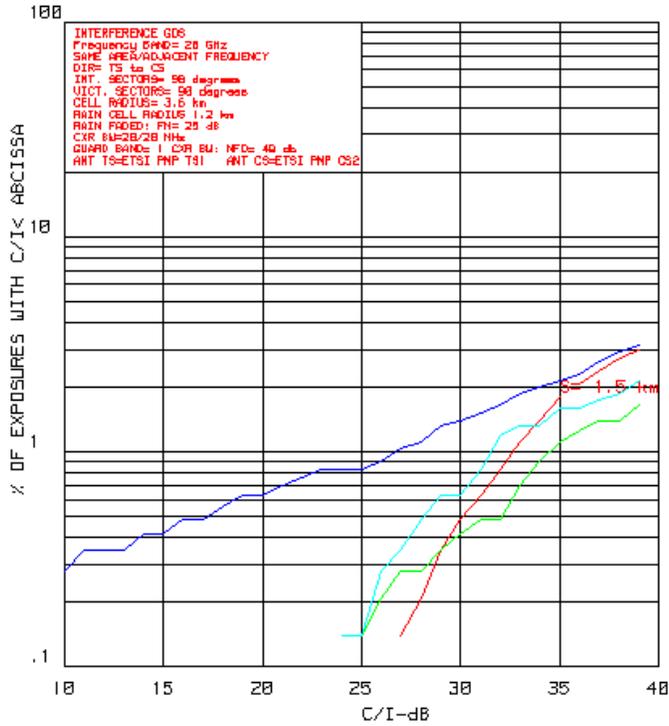


Figure 16 Simulation Example for $D_{rc} = 2$ km and One-Guard Band

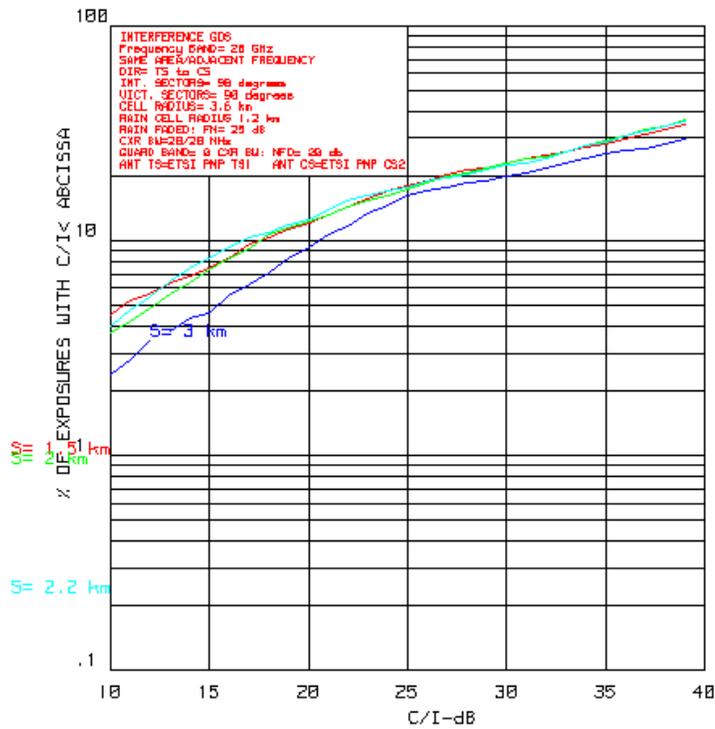


Figure 17 Simulation Example for $D_{rc} = 2$ km and a Zero-Guard Band

6.0 Summary Comments

The simulation results indicate that there is only a weak dependency of antenna RPE on the coexistence interference scenarios examined. However, there are limits to this statement and it has been recommended that one poorly performing IEEE CS antenna be removed from consideration.

A more serious issue is the constraint placed on multiple operator deployments in the same geographical area. Here, the simulation results clearly indicate that one physical guard band (or virtual, via cross polarization) is required. The ability of operators to mitigate against this problem is clearly tied to the amount of spectrum they have available and; hopefully, this will be recognized as additional BWA spectrum is released.

In some jurisdictions, there are no guard bands specified and spectrum has been auctioned off in small blocks. In other jurisdictions, physical guard bands have been legislated, resulting in a large percentage of unused spectrum. Neither policy would appear to represent optimal usage of a non-renewable natural resource. It is hoped that the issues identified herein will be taken into consideration as additional BWA spectrum blocks are made available.

References

[1] ETSI; EN 301 215-2, Antennas for Use in Point-to-Multipoint DRRS in the 11 GHz to 60 GHz Band: Part 2: 24-60 GHz, 1998-07.

- [2] R. W. Whiting, Proposed IEEE Antennas for PMP, Presentation to the IEEE 802.16.2 Coexistence Group at Meeting #7, May, 2000.
- [3] ETSI; EN 301 213-3 V1.1.1, Point-to-Multipoint DRRS in Frequency Bands in the Range 24.25 to 29.5 GHz Using Different Access Methods: Part 3: TDMA Methods, 1999-04.
- [4] Rec. ITU-R P.530-6, Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems, 1995.
- [5] Rec. ITU-R P.452-2, Prediction Procedures for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.7 GHz, 1997.