Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Coexistence Same Area Simulations at 3.5 GHz (Outbound)**
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Re:	Coexistence C/I Simulation Estimates in Support of 802.16a System Design
Abstract	This document examines outbound C/I estimate at 3.5 GHz. It identifies the distance separation between CS locations for which coordination may be required between system operators. The impact of a guard band between multiple operator frequency assignments is also considered. The conclusions are specific to the system model selected. Other system model parameters may modify the distance coordination requirements.
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Coexistence Same Area C/I Simulation

Estimates at 3.5 GHz (Outbound)

1.0 Introduction

When multiple system operators deploy on adjacent carriers in the same geographical area, the possibility of experiencing excessive interference can occur. This is a direct result of the finite emission limits of an interference transmitter for energy that falls in adjacent frequency channels. The protection limits of a victim receiver are set by Net Filter Discrimination (NFD). NFD is simply the cascade of the undesired signal spectra with the victim receiver filter.

The probability of experiencing excessive interference is dependent, in part, by the separation distance of the victim CS location from that of the interference CS and, additionally; CS relative antenna orientation. As interference emissions usually continue to diminish with increasing frequency offset, frequency guard bands between operators offer an interference mitigation technique. Alternative interference techniques, such as cross-polarized operation of flanking carriers can also be considered.

Using Monte Carlo simulation techniques, this contribution examines the preceding. CDF estimates are developed that identify the probability of victim TS receivers experiencing excessive interference levels.

Table 4.0.˜.¯.˘.˙.¨.˚ˆ``• □•`` Simulation Channel Model

A 64 QAM modulation format has been assumed for the outbound CS carriers. From assumed representative equipment parameters, this results in an unfaded C/N of approximately 37 dB for a cell radius of R = 7 km. This represents a modest 13 dB of margin. Unless MIMO and/or other performance enhancement techniques are considered, the available margin is not sufficient to cater to excess path loss of significance, nor to Rician fading. Currently, the performance improvements from such enhancements have not been explicitly defined. Thus, they are not considered in the following. Hence, all interference and victim vectors are assumed to be LOS.

In any event, worst case C/I exposures result when the victim desired path is quite long and the interference path is very short. Under such conditions, one would expect the majority of the interference paths to be LOS.

Table 4.0.˜.¯.˘.˙.¨.˚˙```• □•b` Simulation Transmission Parameters

Anticipated system parameters and *typical* equipment parameters are summarized as follows in Table 1.

Propagation Models:	as per section 2
Maximum Cell Radius:	7 km
Channel Bandwidth:	7 MHz
Modulation Excess Bandwidth:	25 %
TS TX Power:	+21 dBm
CS TX Power:	+29.5 dBm
TS Antenna Gain:	+18 dBi
CS Antenna Gain:	+14.5 dBi
CS Antenna XPD:	>= 25 dB
Receiver Noise Figure:	5 dB
TX/RX RF Losses:	3 dB at each end
Link Availability Objective:	99.99% @ BER=10^{-6}
Modulation:	64 QAM
Receiver C/N Threshold:	24 dB
CS/TS Antenna RPE:	as specified in [1]
NFD:	
1'st Adjacent Channel:	27 dB
2'nd Adjacent Channel:	49 dB
3'rd Adjacent Channel:	53 dB

Table 1 Representative System and Equipment Parameters for 64 QAM.

4.0 System Models

Figure 1 illustrates a frequency re-use plan whereby each operator employs only two frequencies and two polarization's. This is a very aggressive re-use plan as it assumes that a multiple cell deployment can be developed with controlled levels of intra-system interference with such a limited number of frequencies. As well, it makes assumptions as to antenna couplings and as to whether or not the F/B ratio of the CS antennas is adequate to support 64-QAM.

As illustrated, the flanking carriers B and D are assigned to the same polarization. The guard channel C may or may not exist (to be determined). This is a worst case coexistence scenario.

Noteworthy of the plan is that the frequency/polarization assignments are repeated twice in each cell. Hence, in an uncoordinated deployment by system operators, the probability of experiencing a given C/I is likely to be doubled.

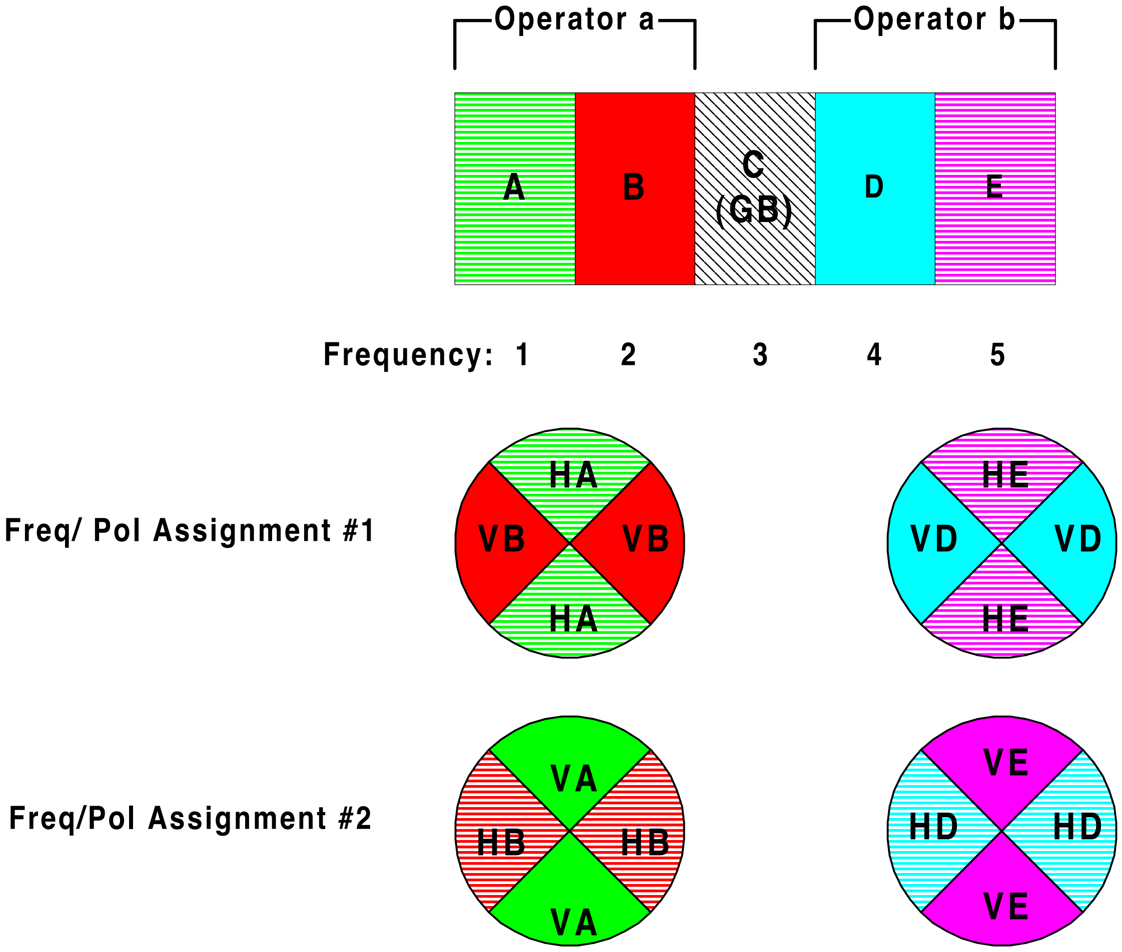

Figure 1. Two Frequency-Two Polarization Frequency Re-Use Plan

Figure 2 illustrates a frequency re-use plan where we have assumed that operators are capable of achieving some degree of coordination. The plan is identical to that of Figure 1, except that operator b has reversed the polarization assignments. The closest flanking channels now gain an XPD attenuation advantage.

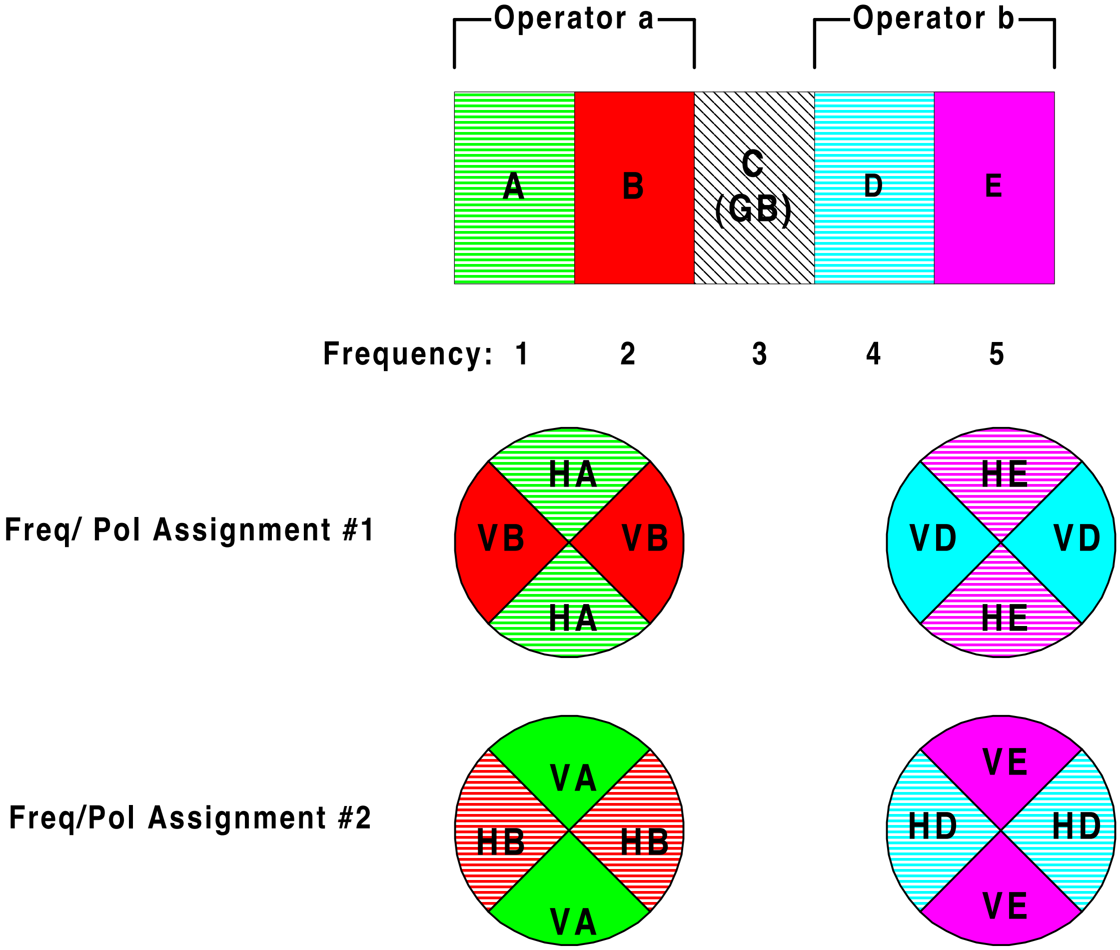

Figure 2. Two Frequency-Two Polarization Re-Use Plan with Polarization Reversal

Figure 3 illustrates a third system model. This is a less aggressive re-use plan. It assumes that each operator deploys four carriers and each is used only once in a cell. This would be expected to reduce the probability of C/I intercept by a factor of 2 referenced to the model of Figure 1.

In the following, the CDF probability vs C/I characteristics of each of these system models will be examined by simulation.

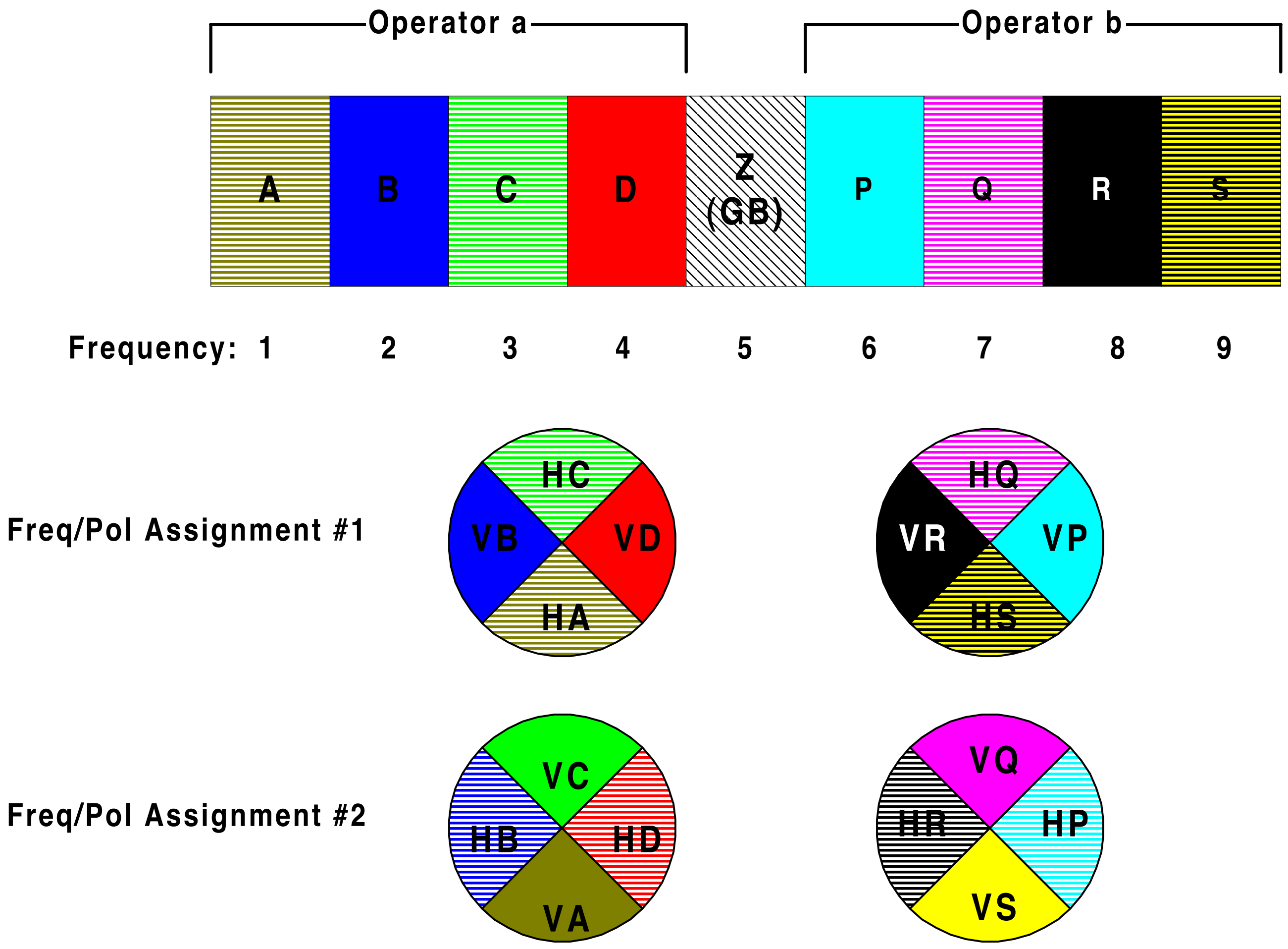

Figure 3. Four frequency-Two Polarization Frequency Re-Use Plan

5.0 Simulation Methodology

Figure 4 illustrates the simulation model selected for analysis. Within a victim sector, an interference CS is positioned at some parameterized distance S from the center of the victim cell. The relative position of the interference CS arc defined by S is set to be uniformly random within the 90 degree range of the arc. Within the victim sector, 20 victim TS assignments are randomly positioned with respect to both link distance and sector angle. The relative distance of the victim locations can be selected on the basis of different assumptions. One might assume that the TS distances R_v are proportionally located with respect to sector area. A second model might be to assume that the T_s distances are uniformly random relative to maximum cell radius R. Both assumptions are subsequently examined.

For any one of the 20 C/I estimates, the interference impact of each of the four interference cell sectors is computed and added in order to develop one C/I estimate. This estimate includes all of the relative geometry considerations, associated antenna RPE, distance differentials and, if it applies, antenna XPD.

As the simulation model assumes that there is no operator coordination, the relative boresight alignments of the two CS antennas are unknown. Consequently, the interference CS is spun in 5 degree increments from 0 to 360 degrees. Each time the interference CS spin is incremented, all of the specified random parameters are assigned a new random seed. Thus, a complete composite simulation run, for a specified CS separation distance S, consists of $20\times(360/5) = 1440$ interference estimates. It is concluded that this is sufficient to provide reasonable statistical significance to the C/I estimates.

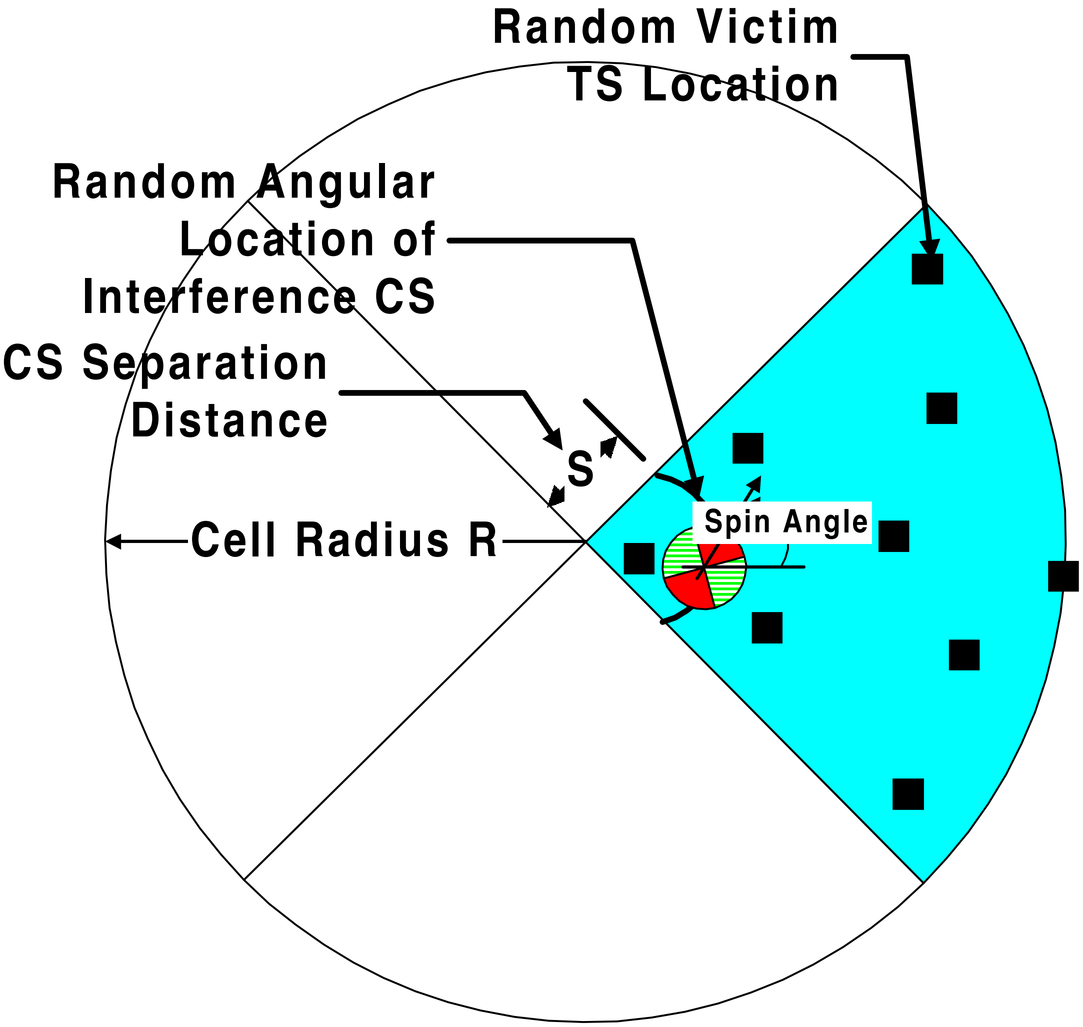

Figure 4. Simulation Model

6.0 Simulation Results

As noted in Table 1, threshold C/N for 64-QAM is estimated to be 24 dB. Hence, this would be the C/I value that would equate to system failure. For a 1 dB impairment to C/N threshold impairment, C/I = 30 dB. These are thus the critical C/I levels to note when reviewing the following CDF simulation results.

Unless otherwise noted, all of the simulations are based on an area proportional assignment of remote TS subscribers. In such a case, 50 % of the subscribers would be expected to be randomly located at a distance greater than 0.75R.

6.1 Zero Guard Band - Same Polarization

Figure 5 illustrates a simulation corresponding to the system model of Figure 1. The flanking carriers are set to the same polarization. For this case, NFD = 27 dB and there is no XPD interference reduction. The simulation examines the case where the CS separation distance S is relatively small, ranging from 0.1 km to 2 km.

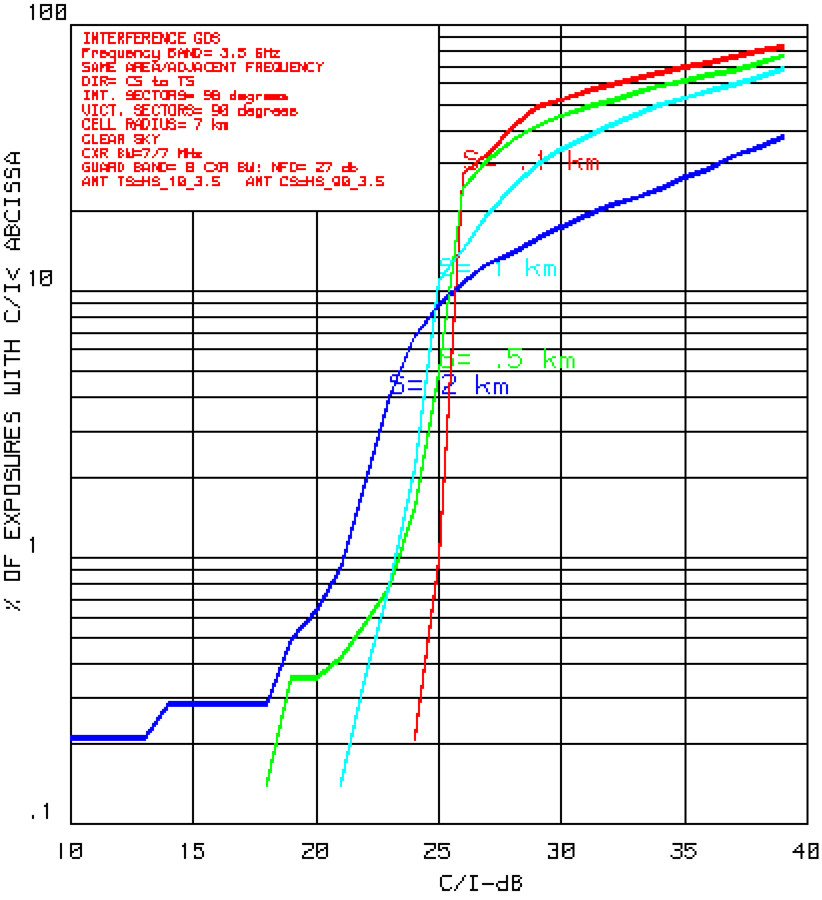

Figure 5. CDF for Zero Guard Band and Same Polarization (S < 2 km)

Figure 6 illustrates a comparable simulation but with the CS separation distance S now set between 3 and 6 km.

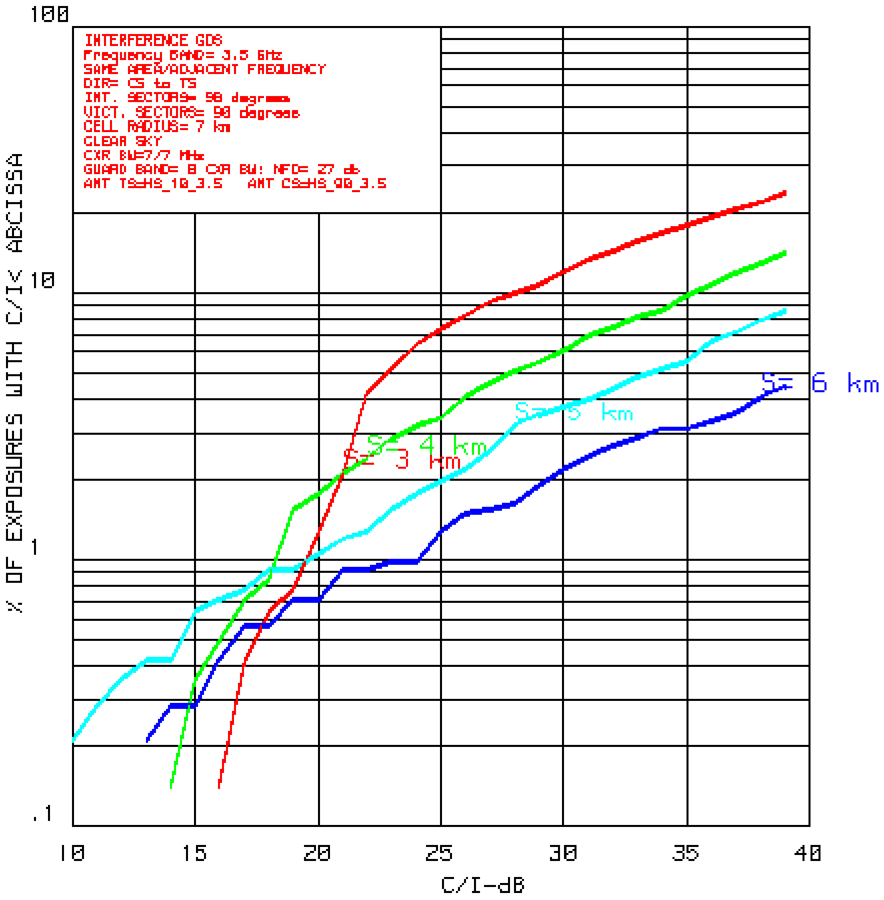

Figure 6. CDF for Zero Guard Band and Same Polarization (S >3 km)

The differences in detail between the two simulations is explained as follows:

NFD is only 27 dB. C/I is improved due to antenna angular discrimination. This is dominated by the narrow beamwidth TS antenna. C/I is reduced by the distance differential between the interference and victim vectors.

When S is small, TS angular discrimination is reduced. However, there will be some distance differentials that are still significant, thus still resulting in a low percentage of C/I values that are noticeably less than NFD. But, with area proportional TS locations, the distance differential between the interference and many of the victim paths is small. Hence, we would expect a large percentage of C/I values to near that of the NFD value.

When S is large, TS angular antenna discrimination is increased. But this is countered by the increased distance differentials between the interference vectors. We would thus expect an increased percentage of very poor C/I values. This is borne out by the simulations. Now, as S continues to increase, so does distance differential. But this is now significantly offset by antenna discrimination, as the likelihood of the TS antenna angle being outside the TS main lobe is greater. Also, as S increases, the number of TS locations subject to serious exposures reduces. As a consequence, we would expect to see the percentage of C/I exposures at, or greater than NFD to reduce. This is also borne out by the simulations.

For 64-QAM, both simulations indicate that there are a significant percentage of exposures that exceed either performance threshold or a 1 dB threshold impairment. Consequently, operation with the same polarization without a guard band is unlikely for 64 QAM. Performance threshold for 16-QAM is typically 18 dB and for 4-QAM is typically 12 dB. For 16-QAM, operation is still somewhat questionable, but 4-QAM operation looks reasonable.

6.2 Zero Guard Band - Opposite Polarization

When flanking carriers are set to opposite polarization's, it would be expected that the C/I values would just shift to the right in correspondence with the XPD available. Nominally, one would expect XPD to be of the order of 25 dB. However, there may be some propagation environments where it is reduced. Referenced to the system model of Figure 2, Figure 7 illustrates a simulation for XPD set to 10 dB. Even with such a low XPD assumption, there are now very few interference exposures that impact on even 64-QAM performance.

However, receiver diversity systems that rely, in part, on polarization diversity, would not be able to take advantage of the added XPD interference suppression. They would have to rely on the reduced C/N thresholds, and related C/I critical levels, that accrue from diversity operation.

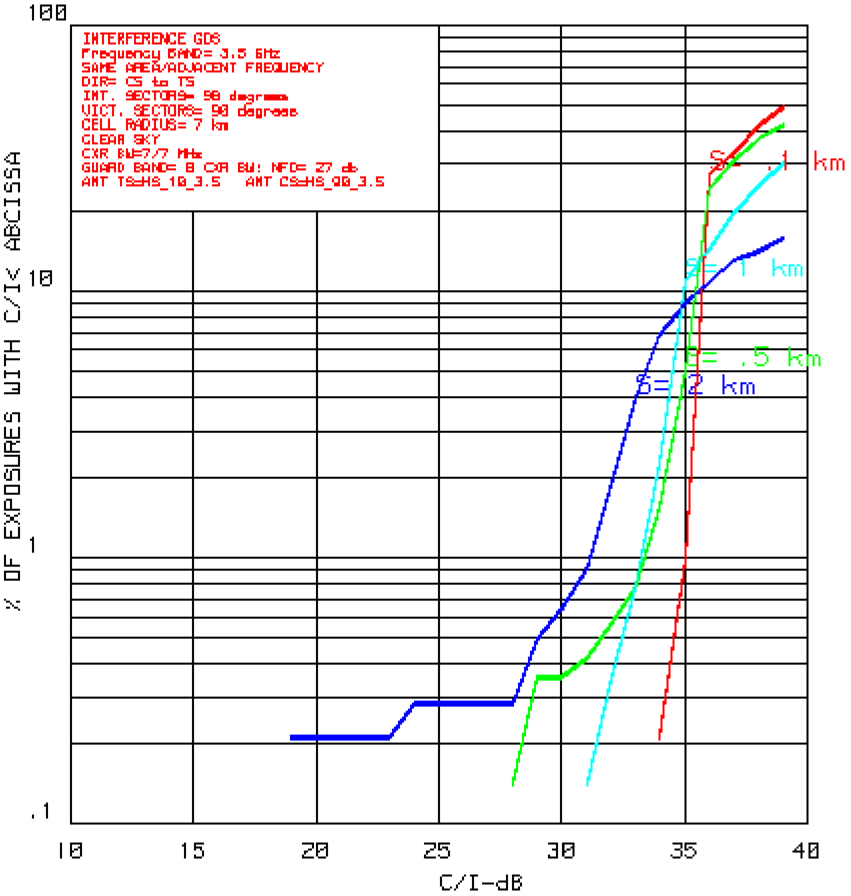

Figure 7. CDF for Zero Guard Band and Opposite Polarization (S < 2 km, XPD = 10 dB)

6.3 Zero Guard Band - Uniform TS Location Assignments

Figure 8 illustrates a simulation where we have again assumed same polarization flanking assignments. However we have modified the re-use plan of Figure 3, such that victim TS locations are now uniformly random relative to cell radius R. Except for minor changes in the CDF detail, the changes in CDF are minor referenced to Figure 5. This indicates that critical C/I probabilities are not significantly influenced by assumptions related to TS locations.

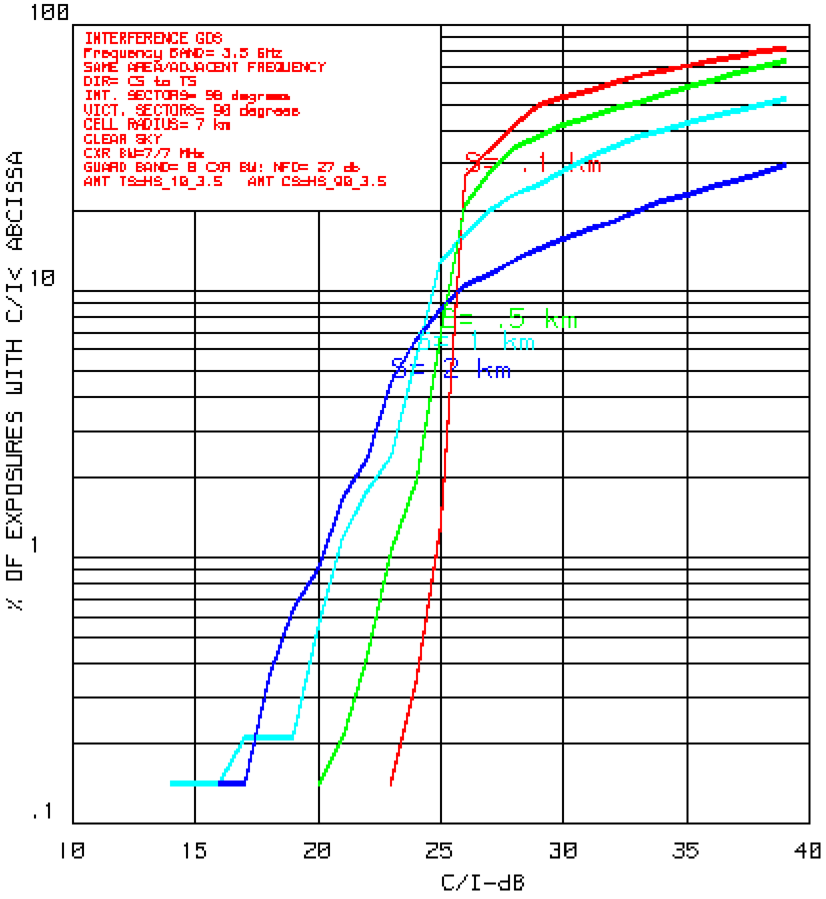

Figure 8. CDF for Zero Guard Band and Same Polarization (S < 2km and Uniform Distribution of TS Locations)

6.4 Zero Guard Band - Four Frequency Re-Use Plan

This re-use plan corresponds to the system model described by Figure 3. As previously discussed, there is now only one adjacent frequency - same polarization flanking assignment in the interference cell. Figure 9 documents the simulation results. As expected, CDF probabilities for some given C/I, referenced Figure 5, are reduced by roughly a factor of 2. CDF outage probabilities for 64-QAM are still marginal. However, for 16-QAM, a 1 dB threshold impairment at a C/I =24 dB is now less than 3 % and threshold outage, at a C/I = 18 dB, is now well less than 1 %.

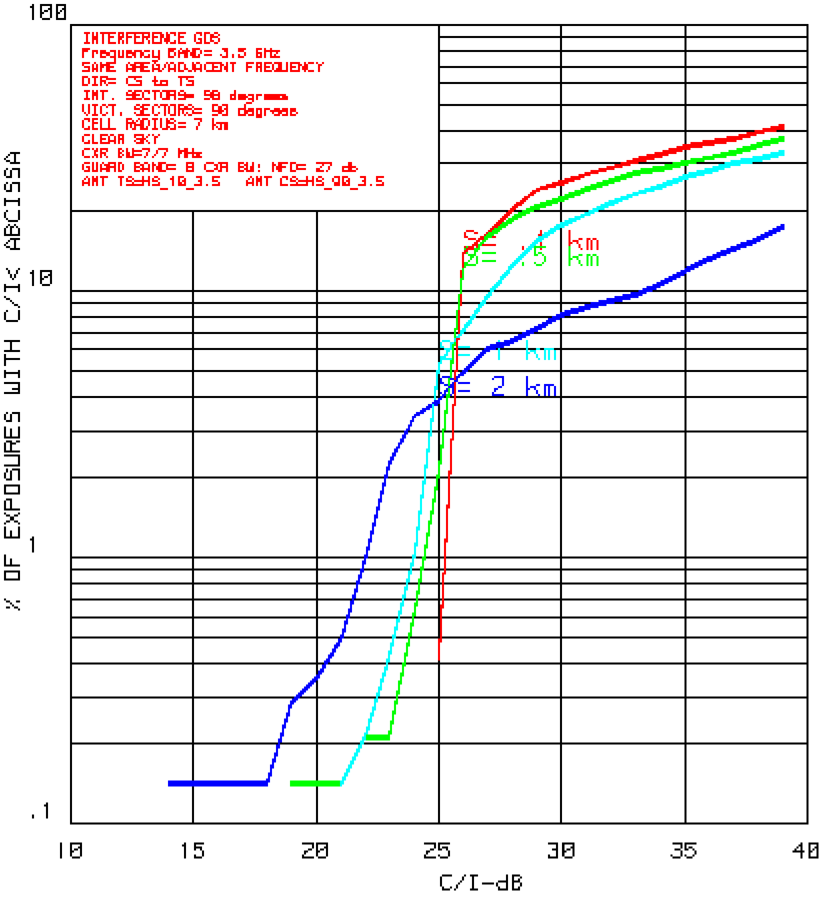

Figure 9. CDF for Zero Guard Band, Same Polarization, and a Four Frequency Re-Use Plan (S < 2 km).

6.5 One Guard Band

With one guard band, NFD = 49 dB, a 22 dB increase above the value for a zero guard band. With such a system model, there are no system configurations that even come close to impacting the C/I performance limits for 64-QAM. Simulations for one guard band are therefore not presented.

7.0 Summary and Discussion

In the preceding, we have examined a number of system model scenarios for adjacent frequency operation with multiple operators in the same geographical area. Some of these scenarios indicate that, without a guard band, or the equivalent (polarization), 64-QAM operation would be questionable. The simulations also indicate that in most cases, 16-QAM would be at worst marginal, but 4-QAM operation would likely be acceptable.

There are an endless number of system scenarios that could be considered and we have examined only a very finite set of them. There are two of these scenarios that may be of significant interest. These are:

1. Modulation Index

It is quite possible that operators a and b could deploy with different QAM modulation indices. In such a case, relative TX power would be expected to be different. This would have to be factored into the GOS vs C/I interference estimates.

2. Relative Carrier Bandwidth

It is also quite possible that operators a and b deploy with quite different carrier bandwidths. Now, it is very simplistic to argue that a guard band, if required, should be that of the widest bandwidth carrier. However, the unwanted emission noise spectra in the 1'st adjacent channel is usually quite colored, and is dominated by the power that is just outside the occupied bandwidth. Hence, the interference impact of receiver filtering may be quite different. Thus, the NFD that would apply from a wide band carrier into adjacent block narrow band carriers could be quite different than assumed herein.

Examination of these issues has not been considered in this report, but they are certainly worthy of subsequent study.

One of the most significant observations of this study is that the guard band requirements at 3.5 GHz are much less onerous than those identified for EHF frequencies [2]. This is a direct result of the absence of rain attenuation at 3.5 GHz. At EHF, the relationship between interference and victim signal vectors are additionally impacted by the differential rain attenuation experienced across the two paths. This can be very significant when the interference CS is near the edge of the victim sector but the rain cell covers most of the victim path. This impairment is not present at 3.5 GHz.

8.0 References

[1] Coexistence Co-Channel Boundary pfd Simulations at 3.5 GHz (Inbound). Revision 1.

[2] Coexistence of Fixed Broadband Wireless Access Systems, IEEE Computer Society, Sept. 10, 2001.