

Project	IEEE 802.16 Broadband Wireless Access Working Group	
Title	TDD Boundary Coexistence Considerations for PMP-FWA Systems	
Date Submitted	1999-12-29	
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Re:	This contribution is in response to the IEEE 802.16 Coexistence Task Group Call for Contributions, dated Dec. 17, 1999. This contribution is in response to requests to define coexistence scenarios. This document was originally submitted to ETSI STC TM4 Meeting No. 22, Dec, 13-17, 1999. In this context, it is identified as contribution 22_TD073.	
Abstract	This contribution examines adjacent area-same frequency boundary coordination scenarios for TDD deployments. Simulation probabilistic grade-of-service interference estimates are developed. The impact of rain correlation/de-correlation between victim and interference links is also examined. The potential of TDD sector substitution or sector swapping to mitigate against interference is also discussed.	
Purpose	This document is submitted for information and discussion purposes. The defined interference scenarios are considered to be appropriate for inclusion in the Coexistence Practice Document.	
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1 INTRODUCTION

Time Division Duplex (TDD) systems have a number of advantages for Fixed Wireless Access (FWA), especially for packet data¹ communications which is rapidly overtaking voice as the dominant type of traffic. Some of the key advantages are as follows.

- a. TDD avoids the use of a diplexer at both the TS and the CS. Diplexers are expensive and bulky components.
- b. Data communications, especially in the access network, can be highly asymmetric in bandwidth terms. Web browsing involves large data downloads with negligible uplink traffic; web serving is the mirror image of this; whilst LAN interconnect tends to be inherently symmetrical. Furthermore, the degree of asymmetry may vary with time quite quickly. TDD can, with appropriate radio link access protocols, inherently and dynamically adjust the proportions of uplink and downlink traffic within a set total bandwidth.
- c. TDD can be deployed in un-paired frequency bands, or in paired bands (subject to coordination).
- d. Even symmetric two-way packet data traffic has a low probability of having to send packets each way simultaneously. Furthermore, even when this situation occurs, the packet in one direction can usually be briefly queued whilst that flowing in the other direction is cleared. As a result, a TDD channel with an appropriate packet protocol and bandwidth B may provide nearly the same grade of service for packet data as an FDD channel of bandwidth $2B$ (i.e. B in the uplink and B in the downlink). This has a number of benefits. For example, overall TDD may be more spectrum efficient for data traffic; and if deployed in typical FDD frequency allocations, the number of channels available for cellular deployment may be effectively doubled (subject to coordination with FDD systems).

Overall these factors may make TDD systems more cost efficient in terms of both equipment and operational costs for a situation with an appropriate traffic mix.

There are also a number of issues with TDD systems which need to be addressed. TDD systems introduce new interference coupling mechanisms, primarily CS to CS and TS to CS, which are not present with FDD and could cause concern both about the ability of TDD systems to coexist with FDD; and the ability of TDD systems to be properly planned for cellular coverage.

This paper is a contribution to the analysis of TDD systems, analysing TDD boundary coexistence scenarios for PMP-FWA systems operating in the 26/28 GHz frequency bands. The analysis examines the major interference scenarios associated with adjacent area-same frequency deployments. Simulated probabilistic grade-of-service (GOS) interference estimates are developed for these boundary scenarios. The impact of rain correlation/de-correlation between victim and interference links is also examined. The potential of TDD sector substitution or sector swapping to mitigate against interference is also discussed.

Future contributions are planned based on similar analysis methods dealing with the issues of TDD/FDD coordination; and the use of adjacent frequency channels in the same area. The contributions will also be input to SE19.

2 PROPOSAL

This document is proposed for information and guidance on the compatibility of TDD point to multi-point systems operating in adjacent geographical areas, as a contribution for DTR/TM 04087. Most of the material is presented in two Annexes. Annex A identifies the general assumptions employed for the simulations,

¹ Predominantly using Internet Protocol (IP).

summarizes the simulation results, and presents general conclusions. Annex B provides additional technical detail on TDD frequency re-use and the selected simulation methodology.

3 SUMMARY OF CONCLUSIONS

Boundary area co-channel interference estimates have been developed for TDD systems that employ an N=9 frequency re-use plan and utilize 30 degree sector assignments. Interference estimates have been developed based on an absolute level of pfd under both clear sky and rain faded conditions.

A rain fade model that accounts for rain attenuation on both the interference and victim transmission links has been described. It is observed that when 30 degree TDD sector assignments are employed, the rain fade model indicates a strong attenuation correlation between both links. This is a direct result of the interrelationships between expected cell size, sector size and rain cell size. Attenuation correlation is diminished as sector size increases.

This analysis shows that useful cellular assignment strategies can be developed for TDD systems *without making any assumptions about synchronisation between base stations* (which is difficult and anyway negates many of the efficiency benefits of TDD).

While interference coordination requirements are normally specified in terms of absolute values of pfd, relative pfd levels are required to develop C/I performance estimates. Relative pfd estimates require knowledge of operational system parameters and ATPC strategies.

Some analysis is given for 90 degree sectored assignments, showing that the isolation provided by the ETSI specified antennas is insufficient for adequate GOS under uncorrelated rain fading conditions for both FDD and TDD systems.

4 REFERENCES

Identified references that apply to both Annex A and Annex B are as follows.

- [1] EN 301 215-2, Antennas for Use in Point-to-Multipoint DRRS in the 11 GHz to 60 GHz band: Part 2: 24 GHz to 30 GHz, 1998-07.
- [2] EN 301 215-3, Transmission and Multiplexing (TM); Digital Radio Relay Systems; Part 3: Time Division Multiple Access (TDMA) Methods, 1999-04.
- [3] Rec. ITU-R P.530-6, Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems, 1995.
- [4] Rec. ITU-R P.452-8, Prediction Procedure for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.7 GHz, 1997.
- [5] IEEE 802.16, Contribution 802.16cc-99/14, Propagation Model for Coexistence Modelling, Sept. 6, 1999.
- [6] IEEE 802.16, Contribution 802.16cc-99/17, Proposed Draft Text for the

ANNEX A

1 General Assumptions

General system assumptions that are required for estimation of interference levels are as follows.

1.1 Antenna Patterns

Angular side lobe discrimination provided by antennas is an important parameter for the accurate determination of coexistence interference levels. Antenna patterns are assumed to comply with ETSI specifications [1]. The TS antenna pattern mask is specified as Class TS1 and the CS antenna pattern is specified as Class CS2. It is further assumed that there is approximately a 16 dB gain differential between the TS and CS antennas.

1.2 Adjacent Channel Emissions Mask

In conjunction with linear modulation (4-QAM to 64-QAM), current power amplifier unwanted emissions are expected to fall well within the spectrum mask specified in ETSI specification [2]. Consequently, this report assumes the emission mask illustrated on Figure A1. The mask illustrates the effective level of energy falling in adjacent carrier frequency bandwidths (dBc) relative to output transmit power. Emission levels between paired low and high transmission blocks are assumed to be at -80 dBc. Adjacent channel emissions are a secondary issue for boundary co-channel interference. However, they do have significance for the intra-system C/I estimates as discussed in Annex B.

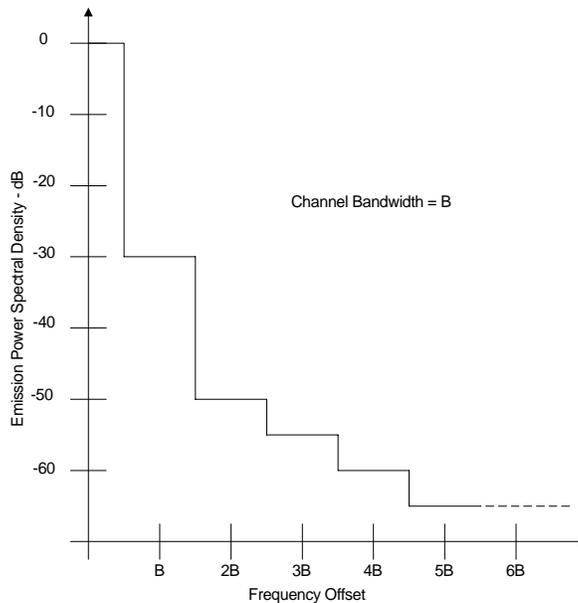


Figure A1: Emission Power Spectral Density vs Channel Bandwidth B

1.3 Cell Size

Maximum cell radius is assumed to be $R = 3.6$ km for 4-QAM. Assuming typical FWA transmission parameters, this equates to a fade margin to performance threshold of $F_m = 25$ dB (ITU rain region K). This maximum cell radius dimension for rain region K is consistent with values previously reported in other ETSI studies. Maximum cell size radius for 16-QAM is estimated to be of the order of 2 km at a fade margin to performance threshold of $F_m = 20$ dB. This reduced cell size alters both clear sky and rain faded interference sensitivity but this has not been explicitly addressed in the subsequent analysis.

1.4 Receiver Threshold

Receiver threshold for 4-QAM (14 MHz channel bandwidth) is assumed to correspond to a $C/N = 13$ dB and for 16-QAM to a $C/N = 19$ dB. A 1 dB threshold impairment caused by co-channel interference is 6 dB higher at respective C/I values of 19 and 25 dB. For typical 4/16-QAM performance parameters, the absolute signal threshold levels are respectively estimated to be -84 dBm and -78 dBm.

These threshold values are set referenced to a link $BER = 10^{-6}$ that includes FEC coding gain. Using ITU calculation procedures [3], the 25 dB fade margin provides a link availability of 99.995%.

1.5 Rain Cells

Corresponding to rain region K, the diameter of a volume rain cell is assumed to be $D_C = 2.4$ km in accordance with the calculation procedure given in [4]. Also in accordance with [4], the rain cell is assumed to be a circular cylinder and the rain rate is assumed to be constant within the rain cell. For interference paths that intersect the rain cell, rain loss is assumed to be proportional to the intersection distance of the interference vector within the rain cell, relative to the rain cell diameter. The victim link is always assumed to be fully within the rain cell and consequently experiences a rain loss F_m that sets its signal level near, or at, receiver threshold.

A rain loss transition band outside the boundary of the volume rain cell is not considered. Interference paths that are entirely outside the rain cell boundaries are assumed to be in the rain debris region. In accordance with the proposal put forward in [5], such interference paths are assumed to experience a rain loss of 0.1 dB/km across the full length of the path.

1.6 Power Control

Outbound (CS-TS) adaptive power control (ATPC) can be demonstrated to cause intra-system C/I problems due to uncorrelated rain fading. We will assume that TDD systems do not employ outbound power control.

We will assume that TDD systems employ ATPC on the inbound (TS-CS) link. Exact values for cell edge power control is specific to an equipment manufacturer's recommendations.

For the subsequent analysis, we will assume that under clear sky conditions, cell edge ATPC is set 10 dB below maximum transmit power and is proportionally greater for shorter links. This provides the inbound link with a clear sky signal level above threshold of $25 - 10 = 15$ dB. As there is a 16 dB antenna gain differential between the TS and the CS antennas, this also sets the relative link gain of a TS-CS victim path to be 6 dB greater than that of a CS to CS interference path. We will employ this gain differential to advantage for intra-system and inter-system C/I estimates as subsequently described.

2 TDD Cellular System Design and Frequency Re-use

TDD systems are assumed to be operating within a cellular environment as subsequently discussed. As TDD frequency re-use for FWA is relatively new, and frequently misunderstood, we will describe it in some detail in Annex B.

TDD frequency re-use begins with recognition of the impact of two additional TDD specific interference exposure mechanisms, these being CS to CS and TS to TS. While there are a number of TDD re-use plans that are viable, we will describe only one that is based on 30 degree sectors and 12 carriers. There is no actual requirement for the TDD carriers to be formed from paired carrier blocks, however this would frequently be the case as most historical frequency plans have been developed with only FDD under consideration.

The frequency re-use plan described is capable of supporting unsynchronized TDD burst operation between cells as well as supporting dynamic asymmetric transmit/receive burst duration within any sector of any cell. With 24 frequency/polarization assignments available, the re-use plan requires the use of only 18 out of the 24 assignments when sectors are repeated at 180 degrees and cells are laid on an N=9 cluster. There are thus 6 reserve sector assignments that can be employed for a number of purposes, including interference mitigation.

Figure A2 illustrates an N=9 cluster that is based on the concepts previously discussed and detailed in Annex B. Cluster concept details and intra-operator grade of service (GOS) performance estimates may also be found in Annex B.

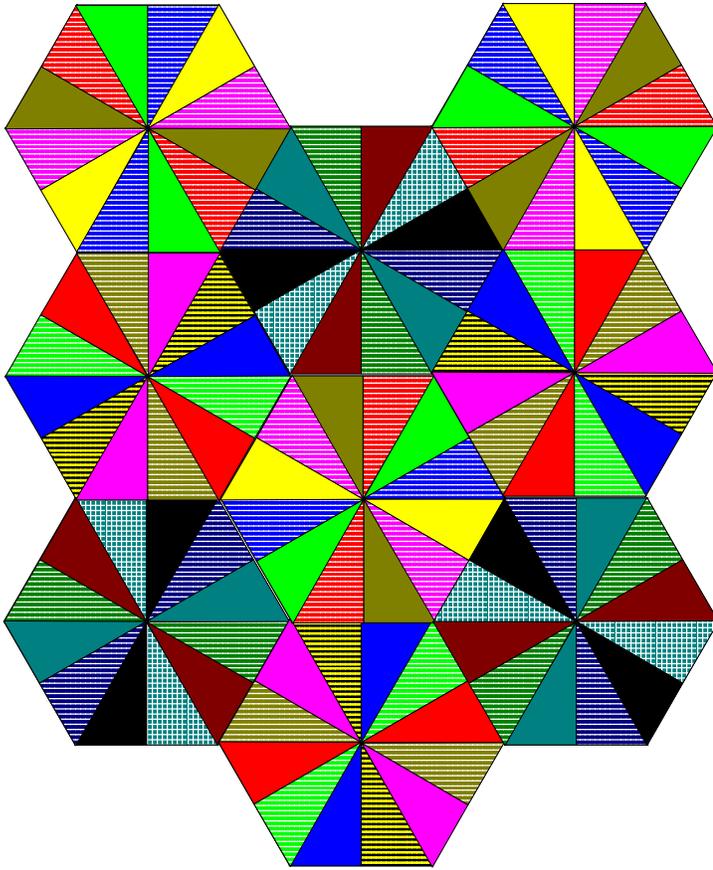


Figure A2: N = 9 Cluster

3 Coexistence Between Two FWA Cells

We will address the coexistence issues based on a Monte Carlo simulation analysis. While algebraic Interference Scenario Occurrence (ISOP) estimates are useful for estimation of worst case exposure likelihood, the Monte Carlo simulation estimates can provide accurate modeling across a sector or a cell that can also include antenna angular discrimination, rain correlation/de-correlation and other system-specific parameters.

The probability of interference will be based on the cumulative distribution function (CDF) of interference likelihood vs. interference power flux density (pfd), expressed in $\text{dBW}/\text{m}^2/\text{MHz}$. This approach has been proposed for the interference coordination process within the IEEE coexistence standards committee 802.16 [6]. Two pfd trigger levels are proposed, these being -114 and -94 $\text{dBW}/\text{m}^2/\text{MHz}$. Below the -114 pfd trigger level, no coordination between operators is required. Between the two trigger levels, coordination is required only for existing stations. Above the -94 trigger level, coordination is required before deployment.

In order to constrain the number of system configuration options to be manageable, we will set the carrier bandwidth to be the same for both operators at 14 MHz. Further, we will set the FWA transmission and equipment parameters to what we envisage to be typical values. These are detailed in Annex B. Both clear sky LOS and ITU-R P. 452-8 rain propagation models will be considered, consistent with the rain loss computation methodology described in Section 1.5.

3.1 Adjacent Area – Same Frequency Block Interference

For this analysis we place the two cells on either side of an area boundary at some CS separation distance D . There are 2 CS sites, one for Operator A (interferer) and one for Operator B (victim). We can always draw a straight line between the two CS stations and therefore the sector alignment is as shown on Figure A3. TS site locations (both interference and victim) are randomly positioned to be on the periphery of their respective sectors.

For a clear sky analysis, the rain cell is not present. Under rain fading conditions the rain cell is positioned at the center position of the victim link as illustrated, noting that the victim TS location has been randomly positioned on the sector periphery.

The relative alignment of the interference and victim sectors is assumed to be uncoordinated. To compute the pfd grade of service we therefore sequentially spin the conflicting sectors of both cells. If appropriate to the calculation, we randomly re-position the victim link TS location within its sector, and hence the rain cell location for each sequential spin. The sector spin increment is somewhat arbitrary. For the following, we have selected a 5 degree spin increment relative to a 360 degree spin rotation. Thus, each pfd GOS interference estimation is comprised of $72 \times 72 = 5184$ interference calculations.

We will examine only TS to CS and CS to CS interference conflicts in detail as these are considered to be the most serious. Both involve at least one CS sector and therefore are expected to be most vulnerable to interference exposure.

While a CS to TS interference link also involves a sector antenna, it is a one-on-many scenario that would limit serious interference only to TS locations with minimum antenna angular discrimination.

Severe TS to TS interference links have a very low likelihood of occurrence, as they require a boresight alignment between two narrow beam width TS antennas. Further, the interference TS transmitter operates under ATPC. This reduces the EIRP differential between the interference TS to TS link and the victim CS to TS link by 10 dB.

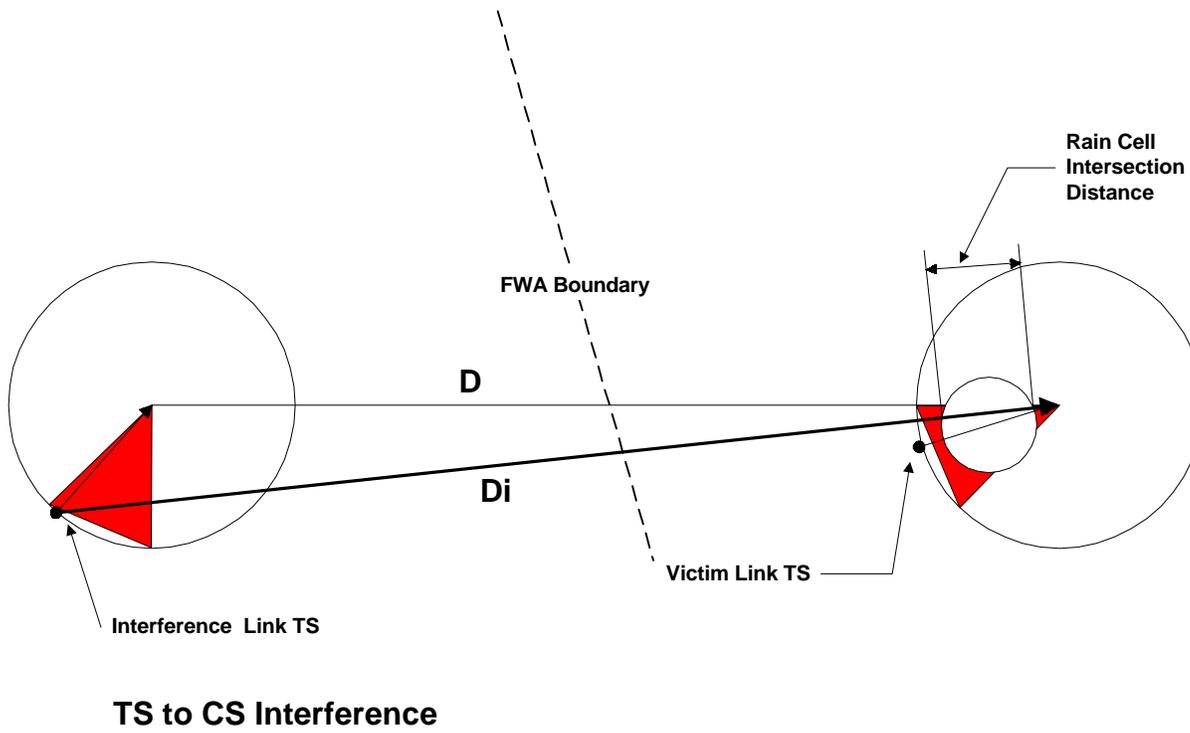
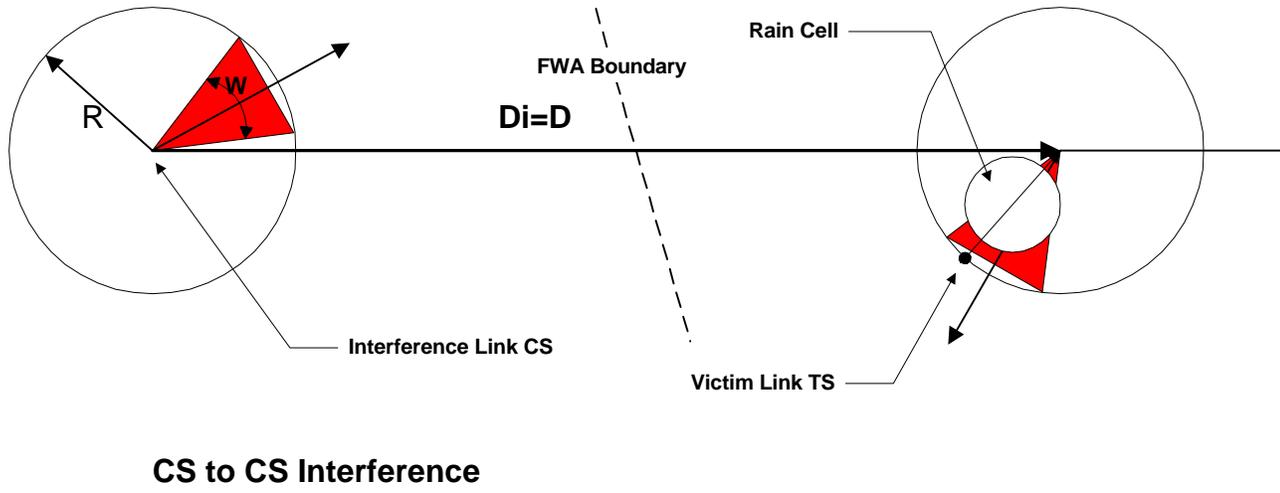


Figure A3: Interference Geometry

3.1.1 TS to CS Interference

Geometrical considerations associated with this interference mechanism are detailed in Annex B. This is a many-on-one interference scenario. Here, we require only 1 worst case TS location to impact on all inbound TS to CS transmission links in the victim sector. To place the following results in perspective we note that the clear sky desired link pfd is $-79.9 \text{ dBW/m}^2/\text{MHz}$. A worst case boresight aligned TS to CS interference link at 3R distance represents a pfd of $-90.2 \text{ dBW/m}^2/\text{MHz}$. These values are computed based on the system parameters defined in Annex B.

3.1.1.1 Clear Sky

For this simulation, we recognize that interference TS locations may be located anywhere in the interference sector. We thus select 20 random periphery positions for each combinatorial spin, compute the pfd for each selection and then select the worst pfd. Absolute pfd levels are shown on Figure A4. Here, we should note that absolute and relative signal to interference pfd levels will be the same. Both interference and victim TS transmitters are operating with ATPC and EIRP is therefore balanced.

For a CS separation distance of 7.2 km, only 1.5% of exposures exceed the upper pfd trigger level of $-94 \text{ dBW/m}^2/\text{MHz}$ while approximately 17% exceed the lower trigger level of $-114 \text{ dBW/m}^2/\text{MHz}$. For larger separation distances, there are no exposures that exceed the upper trigger point and less than 2% exceed the lower trigger point.

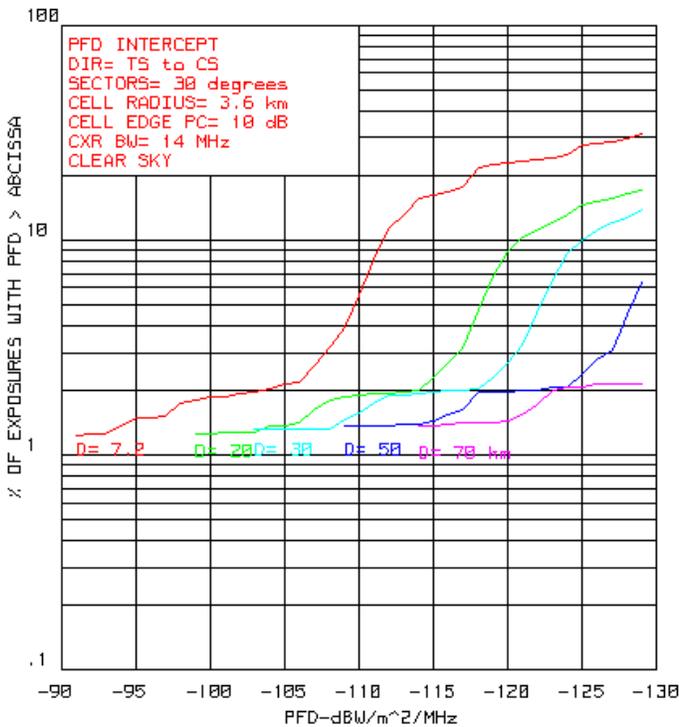


Figure A4: Clear Sky TS to CS pfd vs Distance for 30 Degree Sectors

3.1.1.2 Rain Faded

For this simulation, we also recognize that the victim link TS locations may be located anywhere in the victim sector. A worst case victim link will be experiencing a 25 dB rain fade while the interference vector may experience a lesser level of rain attenuation that can be as low as the debris loss. Consequently, for each random TS interference location, we select 20 random vector assignments for the victim link. We then select the worst pfd estimate for GOS estimation. Absolute pfd levels are shown on Figure A5.

Now, it must be noted that relative signal to interference pfd is increased by 15 dB above the results shown. Here, the victim link operates at full transmitter power while the interference link operates at 10 dB ATPC. Relative pfd is thus set by the fade attenuation experienced by the victim link (25 dB), less the link gain differential (10 dB).

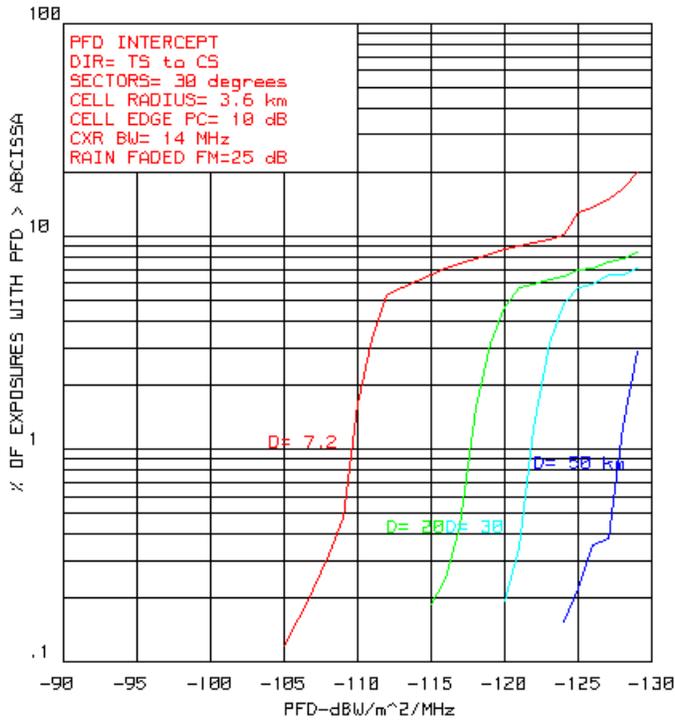


Figure A5: Rain Faded TS to CS pfd vs Distance

3.1.2 CS to CS Interference

The geometrical configuration for this interference scenario is also detailed in Annex B. This is a one-on-one interference scenario that involves interference exposure between two relatively wide beam width sector antennas. Here, the interference sector CS impacts on all inbound transmission links within the victim sector.

Clear sky desired link pfd is again $-79.9 \text{ dBW/m}^2/\text{MHz}$. A worst case boresight aligned CS to CS interference link at distance $2R$ represents a pfd of $-92.3 \text{ dBW/m}^2/\text{MHz}$.

3.1.2.1 Clear Sky

For this simulation, the interference CS sector is aligned with the victim CS sector in accordance with the relative directional spin assignments of the two antennas. Here, there is no requirement to select different TS locations in either sector. Figure A6 illustrates the absolute pfd GOS estimates for this scenario. Relative signal to interference pfd is 6 dB better than the results shown. This is a result of the EIRP differential (antenna gain less $\text{ATPC} = 16 - 10 = 6 \text{ dB}$).

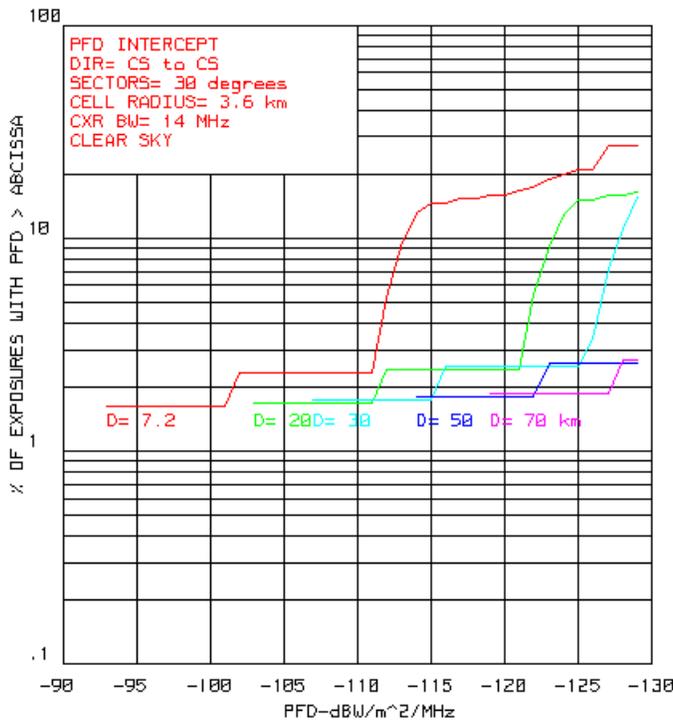


Figure A6: Clear Sky CS to CS pfd vs Distance

3.1.2.2 Rain Faded

This interference simulation also recognizes that the interference CS to CS link may experience some correlated rain fade attenuation. Hence, the victim TS to CS link is set to 20 random vector assignments. The rain cell is again located as previously described and worst case pfd is selected. Simulation results for absolute pfd levels are shown on Figure A7. Relative signal to interference pfd levels are now 9 dB worse than illustrated. In this case, the victim TS transmitter operates at maximum power at an EIRP 16 dB greater than the interference CS transmitter. With a 25 dB rain fade on the victim link, the net differential is $25 - 16 = 9 \text{ dB}$.

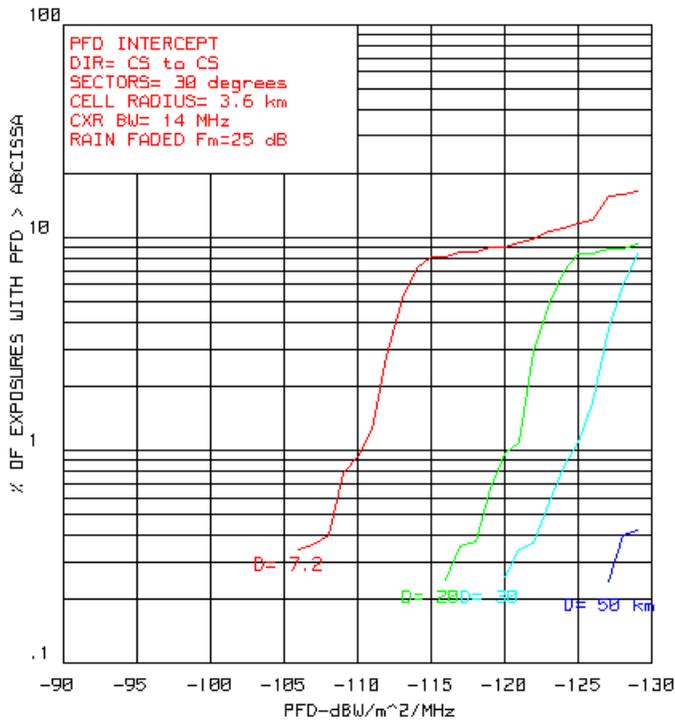


Figure A7: Rain Faded CS to CS pfd vs Distance

4.0 Interference Mitigation

Mitigation of TDD boundary interference can exploit the use of the reserve sector assignments that are available with the described N=9 frequency re-use plan. These reserve assignments can be substituted to eliminate identified interference conflicts.

In addition, the N=9 re-use plan is quite rugged with respect to intra-system interference as discussed in Annex B. Consequently, on a selective basis, boundary interference sensitive sectors can also be replaced by sector assignments fundamental to the re-use plan.

5 Summary and Conclusions

Boundary area co-channel interference estimates have been developed for TDD systems that employ an N=9 frequency re-use plan and utilize 30 degree sector assignments. Interference estimates have been developed based on an absolute level of pfd under both clear sky and rain faded conditions.

A rain fade model that accounts for rain attenuation on both the interference and victim transmission links has been described. It is observed that when 30 degree TDD sector assignments are employed, the rain fade model indicates a strong attenuation correlation between both links. This is a direct result of the interrelationships between expected cell size, sector size and rain cell size. Attenuation correlation is diminished as sector size increases.

While interference coordination requirements are normally specified in terms of absolute values of pfd, relative pfd levels are required to develop C/I performance estimates. Relative pfd estimates require knowledge of operational system parameters and ATPC strategies.

ANNEX B

This Annex provides additional detail about TDD frequency re-use planning and on the methodology employed for the establishment of expected interference between two adjacent area-same frequency FWA cells.

1 TDD Frequency Re-Use Planning

While TDD frequency re-use does not require paired frequency assignments, such assignments are normally found to be the case due to historical FDD frequency planning. TDD frequency re-use planning take's advantage of the fact that TDD can employ two carriers for every FDD paired carrier. For example, 6 paired FDD carriers yield 12 TDD carriers. In conjunction with 2 polarization's H/V there are thus 24 degrees of freedom (DOF) for sector frequency/polarization assignments.

Given 12 TDD carriers, Figure B1 illustrates the frequency/polarization assignments specified for the sectors and Cell Types. V-POL assignments are shown as solid colors and H-POL assignments are shown shaded. With sector assignment repeat at 180 degrees, 6 assignments are required per cell. Hence, $24/6 = 4$ distinct Cell Types can be developed as illustrated. Note that, except for the 180 degree sector repeat, frequency assignments are not repeated within a cell. Also note that adjacent sectors are cross-polarized and that the closest frequency flanking within a cell is a 2nd adjacent carrier separation that is at least 2 sectors removed. Self-cell interference is therefore considered to be minimal.

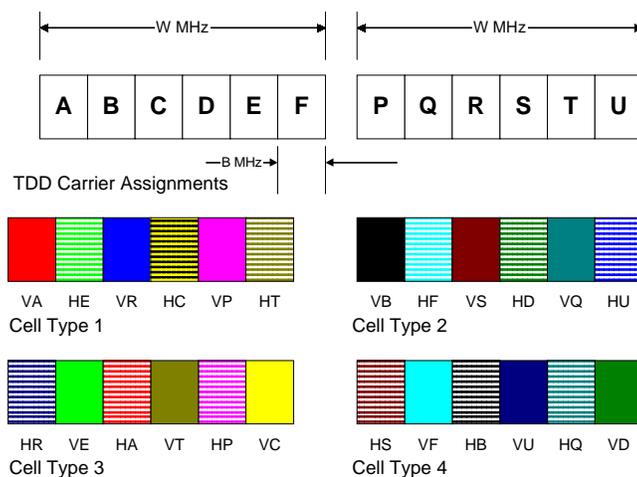


Figure B1: Frequency and Polarization Assignments for 30 Degree Sectors

There are a number of cellular cluster configurations that can be considered for development of expandable TDD frequency re-use plans. These vary in conjunction with the number of available carriers and in conjunction with sector size. An $N = 9$ reference cluster is illustrated on Figure B2 that is appropriate to 12 TDD carriers and 30 degree sectors. The clusters can be repeated in a contiguous tessellating fashion as service requirements dictate.

Cell Types are repeated 3 times within the cluster at sector rotations of 0, 60 and 120 degrees. These sub-clusters form a triangle as illustrated for Cell Type 1 on Figure B2 cells 1, 2, 3). For these rotations, the antenna side lobe isolation provided by ETSI specified antennas is sufficient to minimize both co-channel and adjacent channel exposure problems.

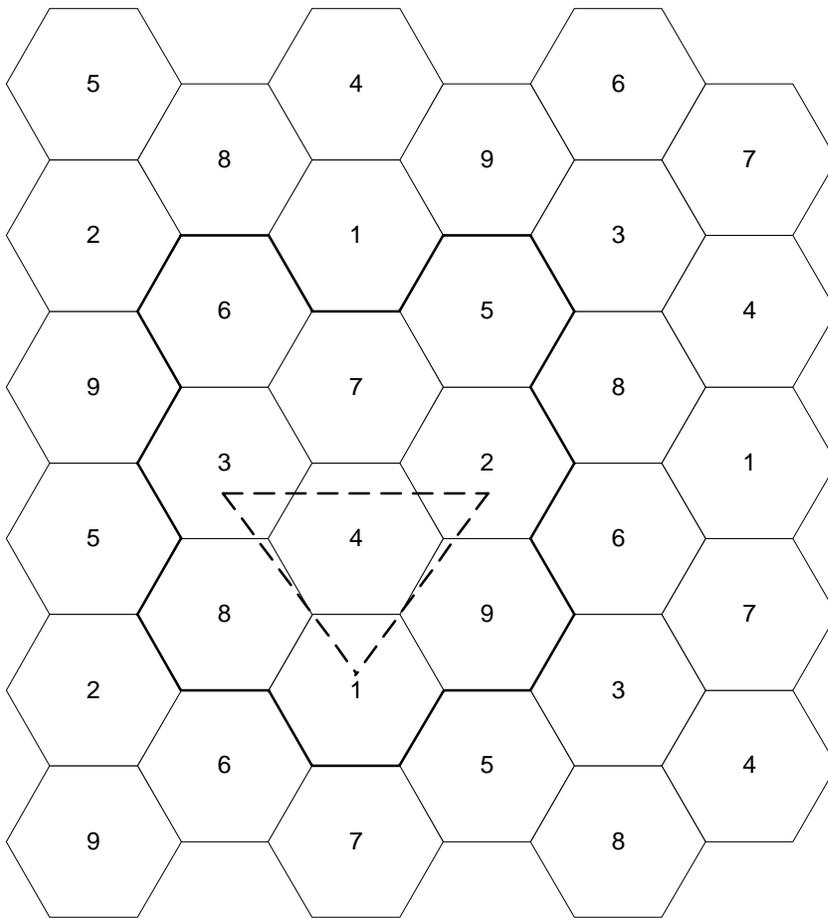


Figure B2: Cell Assignments for an N = 9 Cluster

Excellent intra-system C/I performance is achieved with such a plan. Figure B3 illustrates a clear sky GOS estimate for a victim CS. The simulation C/I is estimated across a 49 cell grid and assumes all interference sectors are active and that all represent LOS coupling levels. Across such a large grid, many of the interference paths would be expected to be blocked, or would be expected to experience significant excess propagation loss. Such estimates can be included in the simulation but are not considered for the result illustrated.

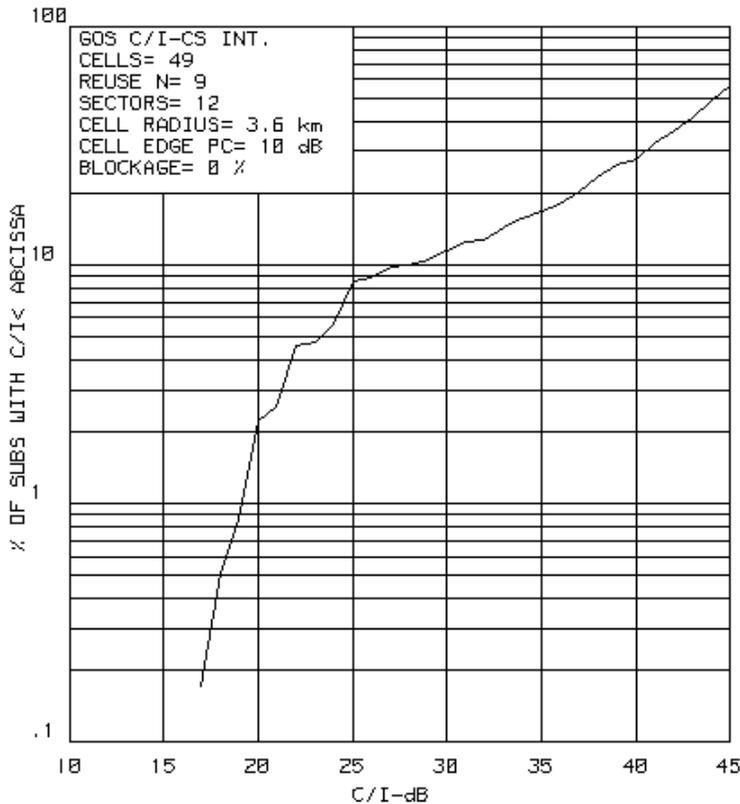


Figure B3: Intra-System CS Interference GOS for N = 9 and 30 Degree Sectors

The simulation assumes asymmetric TDD operation and hence the transmission direction of an interference sector is randomly assigned to be either outbound or inbound. Therefore both CS to CS and TS to CS interference mechanisms are addressed. Adjacent carrier interference is also addressed based on the frequency relationships of the victim and interference signals and the emissions mask specified in Figure A1 of Annex A.

There are no interference exposures that exceed 4-QAM threshold ($C/I = 13$ dB) and only 1% are at the 1 dB threshold impairment level ($C/I = 19$ dB). Only 1% of the exposures exceed 16-QAM threshold ($C/I = 19$ dB) and only 5% exceed the 1 dB threshold impairment ($C/I = 24$ dB).

The development of the N=9 cluster required utilization of only 3 of the 4 Cell Types. There is thus 1 Cell Type in reserve (6 frequency/polarization assignments). Intra-system, these reserve assignments can be selectively employed to increase the capacity of a sector or deployed in support of greater modulation index transmission. Alternatively, they can be employed to resolve coexistence conflicts, both same-area/adjacent-frequency and adjacent-area/same-frequency.

For any hexagonal cellular plan, there are 6 nearest neighbor same cell repeats. These are illustrated on Figure B4. The distance re-use ratio is thus $D/R = 6R/R$, equivalent to 15.6 dB for a LOS interference vector. As illustrated, a CS to CS interference alignment is cell edge; therefore we would expect to gain 3 dB from each antenna (6 dB total). However if we locate a worst case subscriber on cell edge, then we would lose 3 dB of antenna gain, resulting in a net distance plus antenna isolation of 18.6 dB. Now recall that it was proposed that TDD would employ a clear sky PC of 10 dB on cell edge and that there is a 16 dB gain differential between the TS and CS antennas. Hence, the victim TS to CS link achieves a 6 dB positive link gain (EIRP) differential.

Consequently, the net worst case clear sky C/I from this exposure is 24.6 dB. This is less than a 1 dB threshold impairment to 16-QAM.

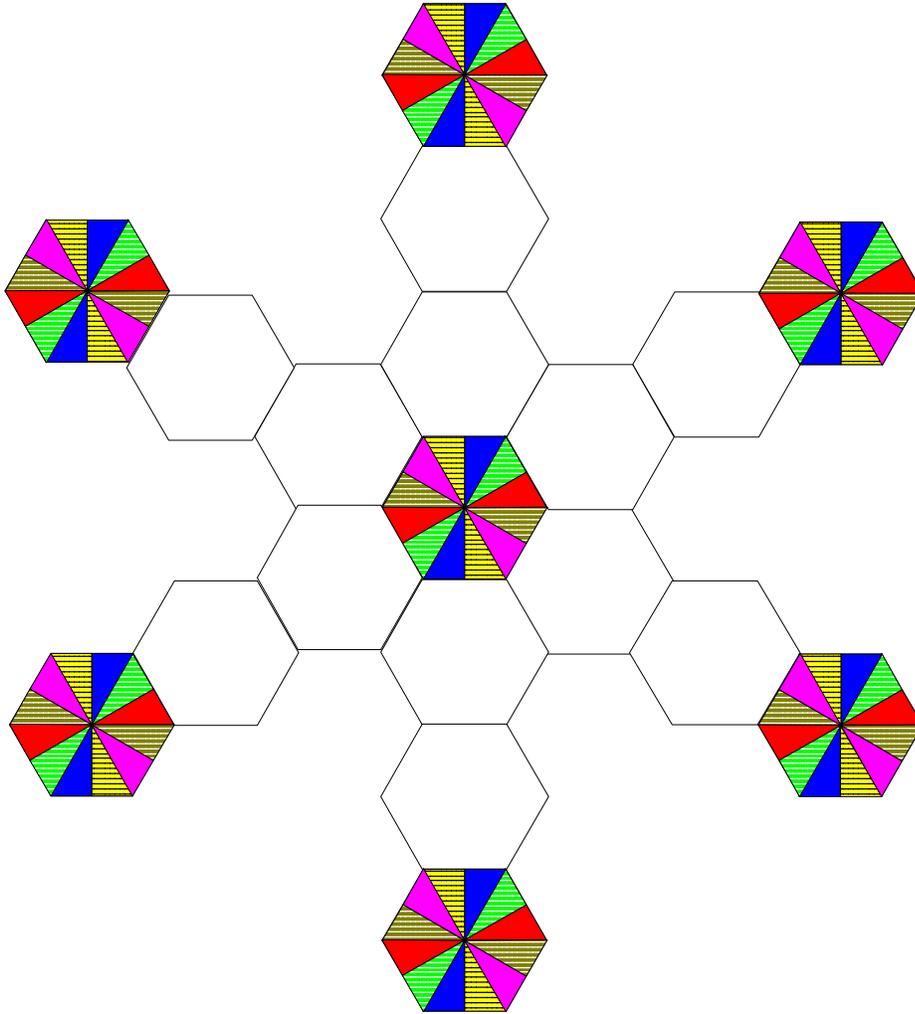


Figure B4: Nearest Neighbor Cell Type Repeats for N=9 and 30 Degree Sectors

Figure B5 illustrates a worst case rain fading alignment. Again the victim TS to CS link is positioned worst case so as to minimize the intersection of the rain cell with the interference vector. The rain cell is centered on the transmission path at $R/2$ and it may be noted that the interference path intersects the rain cell across a significant chord distance. For $R = 3.6$ km and $R_C = 1.2$ km, the intersection chord distance is approximately $D_1 = 1.6$ km. Based on the rain cell characteristics discussed in Section 2.5 of Annex A, we would expect the interference vector to experience $1.6/2.4 \times 25 = 16.7$ dB of rain loss. In addition, the victim sub-hub link is now operating at maximum power and exploits the full antenna gain differential of 16 dB.

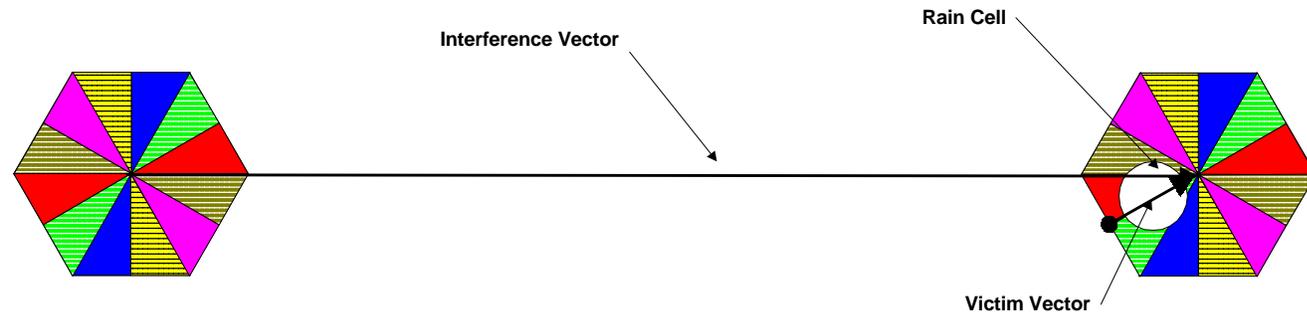


Figure B5: Worst Case Co-Channel Rain Fading Alignment

An interference estimate is now

Distance:	15.6 dB
Antenna Angle:	3.0 dB
Antenna Gain:	16.0 dB
Int. Rain Loss:	16.7 dB
Victim Rain Loss:	-25.0 dB
C/I:	29.3 dB

As previously discussed, same Cell Type rotational repeats are employed at multiples of 60 degrees in order to develop the N=9 cluster. These are shown on Figure B6 for Cell Type 1. There are two CS to CS interference exposures as illustrated. The distance separation is 3R equivalent to a LOS distance protection ratio of 9.5 dB.

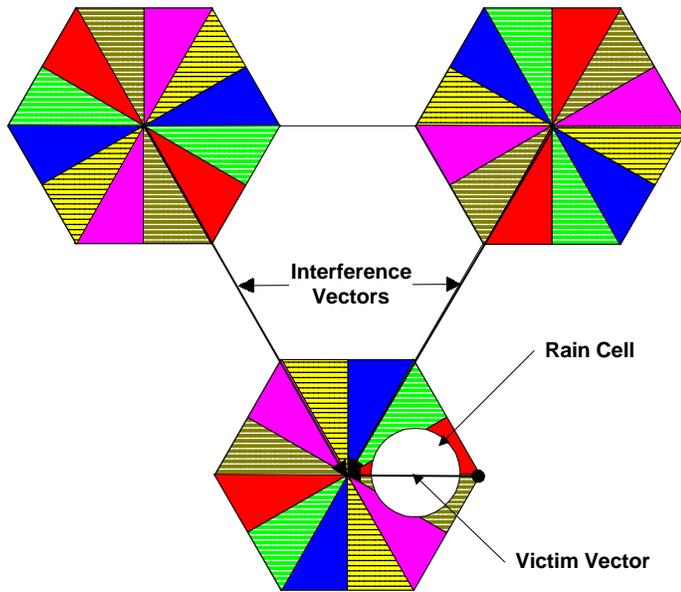


Figure B6: Rotational Repeat Interference Geometry

Interference estimates for these two mechanisms are:

	Exposure 1	Exposure 2
Distance:	9.5 dB	9.5 dB
Antenna Angle:	21.0 dB (45 degrees)	23.0 dB (105 degrees)
Antenna Gain:	16.0 dB	16.0 dB
Int. Rain Loss:	1.1 dB	1.1 dB
Victim Rain Loss:	-25.0 dB	-25.0 dB
C/I:	22.6 dB	24.6 dB

Exposure 1 is just slightly worse than a 1 dB impairment to 16-QAM threshold. Further, at the antenna interference angles noted, it is anticipated that actual antenna side lobe suppression will likely be substantially greater than that of the ETSI mask.

Based on the preceding examples, it is concluded that 30 degree sectored TDD will be quite rugged with respect to uncorrelated rain fading.

2 Coexistence Between Two FWA Cells (Adjacent Area - Same Frequency)

This coexistence performance estimate is based on a Monte Carlo simulation analysis. While algebraic Interference Scenario Occurrence (ISOP) estimates are useful for estimation of worst case exposure likelihood, the simulation estimates can provide accurate modeling across a sector or cell that can also include antenna angular discrimination and other system criteria.

The probability of interference will be computed as a cumulative distribution function (CDF) of likelihood vs. interference power flux density (pfd), expressed in dBW/m²/MHz. In order to constrain the number of system configuration options to be manageable, we will set the carrier bandwidth to be the same for both operators at 14 MHz. Further, we will set the FWA transmission and equipment parameters to what we envisage to be typical values. These are:

Frequency F_C :	26 GHz
TX Pwr P_T :	+18 dBm
TS Antenna Gain G_{TS} :	+36 dBi (ETSI TS1 pattern)
TS Antenna Angular Disc. A_{TS} :	As Computed (dB)
CS Antenna Gain G_{CS} (30 degrees):	+20 dBi (ETSI CS2 pattern)
CS Antenna Angular Disc. A_{CS} :	As Computed (dB)
Cell Edge Inbound ATPC P_C :	10 dB (clear sky); 0 dB rain faded
Atmospheric Absorption L_A :	0.1 dB/km
Cell Radius R :	3.6 km
Int. CS to Victim CS Distance D :	As Specified (km)
Interference Distance D_I :	As Computed (km)
Debris Region Rain Loss L_{DEB} :	0.1 dB/km
Volume Rain Cell Interference Loss L_{VOL} :	As Computed (dB)
Interference Free Space Loss FSL_I :	$32.4 + 20\log(D_I) + 20\log(F_C)$ (dB)
Conversion Factor for a 1 m^2 Isotropic Ant. A_R :	49.75 dB
Rain Cell Diameter D_C :	2.4 km
Fade Margin to 4-QAM Threshold FM :	25 dB
Carrier Bandwidth B :	14 MHz
dBm to dBW Conversion:	-30 dB

Both free space LOS and ITU-R P. 452-8 propagation models will be considered, consistent with the rain loss computation methodology described in Section 1.5 of Annex A.

2.1 Simulation Methodology

Interference geometry and interference GOS was reported on in Annex A. The reader will be referred to the drawing references in Annex A as required.

For the analysis we place the two cells on either side of an area boundary at some separation distance D . There are 2 CS sites, one for Operator A (interferer) and one for Operator B (victim). We can always draw a straight line between the two CS stations and therefore the sector alignment is as illustrated on Figure A3. TS locations (both interference and victim), are randomly positioned on the cell periphery of their respective sectors. The closest CS separation considered is 7.2 km, a distance at which both cells just touch.

For a clear sky analysis, the rain cell is not present. Under rain fading conditions the rain cell is positioned at the center position of the victim link as illustrated, noting that the victim link has been randomly positioned along the sector periphery.

The relative alignment of the interference and victim sectors is assumed to be uncoordinated. To compute the pfd grade of service we therefore independently spin the conflict sectors of both cells. If appropriate to the calculation, we randomly reposition the TS locations for each sequential spin. The sector spin increment is somewhat arbitrary, as long as it is finely enough quantized to develop realistic probabilistic estimates. For the following, we have selected a 5 degree spin increment relative to a 360 degree spin rotation. Thus, each pfd GOS interference estimation is comprised of $72 \times 72 = 5184$ interference calculations.

In the following, we will examine only the two most serious TDD interference conflicts, these being TS to CS and CS to CS

2.2 TS to CS Interference Conflicts

The interference geometry for this case is shown on Figure A3.

2.2.1 Clear Sky

For this case the link pfd equation is

$$PFD = P_T - P_C + G_{TS} - A_{TS} - FSL - A_{CS} - L_A \times D_I - 10\log(B) - A_R - 30 \text{ ----- (1)}$$

It is to be noted in (1) that we have employed the conversion factor for a receive isotropic antenna but that we have included the antenna rejection of the receiver antenna. This is realistic as the only the portion of the isotropic reception that is representative of interference is the magnitude that is received by the angular selective receiver antenna.

To employ this equation, we recognize that interference TS locations are randomly positioned within the interference sector. Consequently, for each sector spin, a single interference TS location may provide significant antenna isolation or negligible antenna isolation. Thus, for each sector spin, we repeat the computation for 20 random locations of the interference TS and select the worst pfd estimate. The absolute level pfd GOS for this computation is shown on Figure A4. The pfd estimates have been developed for a minimum hub separation distances of 7.2 km, and at additional hub separations up to 70 km.

For the clear sky case, both interference and victim links operate with 10 dB cell edge ATPC and therefore link gain is balanced. Hence the effective pfd is

$$PFD_{\text{eff}} = PFD \text{ ----- (2)}$$

Sanity tests are always desirable when simulation estimates are developed. In Annex A, we noted that, for a CS separation of 2R, a worst case interference TS at 3R represented an interference pfd of approximately $-91 \text{ dBW/m}^2/\text{MHz}$ (1 dB sorting bin). This is as shown on Figure A4.

An ETSI specified 30 degree sector mask is flat across ± 20 degrees. Hence, when we spin the victim and interference sectors in 5 degree increments, we will experience 9 worst case alignments of both the interference sector and the victim sector. Consequently, we expect $9 \times 9 = 81$ combinatorial worst case interference conflicts. Given that the total combinatorial intersections equal 5184, then we would expect $81/5184 \times 100 = 1.6\%$ worst case exposures.

Figure A4 indicates a slightly lower percentage of worst case conflicts (approximately 1.3%). This is reasonable, given that each sector spin assigned 20 random interference locations and it is not assured that the worst case TS location will always be within a boresight angular antenna alignment.

2.2.2 Rain Faded

The TS to CS pfd is now

$$PFD = P_T - P_C + G_{TS} - A_{TS} - FSL - A_{CS} - L_A \times D_I - L_{DEB} - L_{VOL} - 10\log(B) - A_R - 30 \text{ ---(3)}$$

If the interference vector is outside an intersection with the volume rain cell, then

$$L_{VOL} = 0.$$

For this simulation, we again select 20 random positions for an interference TS to CS link within the interference sector. For each of these we also select a random position for each victim TS to CS link within the victim sector and center the position of the rain cell on the victim path. We then select the worst pfd based on the 20 jointly random locations with the GOS results as shown on Figure A5.

The effective pfd is now impacted by the victim link rain fade at magnitude FM, however the victim link is now operating at maximum power. The effective pfd is thus

$$PFD_{\text{eff}} = PFD + FM - P_C \text{-----} (4)$$

As noted in Section 3.1.1.2 of Annex A, absolute pfd is improved as worst case direct facing interference exposures are expected to intersect the rain cell and hence experience some magnitude of rain attenuation. The simulation results support this argument. For $D = 7.2$ km, worst case pfd is reduced by 15 dB.

2.3 CS to CS Interference Conflicts

The interference geometry for this case is shown on Figure A3.

2.3.1 Clear Sky

The pfd equation is now

$$PFD = P_T + G_{CS} - A_{CSi} - FSL - A_{CSv} - L_A \times D_I - 10\log(B) - A_R - 30 \text{-----} (5)$$

The pfd simulation results are as shown on Figure A6. This simulation does not require any random positioning of TS locations. However the victim TS to CS link now gains the advantage of the antenna gain differential less ATPC. The effective pfd is thus

$$PFD_{\text{eff}} = PFD + G_{CS} - G_{TS} + P_C \text{-----} (6)$$

A sanity test applied to Figure A6 indicates that we have 1.6% of exposure at a -92 pfd level, exactly what should be expected. An ETSI specified antenna falls 10 dB for the next 5 degrees. Hence, for a 5 degree spin, the next pfd level should be at -102 as shown. Further, this pfd level includes $9 \times 2 \times 2 = 36$ additional interference hits. This should move the CDF to $(81+36)/5184 \times 100 = 2.25\%$. This is confirmed by the simulation.

2.3.2 Rain Faded

For rain fading, the CS to CS interference pfd equation is

$$PFD = P_T + G_{TS} - A_{CSi} - FSL - A_{CSv} - L_A \times D_I - L_{DEB} - L_{VOL} - 10\log(B) - A_R - 30 \text{-----} (7)$$

Again, for this case, we select 20 random locations of the victim TS, position the rain cell as before, and then select worst case pfd. Absolute pfd simulation results for this case are shown on Figure A7. Effective pfd is negatively impacted by the rain fade at level Fm but acquires the full benefit of the antenna gain differential. Effective pfd is thus

$$PFD_{\text{eff}} = PFD + G_{CS} - G_{TS} + Fm \text{-----} (8)$$

3 Sector Width Sensitivity

As sector width increases, we would expect greater interference sensitivity as the likelihood of a critical interference path in alignment with victim receiver increases. We examine this sensitivity for the case of TS to CS interference and 90 degree sectors. This interference case applies equally to both TDD and FDD.

Figures B6 and B7 illustrate the pfd results for clear sky and rain faded conditions. The results can be compared against the pfd estimates shown on Figures A4 and A5. The results are quite revealing. For 30 degree sectors, absolute pfd improved under rain fading conditions as there was a strong likelihood of an interference vector intersecting the volume rain cell and thus experiencing some rain attenuation. For 90 degree sectors, this is no longer the case. There are simply too many possible TS interference locations that do not intersect the rain cell. Consequently, clear sky and rain faded pfd are about the same. Recalling that relative pfd is 15 dB worse than absolute pfd, we would expect an unduly large number of boundary interference exposures to significantly exceed 4-QAM threshold.

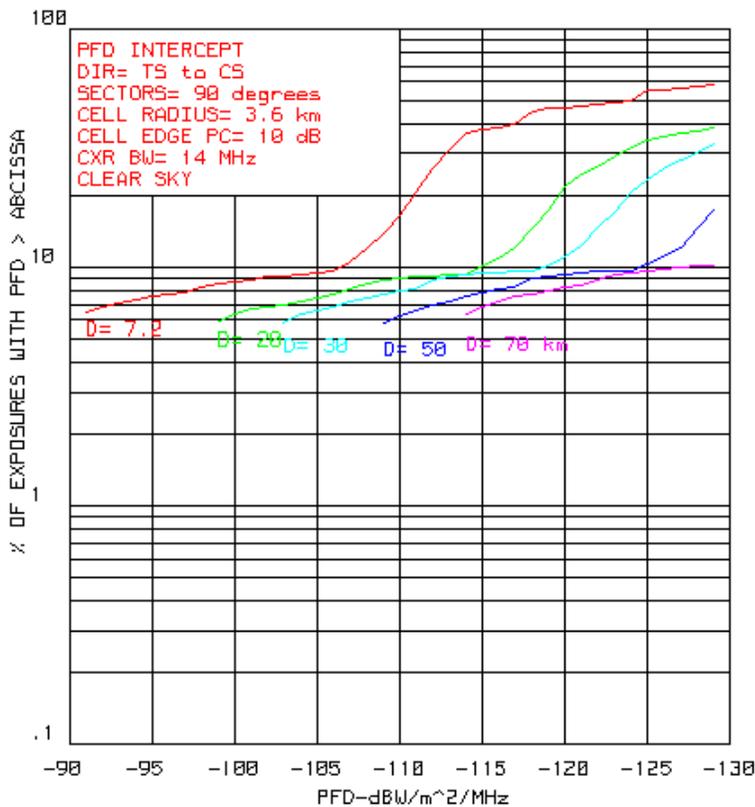


Figure B7: Clear Sky TS to CS pfd vs Distance for 90 Degree Sectors

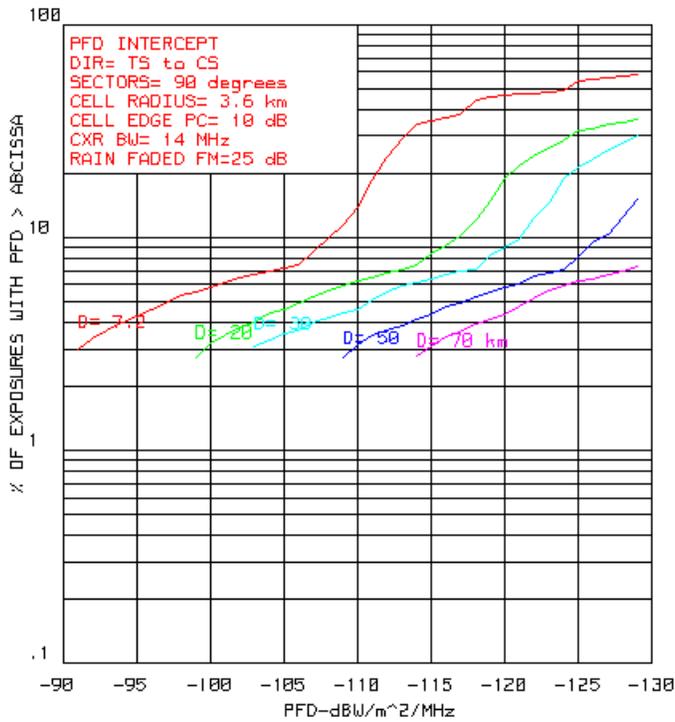


Figure B8: Rain Faded TS to CS pfd vs Distance for 90 Degree Sectors

This has serious system design implications for 90 degree sectored designs, not only for boundary interference coordination, but also intra-system. For example, some aggressive 90 degree - sectored FDD systems propose direct facing of the same frequency/same polarization sector assignments at short separation distances. Simple calculations can demonstrate that the antenna isolation provided by ETSI specified antennas is insufficient to prevent these systems from failing during conditions of uncorrelated rain fading. Further, such calculations show that tighter antenna specifications by themselves will not resolve the C/I issues. Simply stated, additional frequency assignments and alternative frequency re-use plans are required.