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Title	**Co-existence Simulations for P-MP and MP-MP networks**
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Re:	Input paper on interference system simulations for the Montreal Interim Meeting of the Coexistence Task Group, as proposed in session# 5, Albuquerque.
Abstract	This document describes a method and results of simulating the power received from a complete MP- MP system (mesh) at a PMP base station receiver or at a PMP subscriber station receiver, in a cell adjacent to or overlapping the mesh. It shows that the interference created can be kept to a low level without the need to use highly directional terminal station antennas and without the need for strictly applied guard bands between systems operating in the same geographical area.
Purpose	Contribution for consideration during the Montreal Interim Meeting as a basis for the interference scenarios section of the "Recommended Practices to Facilitate the Coexistence of Broadband Wireless Access (BWA) Systems" covering interference scenarios between P-MP and MP-MP Systems.
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Co-existence Simulations for P-MP and MP- MP Networks

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1 Introduction

This document describes a method and results of simulating the power received from a complete MP-MP system (mesh) at a PMP base station receiver or at a PMP subscriber station receiver, in a cell adjacent to or overlapping the mesh. It shows that the interference created can be kept to a low level without the need to use highly directional terminal station antennas and without the need for strictly applied guard bands between systems operating in the same geographical area.

The simulation is performed using a purpose-written program, which repeatedly constructs random (but adequately legitimate) MP-MP (mesh) systems and integrates the total power received at a given range and elevation, based on system, beam and terrain geometries. The main analysis and all the results presented are based on systems operating in the 28GHz band. The results of further simulations at 40GHz (not detailed in this document) are available and can be presented, if required.

Various papers from CEPT SE19 [ref. 1], IEEE [ref. 5,7] and ETSI TM4 [ref. 17] studying interference between P-MP cells conclude that antenna patterns and accuracy of pointing are important and that side lobe performance may need to be very good, in order that intra-system interference is at acceptable levels. Unless the geographical locations of stations in different systems are carefully co-ordinated (which is not generally feasible), the inter- system interference effects are likely to be less dependent on the detailed antenna patterns. The results for mesh systems show that antenna patterns are not at all critical to successful co-existence planning and that less stringent specifications for antennas are entirely satisfactory.

The analysis has concentrated mainly on interference created by a mesh, since this requires a statistical modelling approach. The interference received by a mesh can be estimated by the same methodology required between PMP systems, with slightly different parameter values (such lower gain subscriber antennas). However, the value of such analysis is limited, since a practical mesh will include a self adjustment routine to minimize or eliminate such interference problems.

The cases analysed are as follows:

(a) MP-MP / P-MP co-channel, co-polar, adjacent area

- Multiple MP-MP Subscribers to P-MP Hub
- Multiple MP-MP Subscribers to P-MP Subscriber

(b) MP-MP/ P-MP same area, adjacent and near adjacent channels

- Multiple MP-MP Subscribers to P-MP Hub
- Multiple MP-MP Subscribers to P-MP Subscriber

(c) ALL cases include clear air and rain – faded calculations.

2. Methodology

2.1 Available methodologies

Various methodologies are possible to assess the likely interference between BWA systems. The available methods include:

- Worst-case analysis (generally for a single interferer) [ref .5]
- ISOP (interference scenario occurrence probability) evaluation [ref. 1]
- Statistical modelling

Various scenarios for worst case analysis [5] have been identified in an earlier contribution to the recommended practice. These are not included in the current draft version of the document. Conclusions drawn from this work are highly dependent on assumptions made about certain system parameters, but because they are worst-case, they do not depend strongly on the actual antenna RPE. This kind of calculation is useful for all the possible cases of interference, including hub to hub calculations.

The ISOP method uses a geometrical approach typically in order to estimate the probability that at least one subscriber suffers interference at a level high enough to be unacceptable. A methodology of this kind can be found in [ref. 1] The results appear to be useful for systems with relatively few subscribers. However, for large numbers of subscribers, the probability rapidly becomes very large, so that some other measure of acceptable interference is more appropriate.

This paper describes a statistical approach, applied to the interference between a large number of stations in a MP-MP system and a cell [sector] in a P-MP system. The analysis covers both adjacent area co-polar systems and same area adjacent [or nearby] channel systems.

2.2 System Modelling

A model has been created for a P-MP sector and for a corresponding MP-MP system, using antenna patterns appropriate to each type of system, a model for wanted path length distribution and a propagation model.

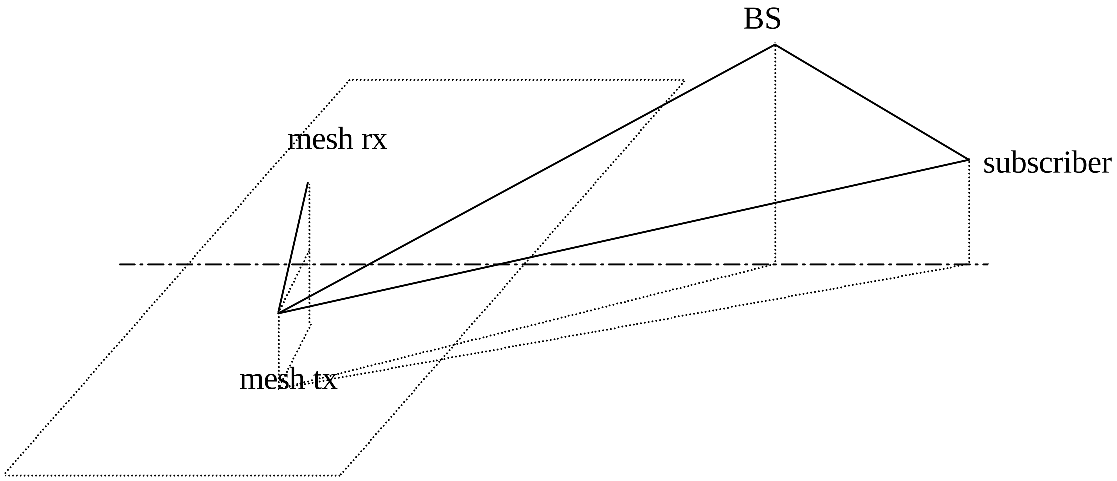


Fig.1 Path Geometry

The main attributes of the model are:

- Monte-Carlo radio- mesh simulation with realistic MP-MP system parameters.
- Line-of-sight propagation probabilities calculated from Rayleigh roof height distribution function as per CRABS WG3 report D3P1B [ref.3]
- Interfering power summed at mesh-facing PMP base or subscriber using full 3D geometry to compute distances and angles between lines of sight and antenna bore-sights.
- Effect of Automatic Power Control granularity (ATPC) included.
- PMP RPE's for 28GHz band to EN 301 215-2 V1.1.1 [ref. 12] with BS elevation profile ignored for realistic worst case.
- MP-MP antenna RPE model for 28GHz band simulates an illuminated aperture with side-lobes to EN 301 215 V1.1.1 [ref.12].
- Atmospheric attenuation to ITU-R P.676-3 [ref.10]
- Rain attenuation to ITU-R P.840-2 [ref. 11].
- Dry, storm and frontal weather patterns considered.
- 38 visible user-adjustable parameters.
- Interference level histogram display resolves level to 1dB and probability to 1ppm.

2.2 Rain Fading

Various rain – fading scenarios have been considered in the simulations:

- The effects of individual storm cells
- The effects of rain fronts
- The effects of rain falling uniformly over the area.

All rain scenarios have only a small effect on the results

2.3 MP-MP System Characteristics

MP-MP systems operate with short link paths, typically in the range 100m to 1km in length. Analysis of model meshes shows the following distribution of link lengths:

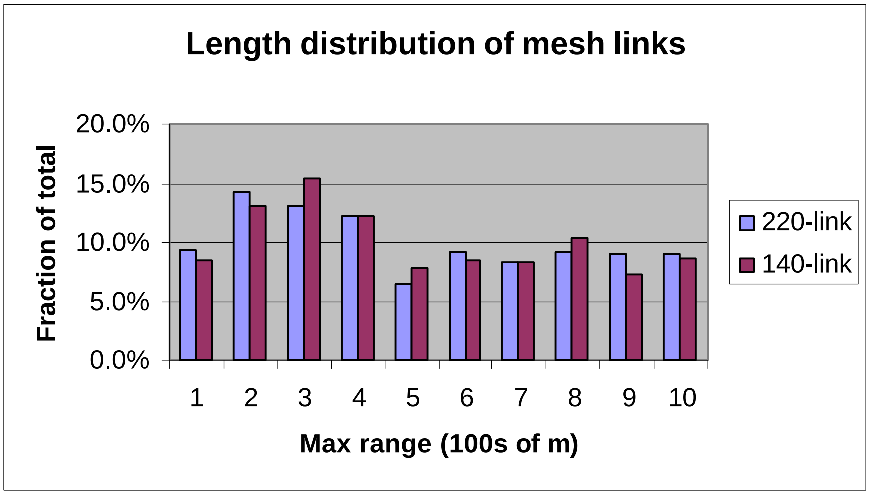


Fig. 2 Link Length Distribution

The significance of this is that the MP-MP system operates with normalised received power levels, i.e. for each link the transmitter power is set to give just enough received signal level. A short link means a low transmit power. The same mechanism serves to reduce the levels of interference outside the mesh.

2.4 Propagation

This document considers only line of sight paths for wanted signals and interference, using line of sight probabilities and free-space propagation.

The probability of interference line of sight is calculated from a model in which building heights are assumed to have a Rayleigh distribution, as in [ref. 3], although the probability calculations follow a slightly different method.

2.5 Antenna Beam Profiles

The current modelling for the 28GHz band is based on an antenna with half power beam-width of 9° in both azimuth and elevation. Slightly different values are likely to be optimum but the simulation results have not been found to be critical to moderate changes to the RPE. At 40GHz, the simulation has also been run with a different antenna pattern. This has a half power beam-width of +/-5 degrees and a front/ back ratio of 35dB. A new draft version of ETSI specification EN301-215 part 3 covering antennas for the 40GHz band includes an antenna with this specification [ref. 16].

A simplified model of the antenna pattern has been used. Although a real antenna will perform better than this model, it turns out not to be necessary from a coexistence point of view or from an intra system interference point of view. For the 28GHz band, the simplified model is based on a formula to represent the main beam and a side lobe pattern conforming to ETSI EN 301 215 part 2 (TS1 antenna) [ref. 12]. This is shown in the following figure:

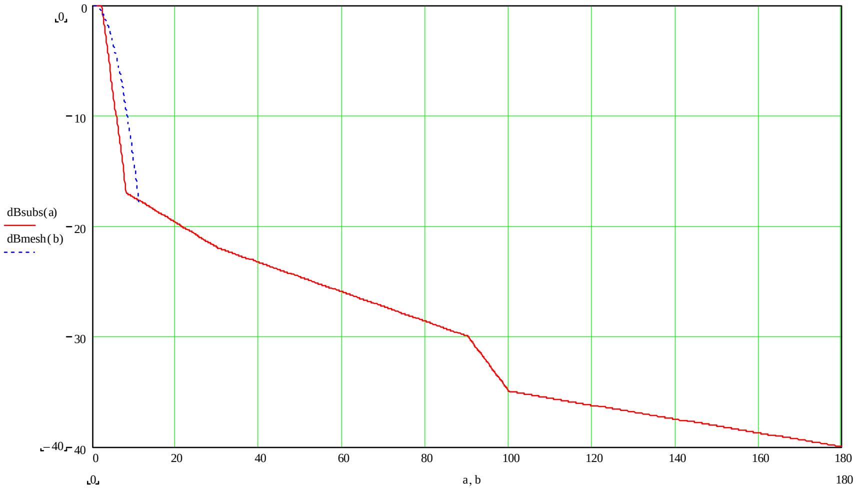


Fig. 3 Mesh Antenna Profile

This profile is used both to compute the increase in power for mesh links which are not horizontal and the reduction in power for interference lines of sight which are off bore-sight in azimuth and/or elevation.

2.6 Geometry

The basic arrangement of the model is shown below. Given a node density and the percentage of nodes which can transmit simultaneously, the simulator places the appropriate number of mesh transmitters randomly within the prescribed mesh area at heights following the Rayleigh distribution.

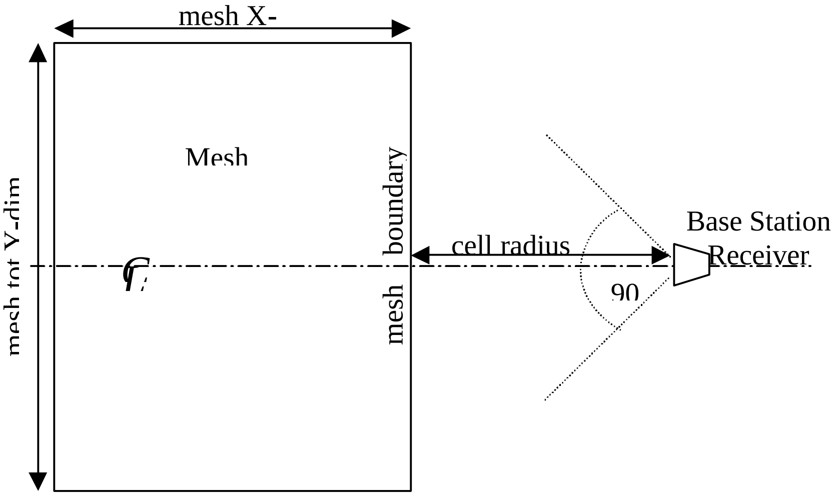


Fig. 4 PMP- Mesh Geometry

For each transmitter it then randomly places a receiver within the limits of link length and at an arbitrary angle. [Conditions near the edge of the mesh are satisfied by repeating any receiver placements which fall to the right of the mesh boundary.]

The effects of buildings are modelled by their density and fractional area, and terrain (the result of both building and land height variation) is modelled with a Rayleigh distribution.

The base station receiver horn is assumed to be a 90° sector aimed directly at the centre of the mesh, with a gain which is flat to ±50°, falling off thereafter at 1dB every 4.5°.

2.7 Interfering Power Calculation

From each mesh transmitter and in line with the line of sight probability, the power received by the base station is computed. All these powers are summed, and the result rounded to the nearest dBm and assigned to a histogram bin, so that the relative probability of each power level can be estimated.

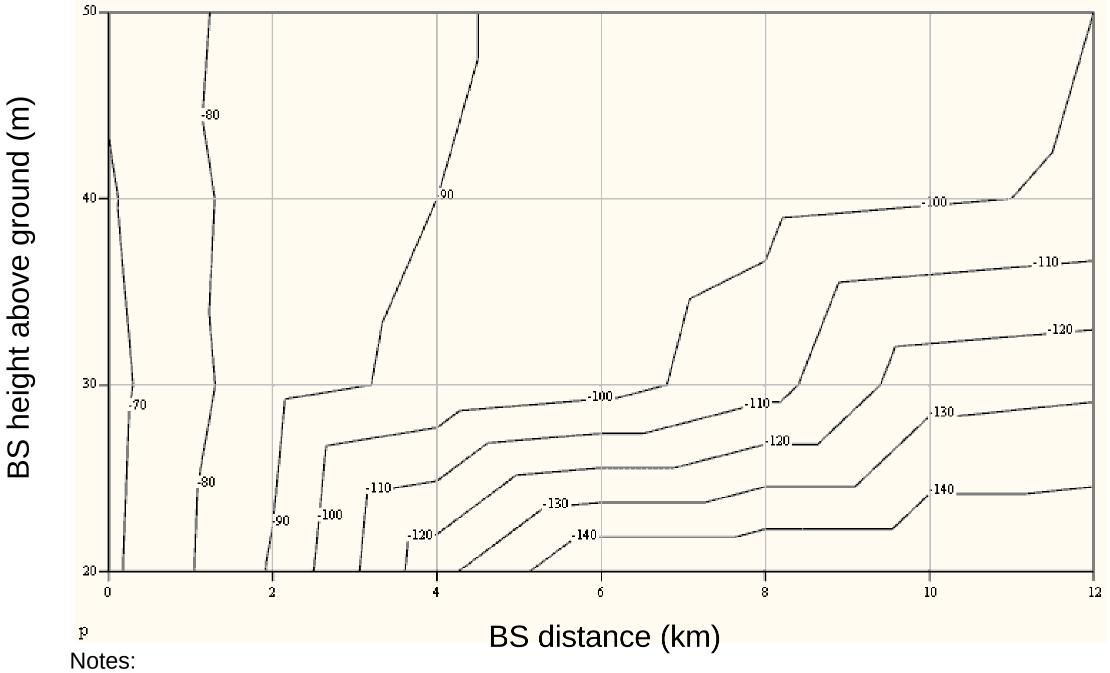
3. Adjacent Area, Co Channel Case

3.1 Mesh to PMP Hub Results –Dry Weather

Simulation runs of a large number of randomly generated meshes have been run to generate a spatial picture of the interference levels. The results are produced for both dry weather and rain fading conditions. Fig 1 (below) shows results for the dry weather case. Note that the levels plotted are the maxima that occurred in the simulations, so could have occurred for only 0.02% of the time.

Fig. 5

BS Interference (dBm) as a function of BS distance (km) and height (m)



Notes:
Rayleigh parameter = 20m

The vertical axis is the hub (base station) antenna height, relative to ground level. The Mesh stations are at various heights determined by the Rayleigh distribution curve. The height that occurs with maximum probability is 20m. The horizontal axis is the distance from the <u>edge</u> of the mesh to the <u>centre</u> of the PMP cell. A series of contour lines are drawn, each corresponding to a different level of total interference received at the hub. The values considered are from –70dBm to –140dBm.

The mesh transmitters in the simulation use 28MHz channels, transmitter power appropriate to 16QAM modulation and a frequency of 28GHz. For a base station with 28MHz channels, the -100dBm contour corresponds to an interference level of –114.5dBm/ MHz, which is low enough to have negligible impact on performance. It can be seen that a 50m high hub antenna needs a spacing of only 12km from the mesh edge to receive negligible interference. Note that this and other results are very much worst-case figures (0.02% probability), so that most simulations give much better results, allowing closer spacings in nearly all circumstances.

3.2 Effects of Rain

Rain fading has also been considered and simulated. Two additional scenarios are considered:

- A single storm cell, randomly placed
- A rain front, oriented in the most adverse position

The results of one representative set of these simulations are shown in fig.2 below (logarithmic probability scale).

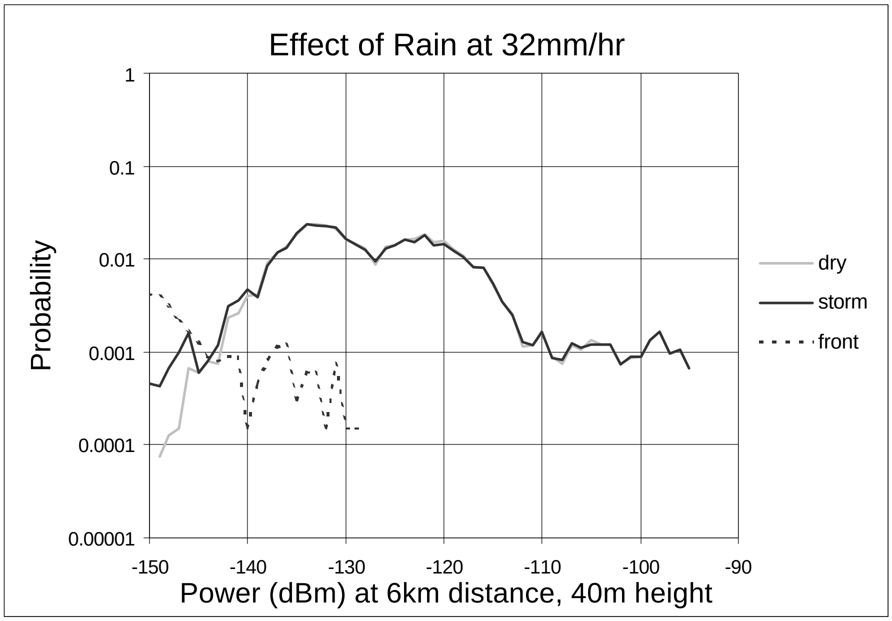


Fig. 6 Effects of Rain Fading (Co- channel systems, geographically spaced)

It can be seen that the effect of a rain storm cell is negligible, except where interference is at a very low level (in which case the results are actually improved by rain). For a rain front, the worst case result found shows a general reduction in interference during rainy periods. Very similar results were found for other base station heights and values of system spacing.

3.3 Mesh to PMP Subscriber Interference

A similar analysis to the mesh – hub simulations can be carried out for the mesh to PMP subscriber case. From a large number of simulations, two plots of results are presented, as follows:

a) with the PMP subscriber antenna pointing horizontally towards the mesh:

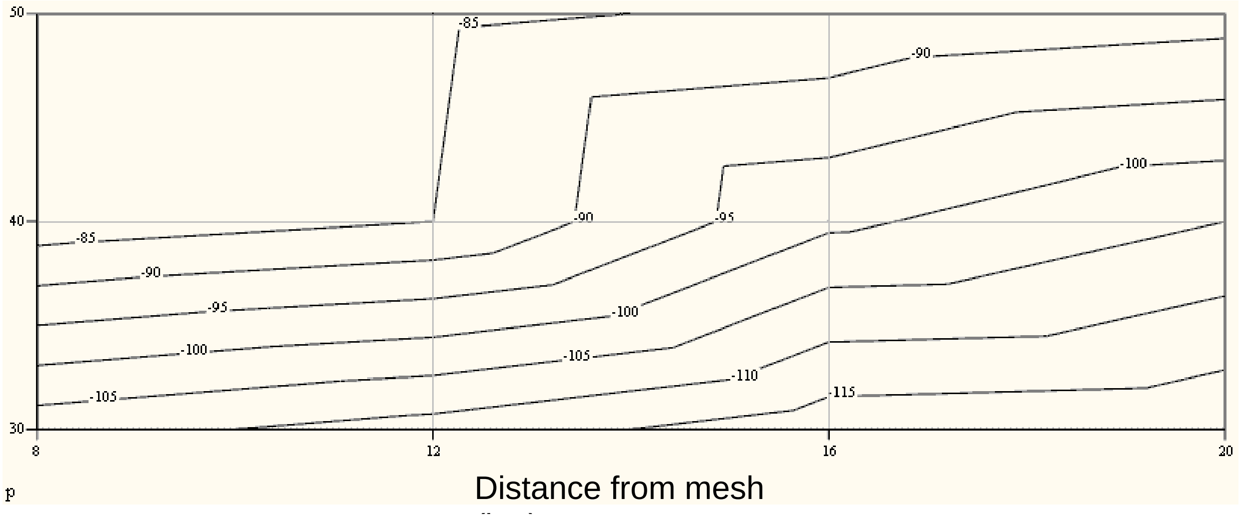


Fig.7

This plot shows that for typical antenna heights (20m) an approximate spacing of 12km is required between the PMP subscriber and the edge of the mesh to reduce interference to the required threshold. PMP subscribers with this orientation will be on the far side to the hub, so that in most cases the mesh to hub spacing requirement will dominate.

b) with the PMP subscriber antenna pointing towards a hub 50m high, 12km from mesh:

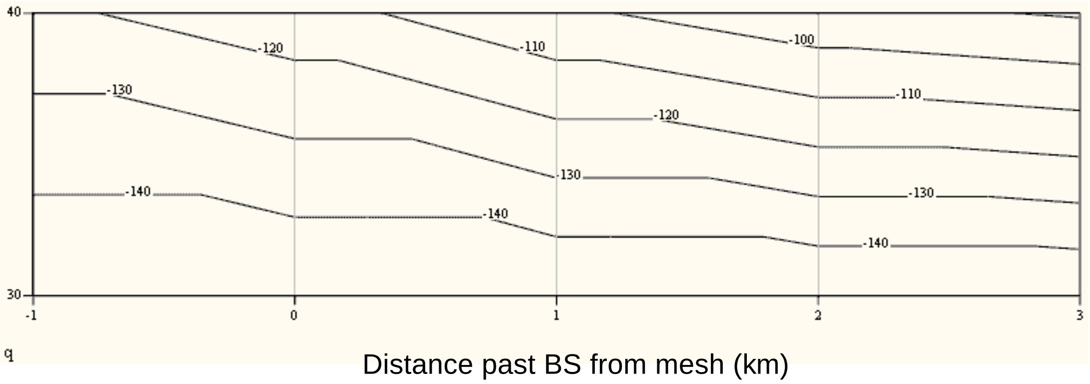


Fig.8

This is a more realistic case and again shows that the nominal spacing required for the hub will be the controlling factor. All PMP subscribers that are closer than the hub (12km in this example) receive negligible interference.

The effects of rain fading are, as for the hub case, negligible.

3.4 Conclusions for the Co-channel Case

Mesh systems do not generate high levels of external interference. The analysis, based on a large number of simulations of relatively high- density random mesh configurations, show that system spacings can generally be less than those required for P-MP systems. The analysis is valid for TDD and FDD systems.

In a practical mesh system, self-adaptation to avoid interferers will be a standard feature. The result will be a reduction in the necessary spacing of co-channel systems, which in some cases could nbe reduced to zero. In any event, a guideline based on random (non adapting) mesh systems is conservative.

A summary of the conclusions for the co-channel case is as follows:

1. A mesh system does not need high gain antenna with strongly suppressed side-lobes in order to reach acceptable levels of external interference

2. The effects of rain fading are very small

2. There is no hub to hub interference (an MP-MP system does not use hubs)

4. Co-channel system geographical spacing can be low

5. Self- adjustment of an MP-MP system will mitigate many or all of the potential interference cases between individual stations

4. Same Area Adjacent Channel Case

4.1 The interference model

This model is similar to that used for studying individual interferers, but differs in the following ways.

The mesh

Mesh nodes are randomly distributed, so that each mesh link is determined by two random nodes chosen such that their separation lies between 50m and 1000m.

The inclination of each mesh link is limited to a maximum of 4.5° from the horizontal and is determined by the Rayleigh-distributed heights of its terminal nodes.

The PMP cell

Subscriber antennas are mounted at Rayleigh-distributed heights but all have line of sight to the hub antenna.

Propagation

Propagation is considered for uniformly dry conditions, and also for a randomly-placed weather front (an approximately linear boundary between wet and dry weather) and for a single randomly-placed storm (circular area of rain).

Interference

The probability that a line of sight exists from any mesh subscriber to the PMP hub is derived assuming a Rayleigh height distribution for randomly-placed intervening buildings. The elevation angle of the interference line-of-sight is calculated from the height difference between the two interfering elements.

Weather

Apart from uniformly dry and wet weather, calculations were performed for

- a randomly positioned and orientated weather front dividing dry from wet propagation conditions,
- a single randomly positioned rain storm of diameter between 1km and 3km.

4.2 Results for Mesh to PMP Hub – Adjacent Channel

Results are presented for interference caused by a mesh. Interference from specific cellular configurations to a mesh can also be simulated, but given the way in which a mesh avoids interference in normal operation, it is not clear what value such results might have. In a practical mesh, each station will measure incoming interference from all sources and directions and provide this information to a database. The system configuration will then be adjusted automatically to minimize or eliminate the incoming interference. This means that the random orientation assumed in the simulations is very pessimistic and will over –estimate the amount of interference actually experienced.

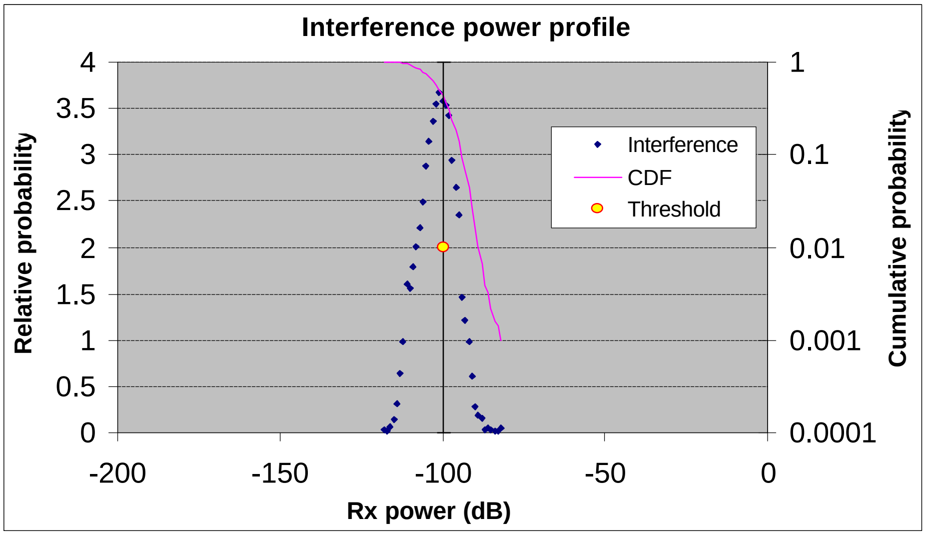


Figure 9 Aggregate mesh to PMP hub: dry weather, adjacent channel

The received total power profile is very similar under all conditions. However, the coloured curve (solid curve) in Figure 9 shows the probability that the received power exceeds any given value, and the table below shows how the probability of exceeding the receive threshold varies between scenarios.

Weather	Max. interference power	Probability of exceeding threshold
Dry	-82.2 dBm	37.4%
Random rain front	-78.5 dBm	31.9%
Random rain storm	-79.4 dBm	36.0%
Uniform rain	-78.7 dBm	28.2%

It can be seen that the highest value for interference power exceeds the desired interference threshold (-100dBm) by around 22dB, so that by requiring a single-channel guard band (21 dB additional attenuation, taken from ETSI NFD[1] tables) interference can largely be avoided under all scenarios.

(1 NFD = Net Filter Discrimination value)

4.3 Effect of Guard Bands

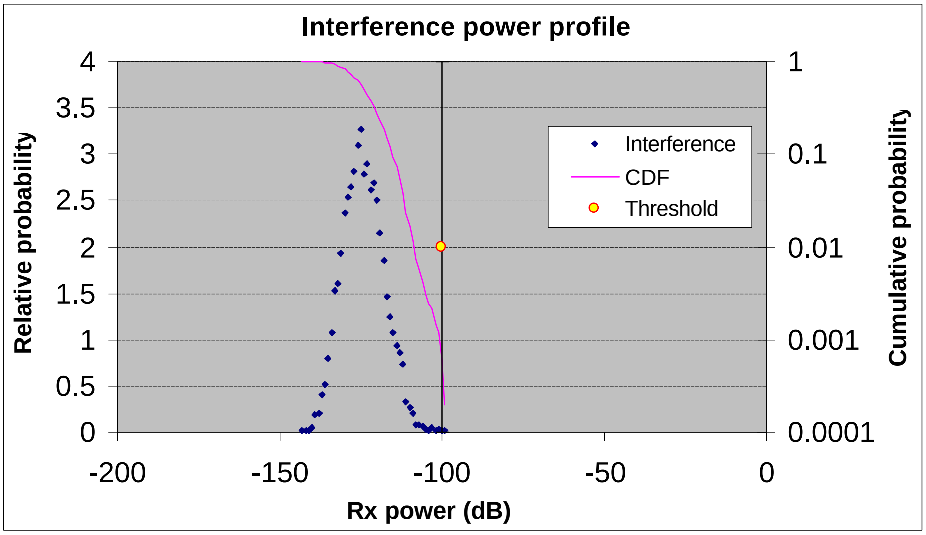


Figure 10 Aggregate mesh to PMP hub: uniformly wet weather, single-channel guard band

The results of the simulation with a single (28MHz) guard channel between the mesh and PMP cell are shown in Figure 10. The worst scenario of those computed is shown, with uniform wet weather conditions applied, although other weather conditions have negligible effect on the results. This corresponds to a 0.02% (and therefore negligible) probability that the –100dBm interference threshold is exceeded. The full table of probabilities is shown below.

Weather	Max. interference power	Probability of exceeding threshold
Dry	-103.2 dBm	0.00%
Random rain front	-99.7 dBm	0.02%
Random rain storm	-100.4 dBm	0.00%
Uniform rain	-99.7 dBm	0.02%

Since this analysis is based on randomly oriented mesh links, the results are pessimistic. A real mesh will automatically avoid interference to and from the hub as much as possible. However, it does show that, for all weather conditions, mesh and PMP systems are easily co-ordinated in the same area, with a channel spacing similar to or less than that required between two P-MP systems.

4.4 Results for Mesh to PMP Subscriber

Interference from a mesh to a single PMP subscriber has also been modelled. The scenario is only slightly different from the case of two PMP subscribers. It has relatively low probability of occurrence but, where interference occurs, it could have a high level (in an extreme case, receiver blocking is possible), as with the case of PMP systems.

A PMP subscriber is most susceptible at the edge of a PMP cell. The results below are therefore reported assuming such a subscriber.

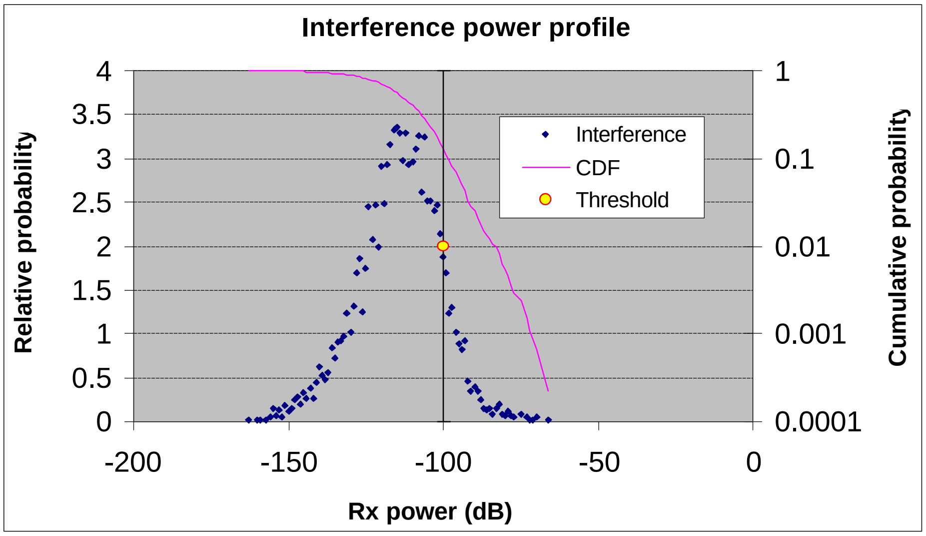


Figure 11 Aggregate mesh to cell-edge PMP subscriber: dry weather, adjacent channel

The interference criterion for the PMP subscriber assumes that it is operating at its noise threshold.

Weather	Max. interference power	Probability of exceeding threshold
Dry	-66.5 dBm	11.2%
Random rain front	-70.0 dBm	12.1%
Random rain storm	-70.9 dBm	11.9%
Uniform rain	-64.7 dBm	12.3%

The table above shows that the probability of interference is insensitive to the weather (except that in dry weather the subscriber will be operating above its receive threshold sensitivity, and so the allowable interference will be governed by C/I rather than the receiver noise level).

The maximum interference exceeds the threshold by around 35dB

4.5 Effect of Guard Bands

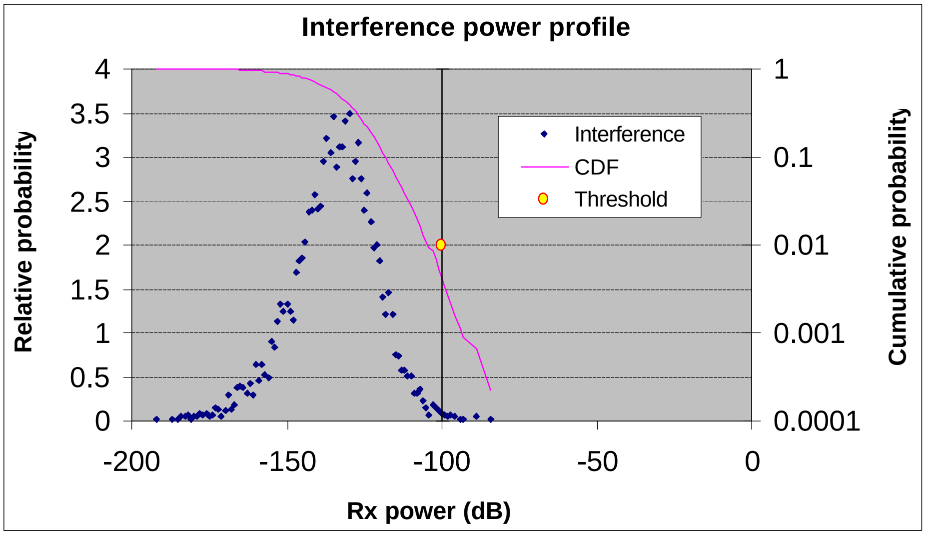


Fig. 12 Mesh to cell-edge PMP subscriber, random rain front, single channel guard band

If a single channel guard band is provided between the systems, then the maximum interference power still exceeds the threshold by around 15dB, but the probability of interference has now reduced to a very low value of around 0.35% (i.e. only 0.35% of randomly chosen mesh layouts leads to a figure above the required noise threshold).

A two-channel guard band would eliminate all cases of interference (other than where blocking dominates the interference) but would clearly be wasteful, since the probability is very low.

4.6 Conclusions for Systems in Overlapping Areas

The analysis by simulation of interference from a large number of relatively high density, randomly chosen, mesh configurations shows that interference to a PMP system in the same area (both with hubs and PMP subscribers) will be at a very low level when a single channel guard band is deployed between systems. This is valid for both FDD and TDD implementations.

Similar results have been found for the PMP to PMP case but applying to FDD systems only. Larger spacings may be necessary for the TDD case (still under study in [ref .17]).

The results are pessimistic, because, in practice, mesh configurations are not random. They are chosen so as to minimize intra – system and inter- system interface. In fact, a practical system can do this automatically. The result is that in many or most cases, the single channel guard band can be eliminated.

The reciprocal cases (PMP to Mesh) are still being analysed. A different methodoly is required, since the hubs and PMP subscribers are not pointed randomly. However, preliminary results show that similar guidelines on channel spacing will be satisfactory, combined with additional rules about location and pinting of victim subscribers that are positioned very close to hubs.

The type of weather has a minor effect on the total probability of interference; in general, the increased transmit power required by wet weather is also largely attenuated by the rain and so the net effect is small.

5. References and Related Documents

[1] CEPT SE19 Draft Report SE19(99) 195 rev.6; “Preliminary SE19 Report on the analysis of the coexistence of two FWA cells in the 24.5-29.5GHz bands”.

[2] “Coexistence between PMP and mesh architectures”, CSELT, ETSI BRAN #13.5 HIPERACCES Group, May 18-19,1999, London.

[3] RAL CRABS Report D3P1B, January 1999. Line-of-sight propagation probabilities calculated from Rayleigh roof height distribution

[4] HA13.5CSE1a; ETSI BRAN input paper; “Coexistence between PMP and Mesh architectures”

[5] IEEE 802.16cc-99/05; Coexistence scenarios for [PMP] systems

[6] IEEE 802.16cc-99/14; Power control assumptions for coexistence modelling

[7] IEEE 802.16.2-00/01; “Recommended practices to facilitate the coexistence of BWA systems”

[8] ITU-R P.838; “Specific attenuation model for rain for use in prediction methods”

[9] ITU-R P.452-8; “Prediction procedure for ... microwave

[10] ITU-R P.676-3; Atmospheric attenuation

[11] ITU-R P.840-2; Rain attenuation

[12] ETSI EN 301 215-2,V1.1.1; “Antennas for use in PMP systems (24GHz to 30GHz)”

[13] ETSI EN 301 213-3,V1.1.1; “Transmitter characteristics for TDMA PMP systems”

[14] BFWtg(00)03; UK RA paper; “Co-ordination between BFWA systems (28–42 GHz)”

[15] AC215/RAL/RCRU/DR/P/D3P1B/b1; Propagation planning procedures for LMDS

[16] ETSI EN 301 215-3 (draft); Antennas for use in 40GHz MWS

[17] ETSI TM4; DEN/TM04069: Draft report on coexistence of PMP and PTP systems

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