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millimetre Wave Transmission (mWT); V-band street level interference analysis

Disclaimer

Reference
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Keywords
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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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Contents

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document is related to the evaluation of interference that is expected to affect Fixed Service (FS) links, operating at street level in Radio Frequency (RF) band 57 - 66 GHz, (so called V-band), which is widely subject to unlicensed or light licensed regimes for part below 64 GHz.

The interference level in such conditions is a function of network density, equipment and antenna characteristics, available Bandwidth (BW).

In particular, the probabilistic analysis made with the SEAMCAT® tool, and the equipment and antennas designed according to the ETSI EN 302 217 multipart standard [i.1] and [i.2], show that, provided that a limited number of channels (5 to 10) are available, with limited channel BW (200 to 400 MHz), the operations of very high density networks with link density of up to about 200 links / km^2, to transmit high transmission capacities (in the order of 1 GHz/s per channel), are achieving acceptable confidence levels of operations (less than 2 % interference probability). Antenna class 2 RPE is proven to be already enough effective.

NOTE: SEAMCAT® is the trade name of a product supplied by the European Communications Office (ECO) This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Introduction

The specific characteristics of the V-band, concerning propagation and licensing, implies further analysis for understanding the condition of usage in specified environments.

While the high propagation loss due to oxygen absorption is expected to simplify frequency reuse and interference related impairments, the widespread adoption of licensing regimes, not generally link-by-link based, implies that it is not generally possible to implement an interference control mechanism based on the knowledge of the characteristics of links in a common geographic area.

For same reasons, even in the case a block license is assigned, the licensee can experience difficulties in undertaking this activity, due to the difficulty of knowing if other services, apart from FS, are also using the band in some locations. In any case, the user of the block needs to evaluate, in relation with the block size, how much the block can be used in term of exploitable link density.

The present document is intended to clarify these issues and aims to provide some general considerations and guidance.

1 Scope

The present document examines the application of radio links in the V-band frequencies, in urban applications, with special regard to interference issues, taking into account equipment characteristics, propagation issues and expected requirements.

Wherever possible, punctual and statistical analyses are performed and applicability of calculation methods is investigated.

The purpose of the present document is to investigate the feasibility of using unlicensed band by analysing interference levels in co-channels and adjacent channels in dense deployment of Point to Point (PP) radio at the street level, taking into considerations

- equipment characteristics,
- capacities and BW requirements,
- standards,
- available channels,
- antennas,
- available standards and propagation:
  - oxygen absorption;
  - loss and modelling.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 302 217-3: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 3: Equipment operating in frequency bands where both frequency coordinated or uncoordinated deployment might be applied; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.2] ETSI EN 302 217-4-2 (V1.4.1): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-2: Antennas; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.3] ECC Report 20: "Methodology to determine the density of Fixed Service".

[i.4] Recommendation ITU-R F.699: "Reference radiation patterns for line-of-sight radio-relay system antennas for use in coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz".

[i.5] Recommendation ITU-R P.676: "Attenuation by atmospheric gases".

[i.6] ECC Report 114: "Compatibility studies between multiple gigabit wireless systems in frequency range 57-66 GHz and other services and systems (except its in 63-64 GHz)".

[i.7] Recommendation ITU-T G.826: "End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections".

[i.8] ETSI EN 302 217-4-1: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-1: System-dependent requirements for antennas".

[i.9] SEAMCAT® Spectrum Engineering Advanced Monte Carlo Analysis.

NOTE: Available at: http://www.seamcat.org/.

[i.10] ITU-R Recommendation P.452: "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Void.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

C/I	Carrier-to-interference Ratio
I/N	Interference-To-Noise Ratio
P.Out	Output Power
Rx	Receiver
Tx	Transmitter

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ATPC	Adaptive Transmitter Power Control
BW	BandWidth

C	Carrier
dBi	dB relative to an isotropic radiator
DFS	Dynamic Frequency Selection
FR	Frequency Range
FS	Fixed Service
G	antenna Gain
I	Interferer
LoS	Line of Sight
N	Noise
PP	Point-to-Point
RF	Radio Frequency
RPE	Reference Pattern Envelope
RSL	Received Signal Level
thr	threshold
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying

4 Equipment and propagation characteristics

4.1 Equipment and RF

Link calculation has been executed starting from different equipment characteristics with different modulation schemes.

The following assumptions were made, based on ETSI EN 302 217-3 [i.1] for equipment in the 64 - 66 RF band:

Transmitter (Tx) power = +10 dBm

Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM) and 64QAM modulation schemes are considered.

Receiver (Rx) threshold: 4 QPSK: -65,5 dBm

16QAM: -58,5 dBm

64QAM: -52,5 dBm

Carrier-to-interference Ratio (C/I) (1 dB degradation): 4 QPSK = 24 dB

16QAM = 31 dB

64QAM = 38 dB

C/I (3 dB degradation): 4 QPSK = 15 dB

64QAM = 29 dB

Channel size: 200 MHz Channels have been used, obtained by joining 4 consecutive 50 MHz basic channels.

4.2 Capacities and requirements

Modulation schemes adopted in the examples are QPSK, 16QAM and 64QAM, corresponding to capacities in the order of 300 Mbit/s to 1 Gbit/s.

Parameters and Objectives:

- Availability has only been accounted for two values: 99,9 %, 99,99 %.

Values in this range are commonly used when unlicensed spectrum use is considered, and are coherent with the general approach of objectives' apportionment expressed by the ITU-T (e.g. Recommendation ITU-T G.826 [i.7]) for end-to-end paths, where less relaxed objectives are allowed to the edge (terminating) sections in comparison with the transit portions, where much higher requirements are needed to allow for proper end-to-end figures.

Rain rate: Three values for rain rate have been used from low to moderate: 30 mm/h, 42 mm/h, 60 mm/h.

- Antennas:
  - Antennas - RPE have been calculated according to Recommendation ITU-R F.699 [i.4] and ETSI EN 302 217-4-2 [i.2].
  - Antenna gain: Two gain values have been considered: 38 dBi; 32 dBi.

In order to be relatively close to real devices, characteristics in the main lobe have been done in accordance with Recommendation ITU-R F.699 [i.4], while Reference Pattern Envelope (RPE) outside the main lobe has been obtained as a realistic compromise between ITU-R and ETSI, since ETSI does not provide values for mainlobe.

An example of the RPE derivation is shown in figure 4.2.1 (38 dBi, ETSI EN 302 217-4-2 [i.2] FR7 class 3).

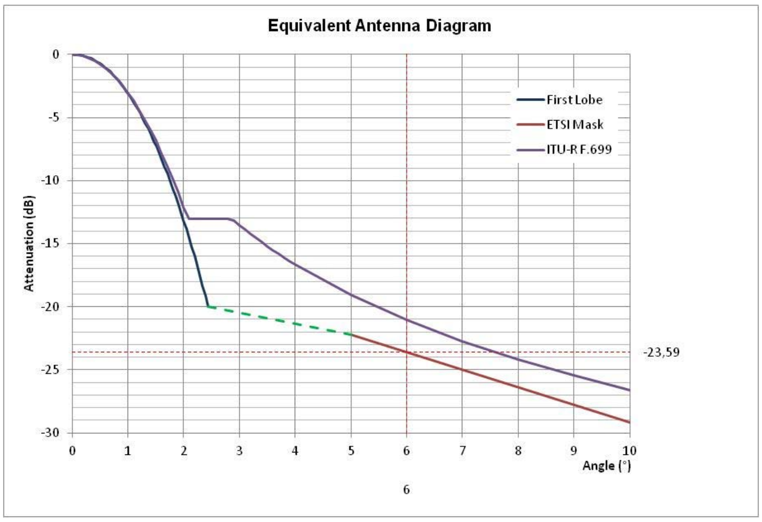


Figure 4.2.1: RPE derivation

4.3 Propagation: oxygen absorption - loss

Effect of gas absorption can be found in Recommendation ITU-R P.676 [i.5].

Figures 4.3.1 and 4.3.2 show current values according to version in force (Recommendation ITU-R P.676-10) [i.5].

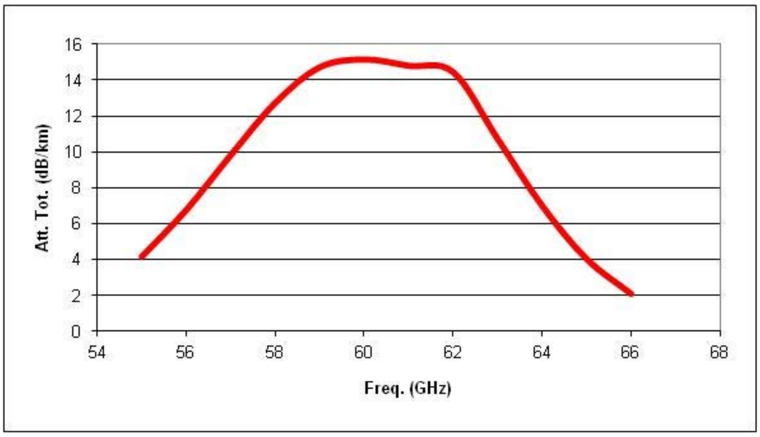


Figure 4.3.1: total attenuation

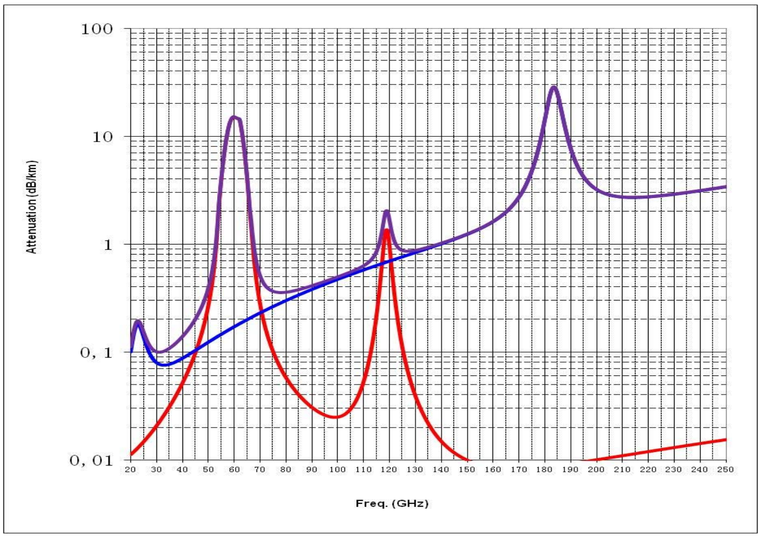


Figure 4.3.2: attenuation

5 Link Planning

5.1 Model used

Initial calculations have been performed based on a single link in Line of Sight (LoS) condition:

- Analysis of expected hop length has been performed.
- Analysis of interference areas in same conditions are reported.

6 Link calculations - geometrical approach

6.1 Physical analysis

6.1.1 Single link- LoS -Mainbeam

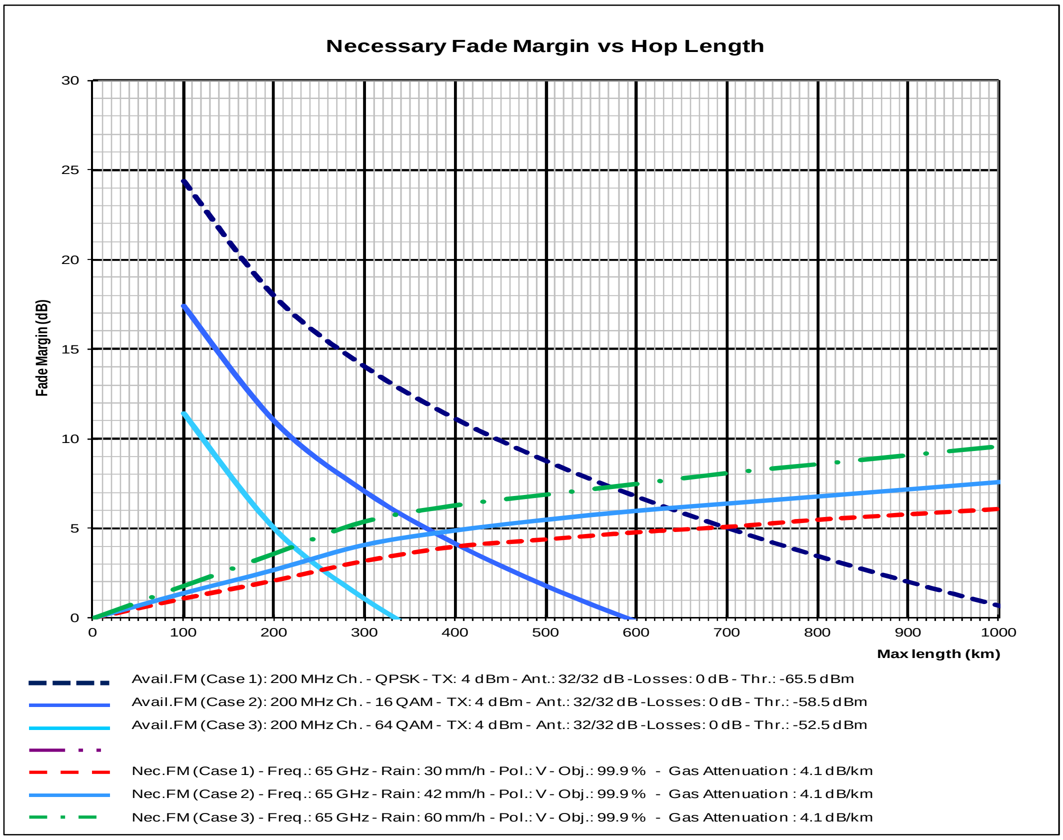
Effect of frequency /Effect of rain

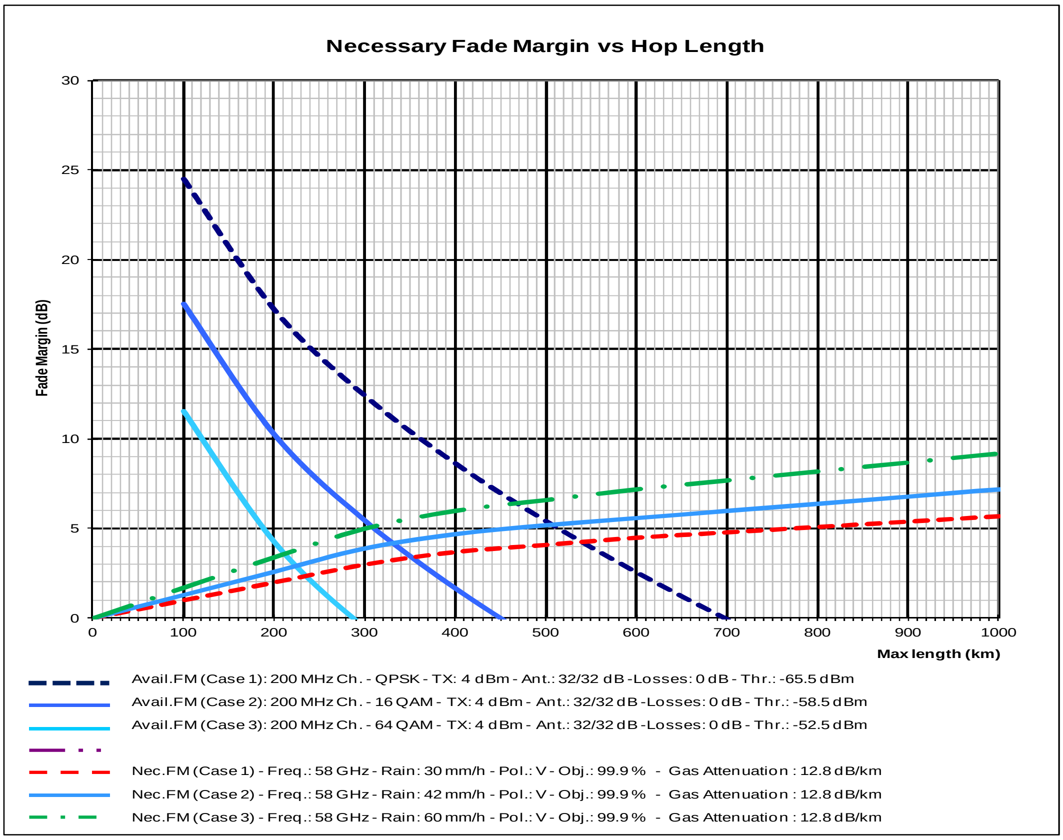
The maximum hop length corresponding to 99,9 % of availability have been computed for QPSK, 16QAM, 64QAM with a 32 dBi and 38 dBi antennas, at three rain rates as above.

Three different oxygen attenuations have been used (4,1 / 12,8 / 14,6 dB/km) representing different frequency (58, 61,5 and 65 GHz) of the considered V band.

Related diagrams are shown in figures 6.1.1.1 and 6.1.1.2.

Same results are shown with 99,99 % availability (figures 6.1.1.3 and 6.1.1.4).


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -65.5 dBm
Avail.FM (Case 2): 200 MHz Ch. - 16 QAM - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -58.5 dBm
Avail.FM (Case 3): 200 MHz Ch. - 64 QAM - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -52.5 dBm
Nec.FM (Case 1) - Freq.: 65 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 2) - Freq.: 65 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 3) - Freq.: 65 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -65.5 dBm
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Nec.FM (Case 1) - Freq.: 58 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 2) - Freq.: 58 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 3) - Freq.: 58 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km

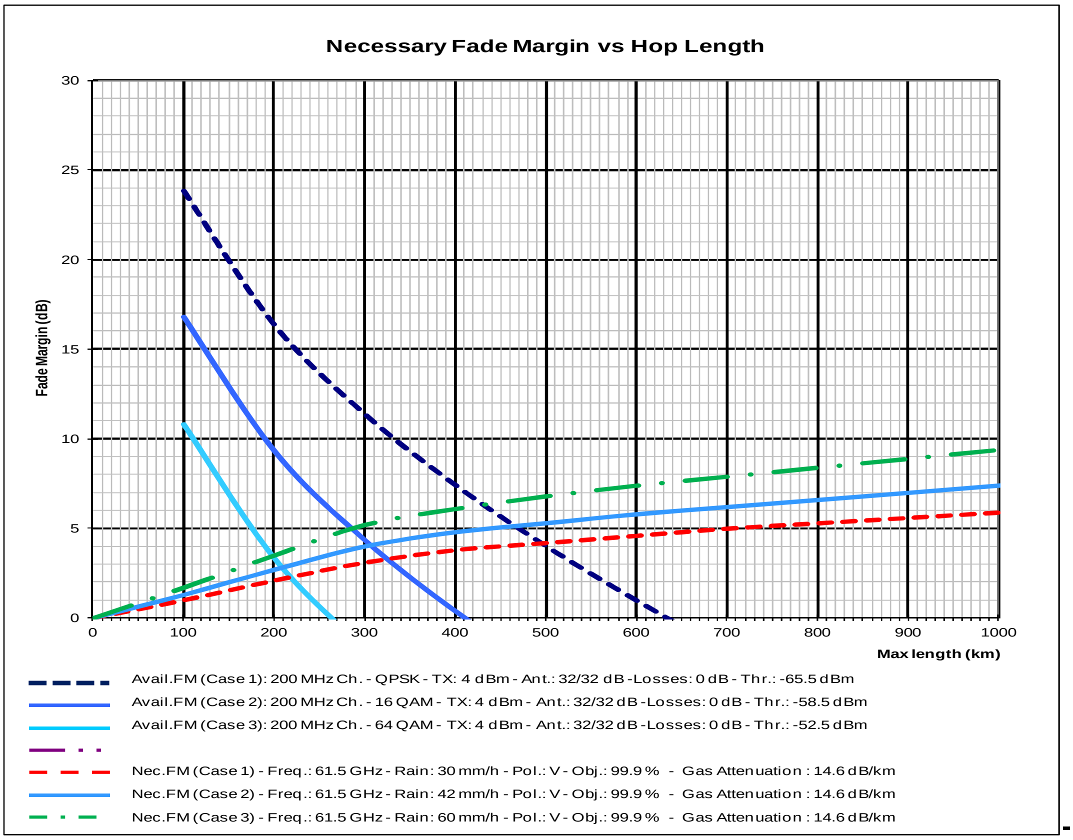
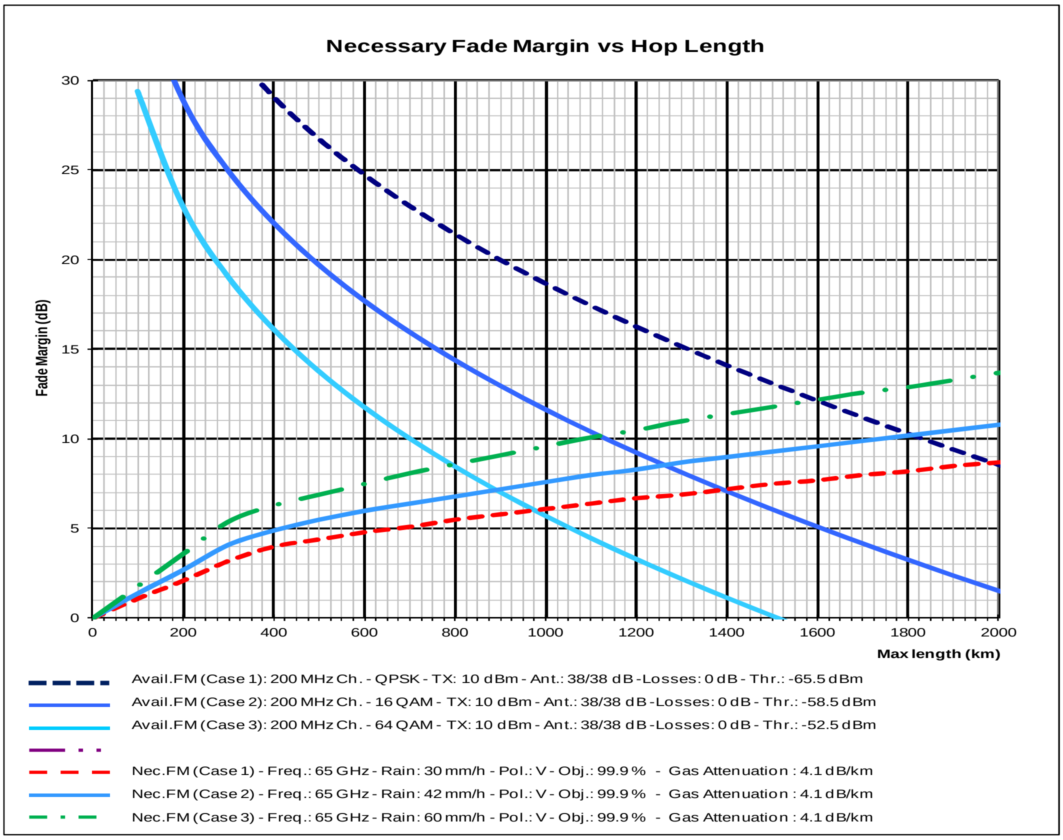
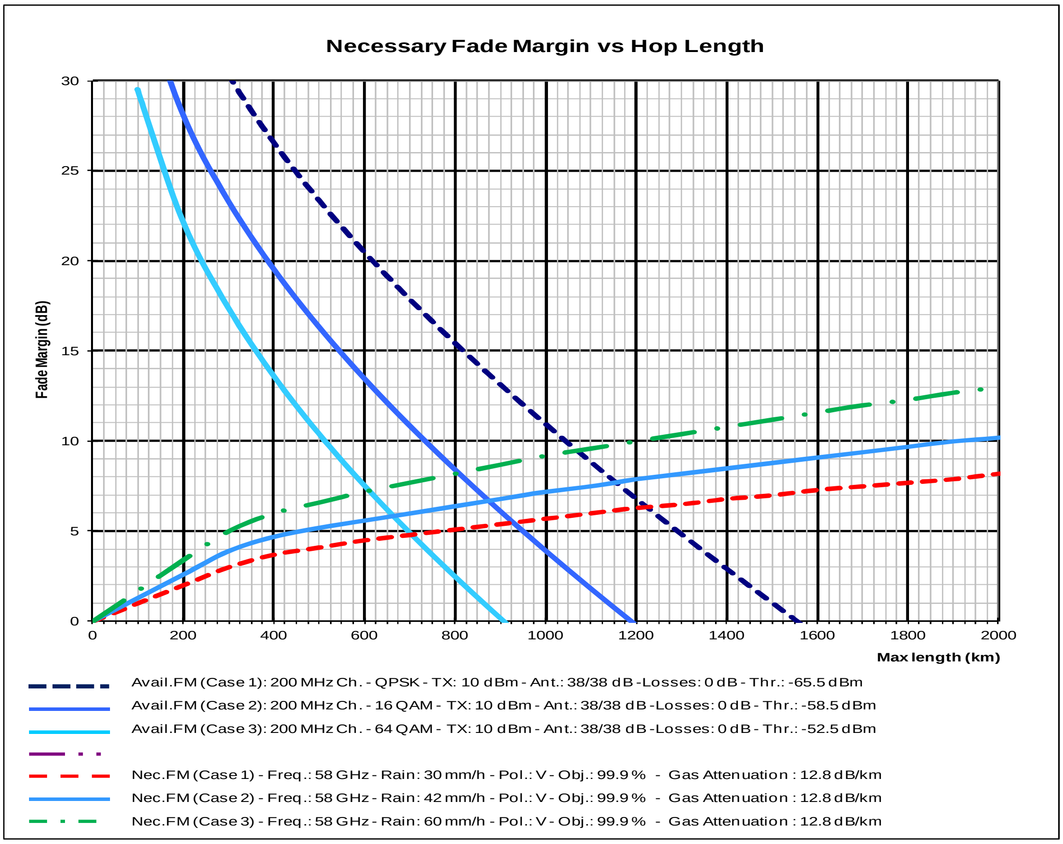


Figure 6.1.1.1: Maximum hop length, avail 99,9 %, 32 dBi antenna, QPSK to 64QAM


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -65.5 dBm
Avail.FM (Case 2): 200 MHz Ch. - 16 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -58.5 dBm
Avail.FM (Case 3): 200 MHz Ch. - 64 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -52.5 dBm
Nec.FM (Case 1) - Freq.: 65 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 2) - Freq.: 65 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 3) - Freq.: 65 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 4.1 dB/km


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -65.5 dBm
Avail.FM (Case 2): 200 MHz Ch. - 16 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -58.5 dBm
Avail.FM (Case 3): 200 MHz Ch. - 64 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -52.5 dBm
Nec.FM (Case 1) - Freq.: 58 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 2) - Freq.: 58 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 3) - Freq.: 58 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.9 % - Gas Attenuation : 12.8 dB/km

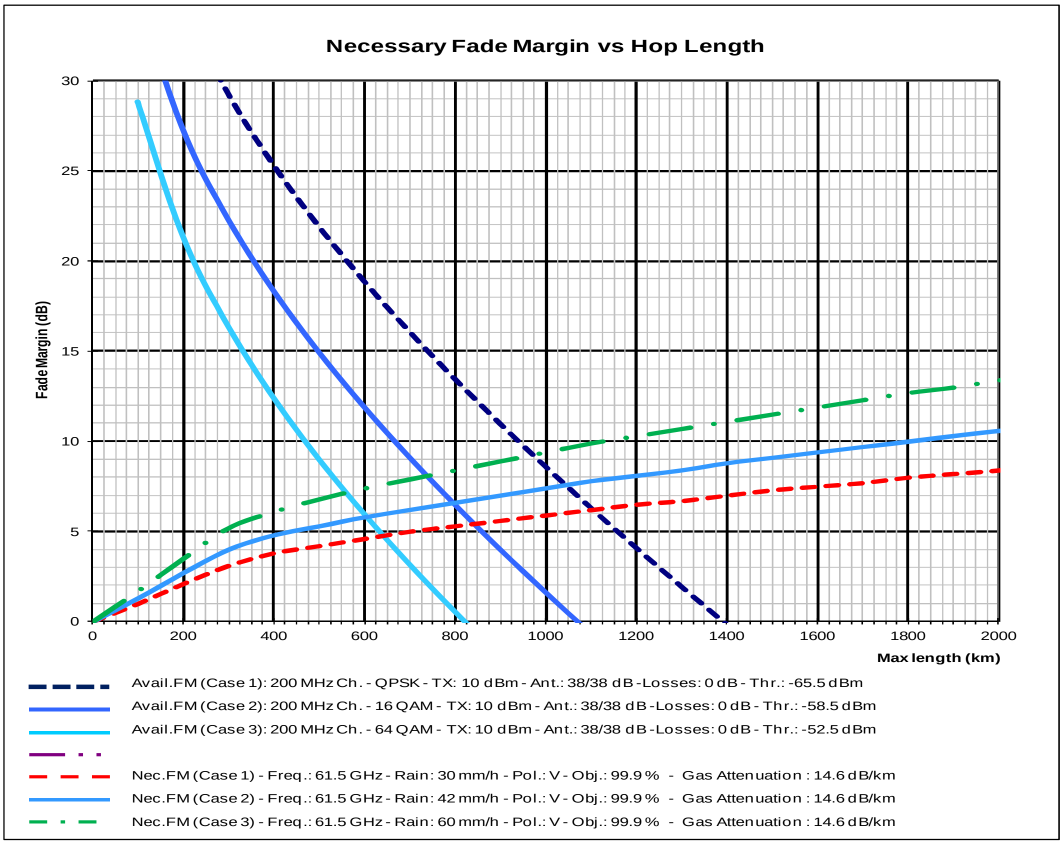
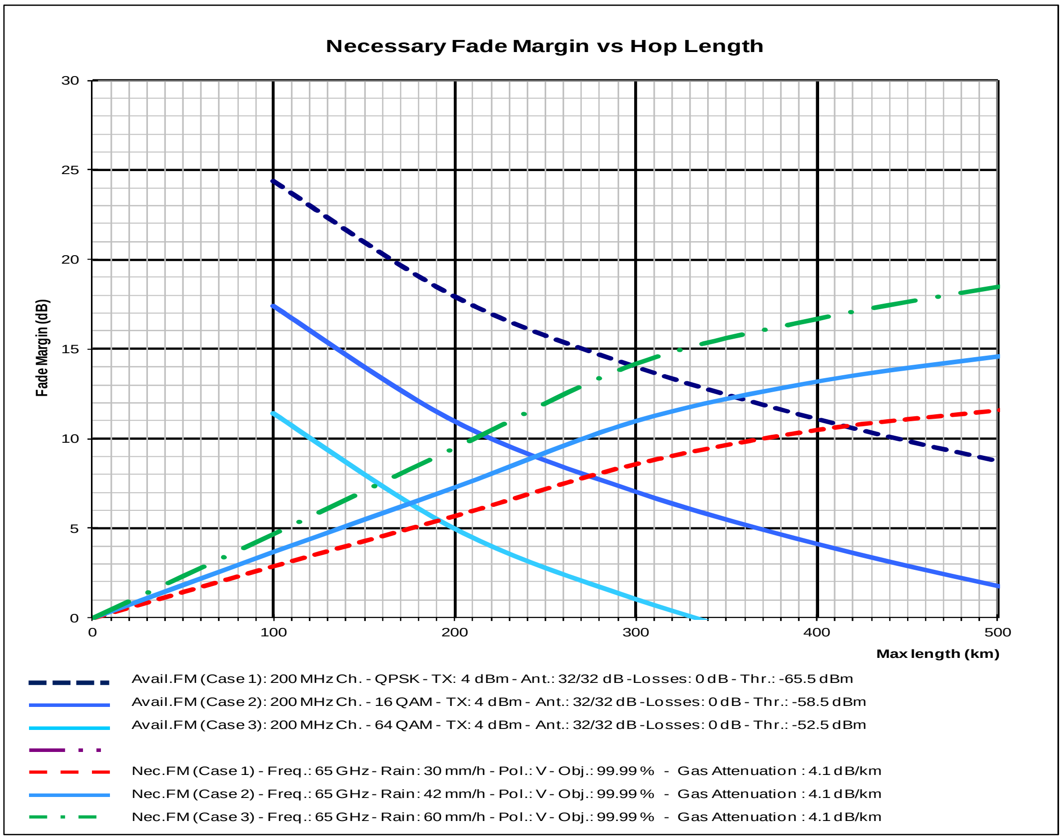
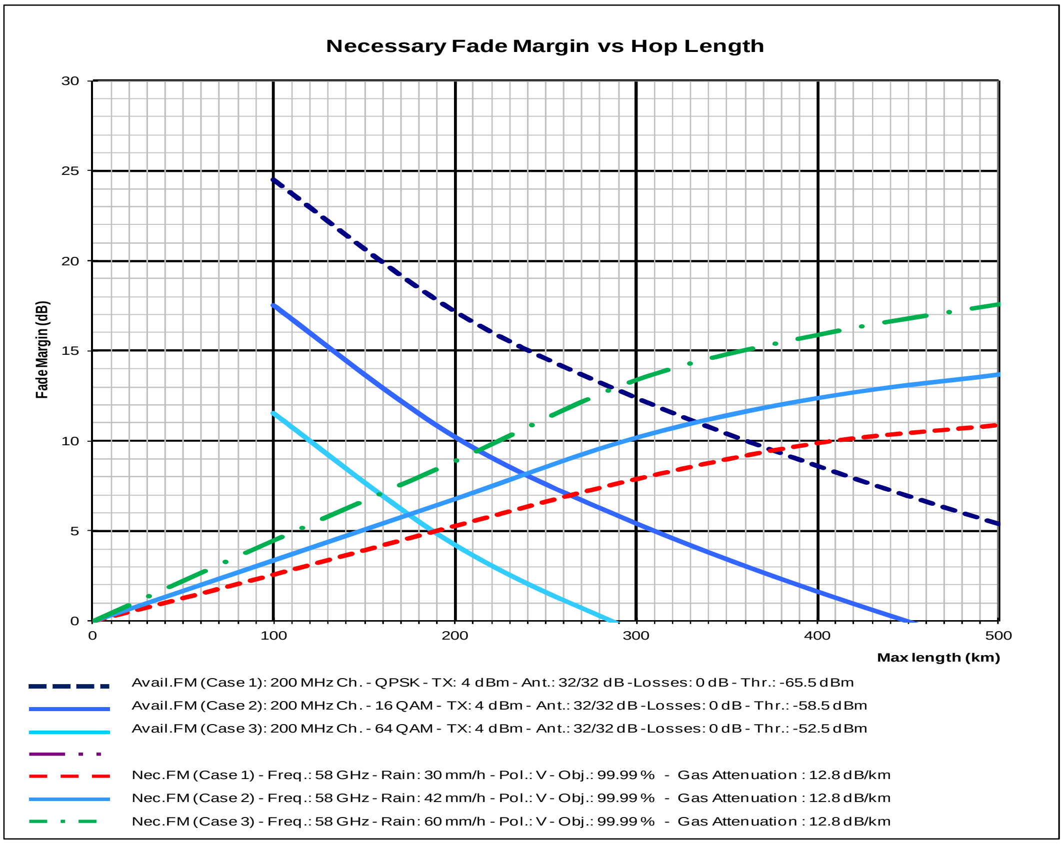


Figure 6.1.1.2: Maximum hop length, avail 99,9 %, 38 dBi antenna, QPSK to 64QAM


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -65.5 dBm
Avail.FM (Case 2): 200 MHz Ch. - 16 QAM - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -58.5 dBm
Avail.FM (Case 3): 200 MHz Ch. - 64 QAM - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -52.5 dBm
Nec.FM (Case 1) - Freq.: 65 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 2) - Freq.: 65 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 3) - Freq.: 65 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km


Necessary Fade Margin vs Hop Length
Fade Margin (dB)
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 4 dBm - Ant.: 32/32 dB -Losses: 0 dB - Thr.: -65.5 dBm
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Nec.FM (Case 1) - Freq.: 58 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 2) - Freq.: 58 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 12.8 dB/km
Nec.FM (Case 3) - Freq.: 58 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 12.8 dB/km

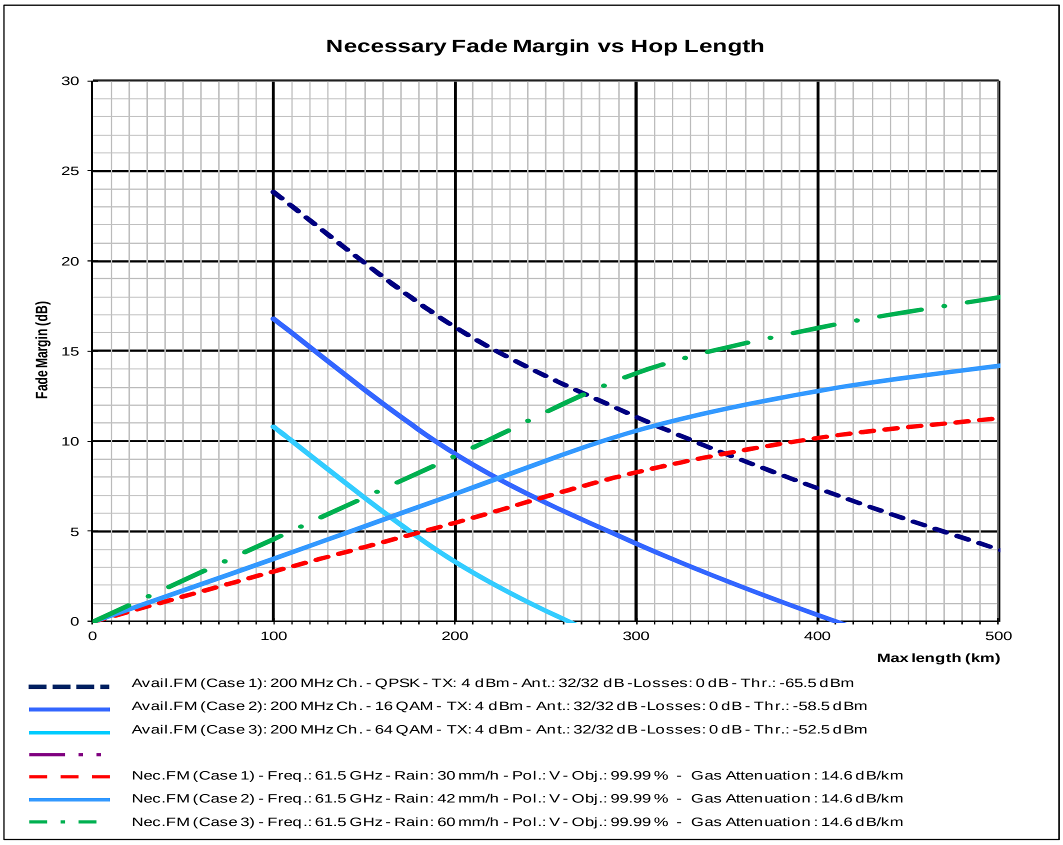
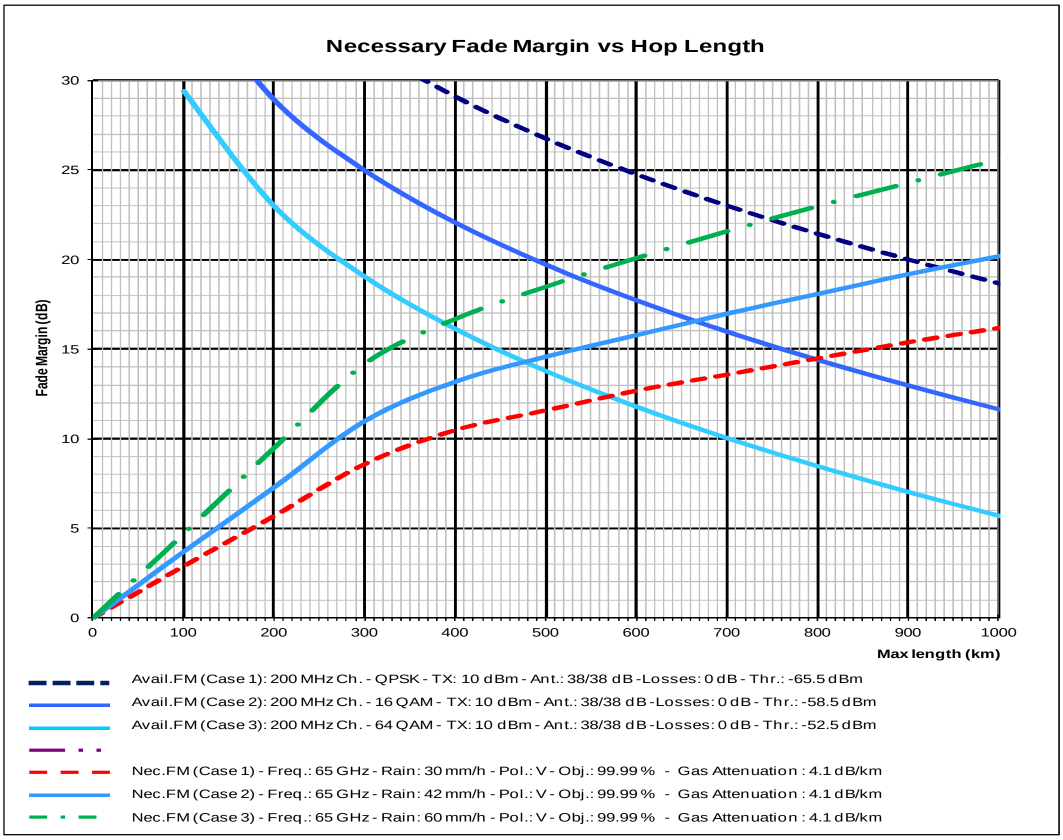
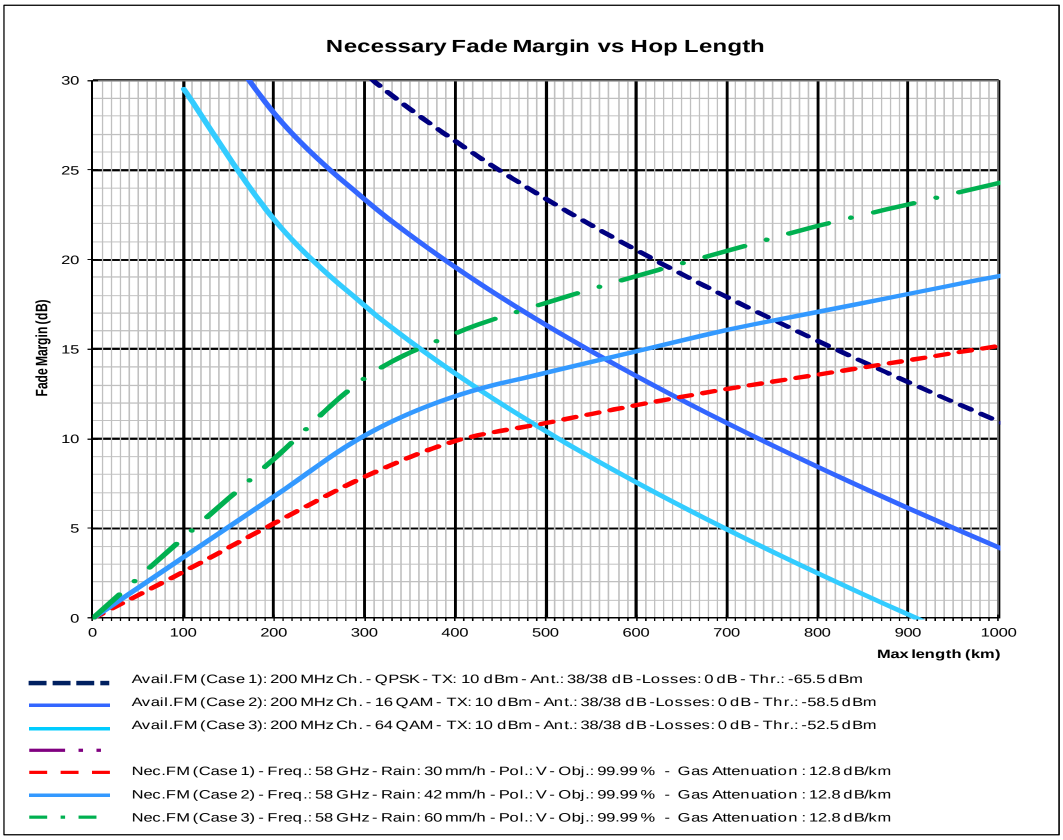


Figure 6.1.1.3: Maximum hop length, avail 99,99 %, 32 dBi antenna, QPSK to 64QAM



Necessary Fade Margin vs Hop Length
Fade Margin (dB)
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900
1000
Max length (km)
Avail.FM (Case 1): 200 MHz Ch. - QPSK - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -65.5 dBm
Avail.FM (Case 2): 200 MHz Ch. - 16 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -58.5 dBm
Avail.FM (Case 3): 200 MHz Ch. - 64 QAM - TX: 10 dBm - Ant.: 38/38 dB -Losses: 0 dB - Thr.: -52.5 dBm
Nec.FM (Case 1) - Freq.: 65 GHz - Rain: 30 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 2) - Freq.: 65 GHz - Rain: 42 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km
Nec.FM (Case 3) - Freq.: 65 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 4.1 dB/km



Necessary Fade Margin vs Hop Length
Fade Margin (dB)
0
5
10
15
20
25
30
0
100
200
300
400
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600
700
800
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Nec.FM (Case 3) - Freq.: 58 GHz - Rain: 60 mm/h - Pol.: V - Obj.: 99.99 % - Gas Attenuation : 12.8 dB/km

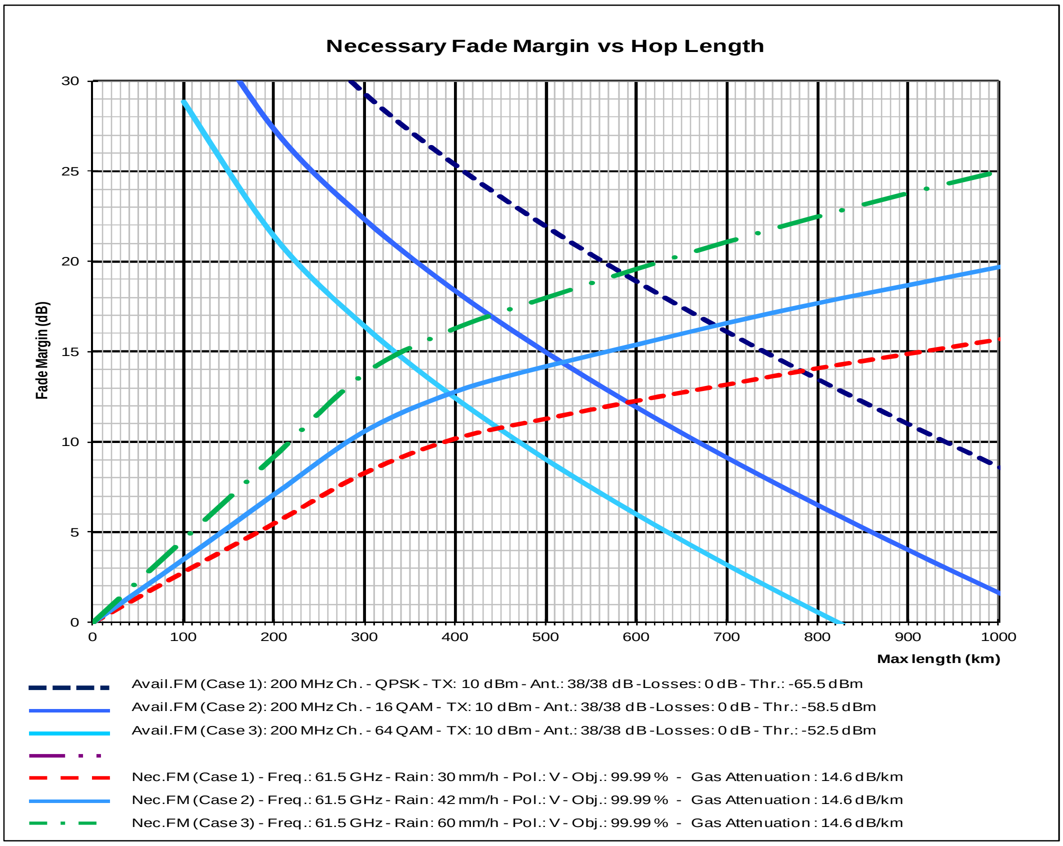

Figure 6.1.1.4: Maximum hop length, avail 99,99 %, 38 dBi antenna, QPSK to 64QAM

Table 6.1.1.1 summarizes examples of calculations, in accordance with figures 6.1.1.1 to 6.1.1.4.

Table 6.1.1.1: maximum hop length (m) according antenna and propagation conditions

99,9 % Availability						
Frequency	**58 GHz**		**61,5 GHz**		**65 GHz**	
Antenna Gain	32 dBi	38 dBi	32 dBi	38 dBi	32 dBi	38 dBi
30 mm/h						
QPSK	540	1 220	500	1100	700	1 990
16QAM	350	920	330	840	400	1 400
64QAM	240	700	220	630	250	980
42 mm/h						
QPSK	510	1 150	470	1040	640	1 800
16QAM	330	860	310	800	380	1 250
64QAM	230	660	210	600	240	890
60 mm/h						
QPSK	470	1 080	430	980	580	1 600
16QAM	310	800	290	750	340	1 110
64QAM	210	600	200	560	220	800
99,99 % Availability						
Frequency	**58 GHz**		**61,5 GHz**		**65 GHz**	
Ant. Gain	32 dBi	38 dBi	32 dBi	38 dBi	32 dBi	38 dBi
30 mm/h						
QPSK	370	860	350	790	420	1 100
16QAM	260	650	250	590	270	800
64QAM	190	490	180	450	190	580
42 mm/h						
QPSK	340	750	310	690	360	930
16QAM	240	570	220	520	250	670
64QAM	170	430	160	400	180	480
60 mm/h						
QPSK	290	670	270	590	300	740
16QAM	210	470	200	440	220	530
64QAM	160	360	150	340	160	390

Effect of P. out at different power level is shown in figure 6.1.1.5.

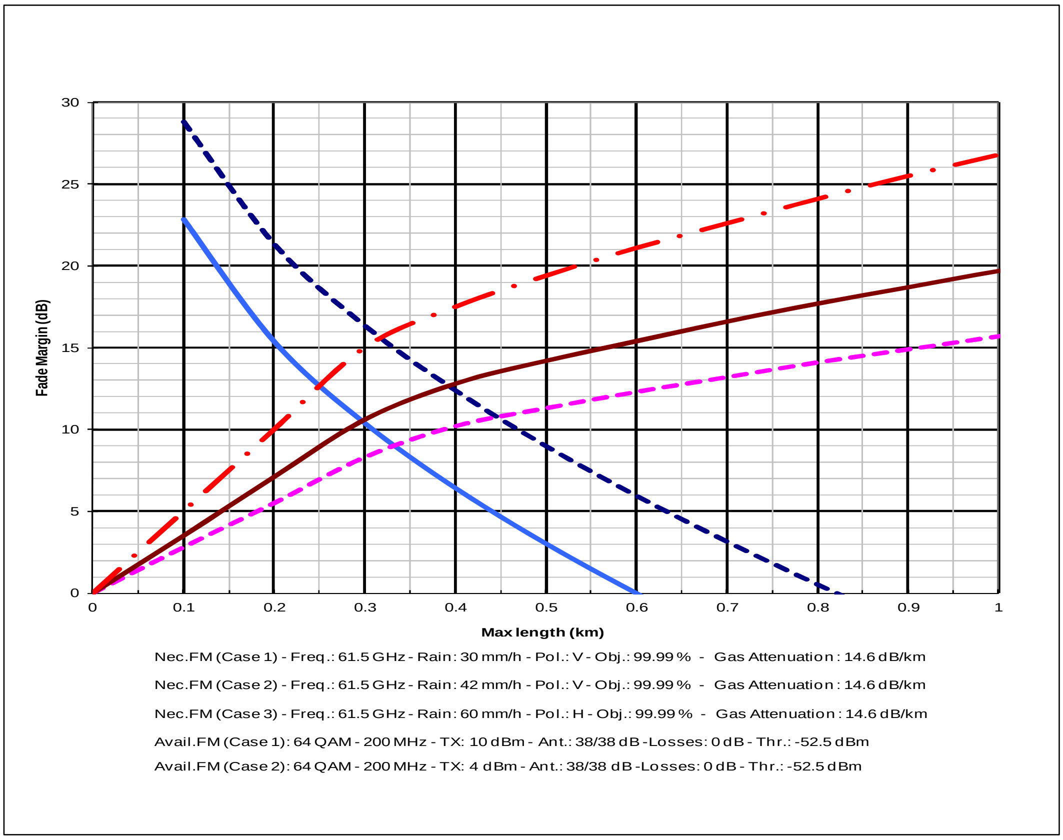

Figure 6.1.1.5

Example (61,5 GHz / 38 dBi) impact of Tx power (4 or 10 dBm) on hop length / fade margin is shown.

6.1.2 Interference area

Figures 6.1.2.1 to 6.1.2.3 show examples of results on calculation related to the area where a given level of interference is detected by a victim receiver, in case a interfering transmitter with same characteristics and frequency of the victim receiver is pointing towards the victim receiver location, for each angular direction identified by connecting the victim station to interfering station located to any generic point on the border.

Examples are shown for a level corresponding to C/I degradation less than 1 dB. This practically corresponds to the separation distance needed for frequency reuse without victim link degradation.

Separation distance is explicitly reported for each observation angle (second diagram in each figure).

Note that the area graphs are bi-dimensional, but with standard dish antennas, the symmetry may be assumed circular for any azimuth/elevation of the paths.

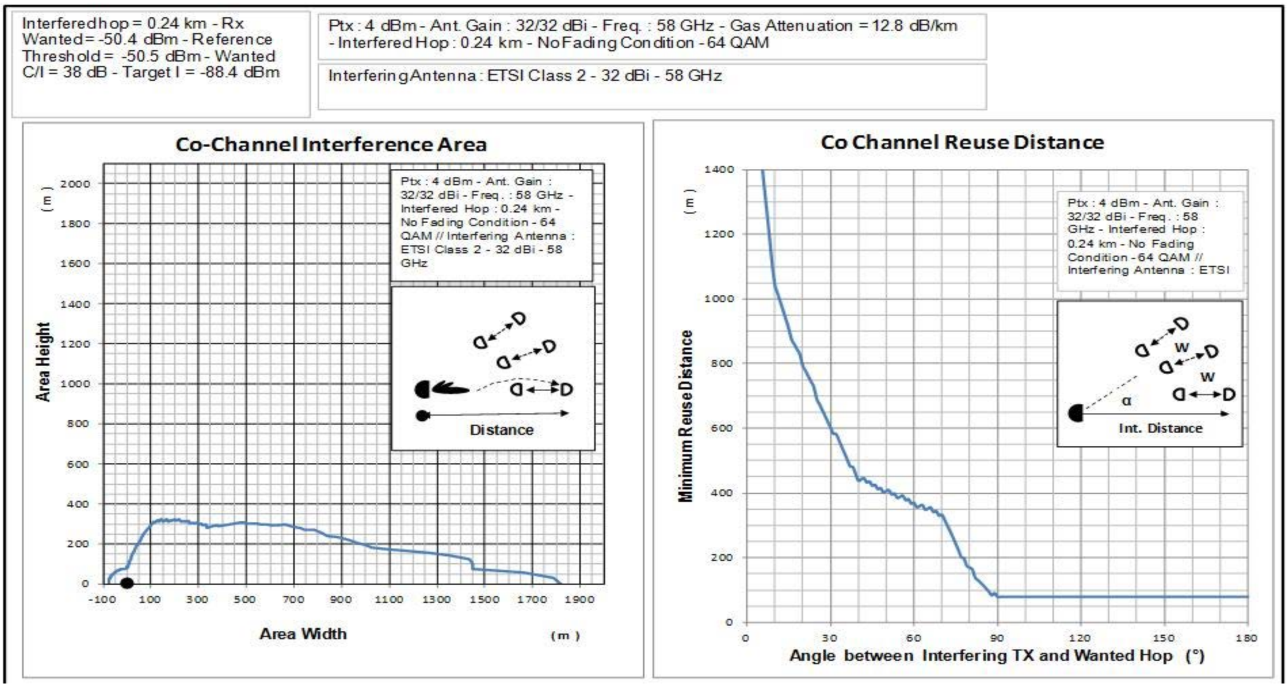

Figure 6.1.2.1: Protection area and distance for antenna 32 dBi and link length 240 m

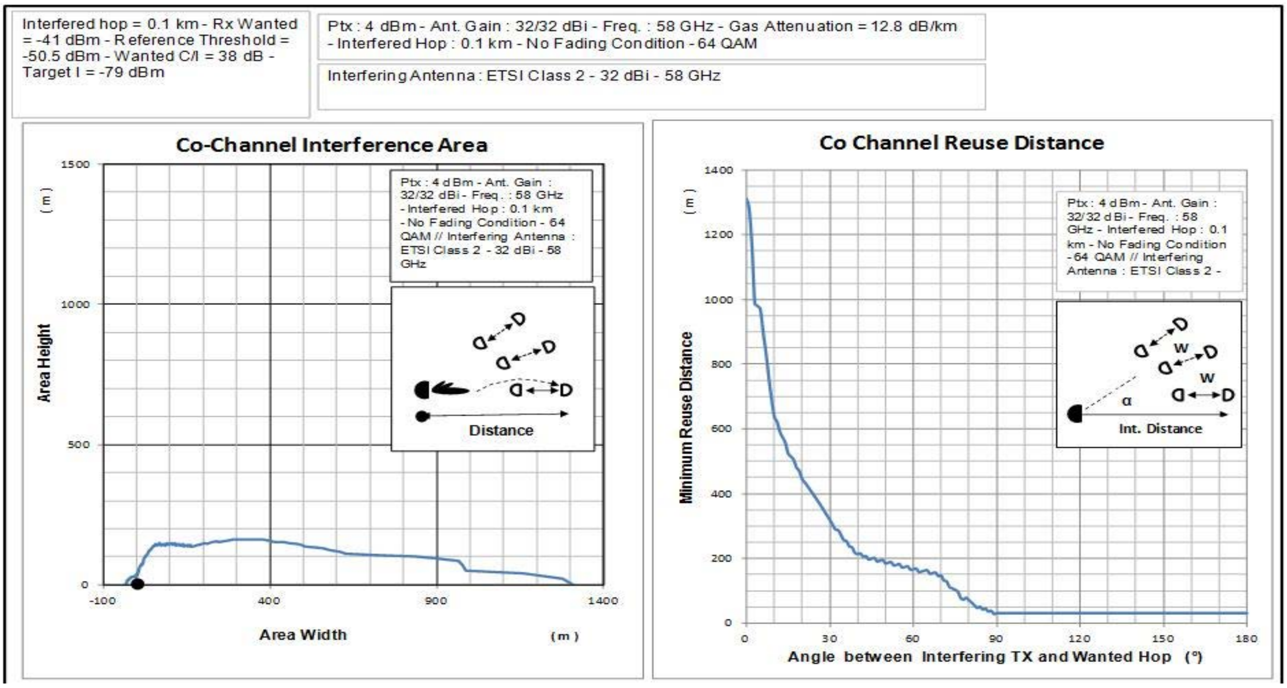

Figure 6.1.2.2: Protection area and distance for antenna 32 dBi and link length 100 m

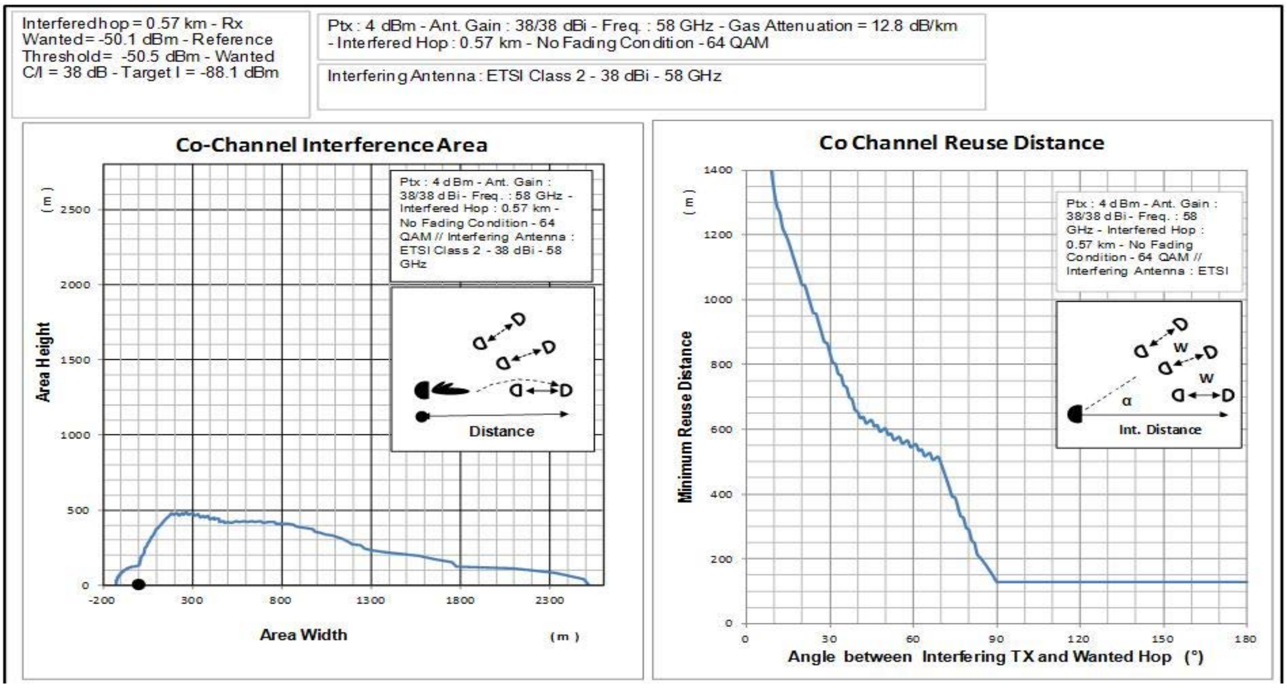

Figure 6.1.2.3: Protection area and distance for antenna 38 dBi and link length 0,57 km

Figure 6.1.2.4 shows an example of similar calculations (with slight different frequencies and equipment parameters) given as result from interference coexistence studies carried out in ECC Report 114 [i.6].

In general, information on separation distances is made available, and increases significantly as long as mainbeams of two links tend to be aligned.

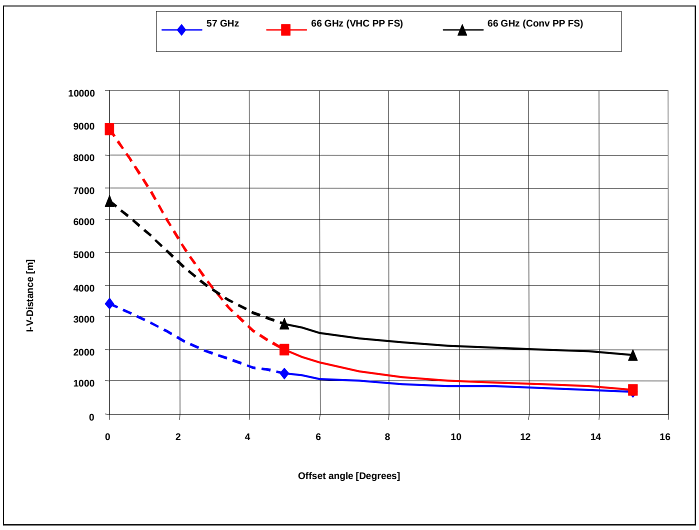

Figure 6.1.2.4: separation distances for FLANE Tx main beam to PP FS Rx (ECC Report 114 [i.6])

6.1.3 Urban Streets' geometry

Figure 6.1.3.1 shows the horizontal geometry of a H(m) wide road interference situation where two links are present, and two paths are not mutually crossing.

For each possible realization, it is possible to compute the interference received by each receiver.

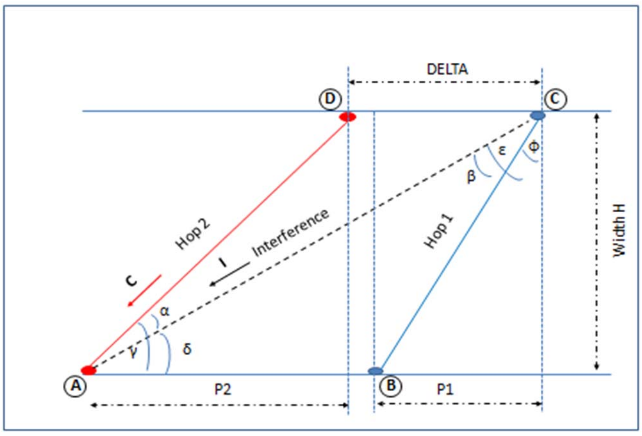

Figure 6.1.3.1

Examples of C/I calculation have been done for various distances among two links, with simplified assumption of parallel links (A-B = D-C in figure 6.1.3.1). Results are shown in figure 6.1.3.2 (a, b, c).

As expected, that figures show that, for the same distance between links, interference increases with decreasing road width, as all angles decrease (see interferer towards victim angle in figure 6.1.3.1).

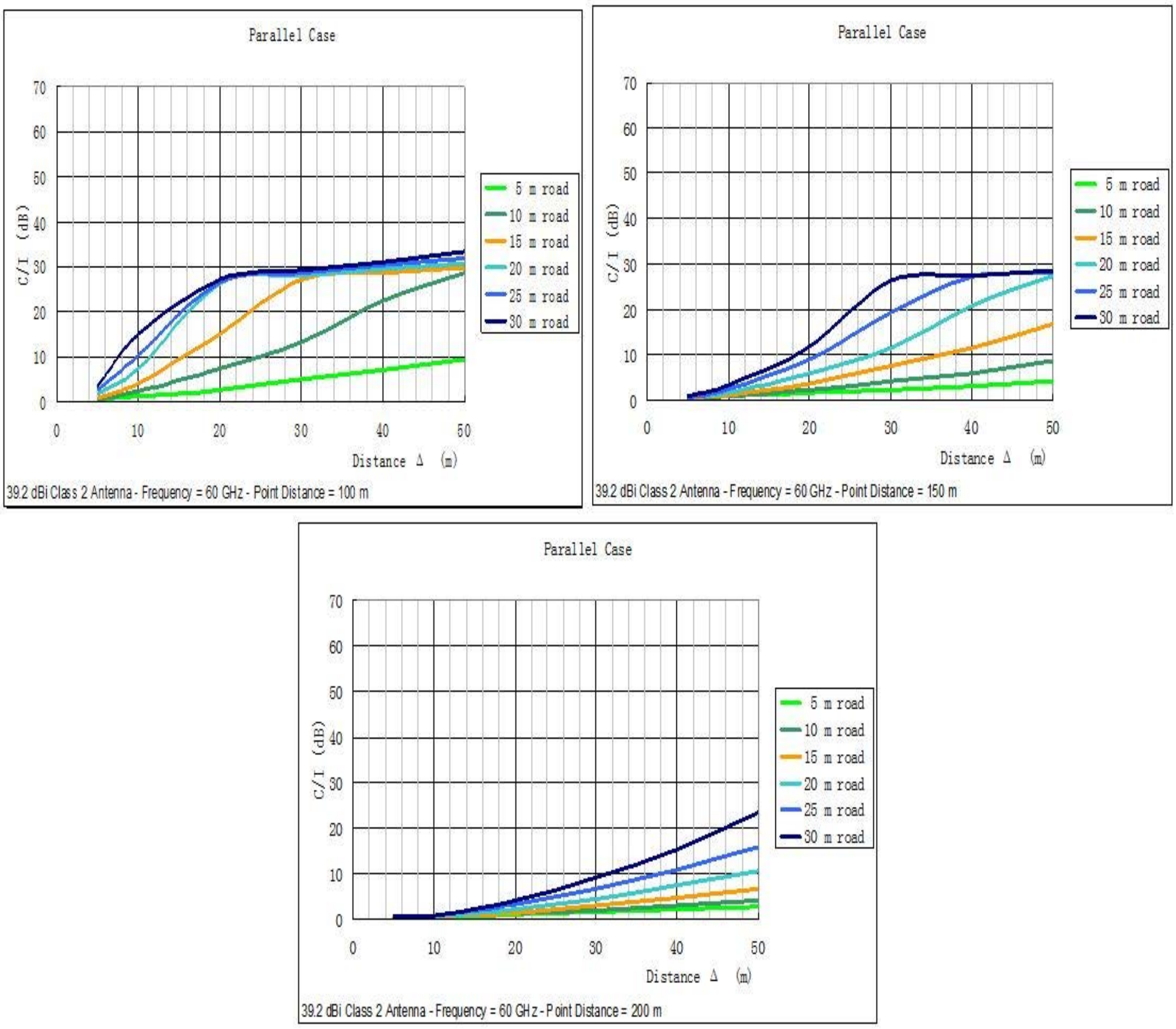

Figure 6.1.3.2 (a, b, c)

Figure 6.1.3.3 shows same geometry of a road interference situation where two links are present, both paths are mutually crossing.

Examples of calculation are shown in figure 6.1.3.4 (a, b, c).

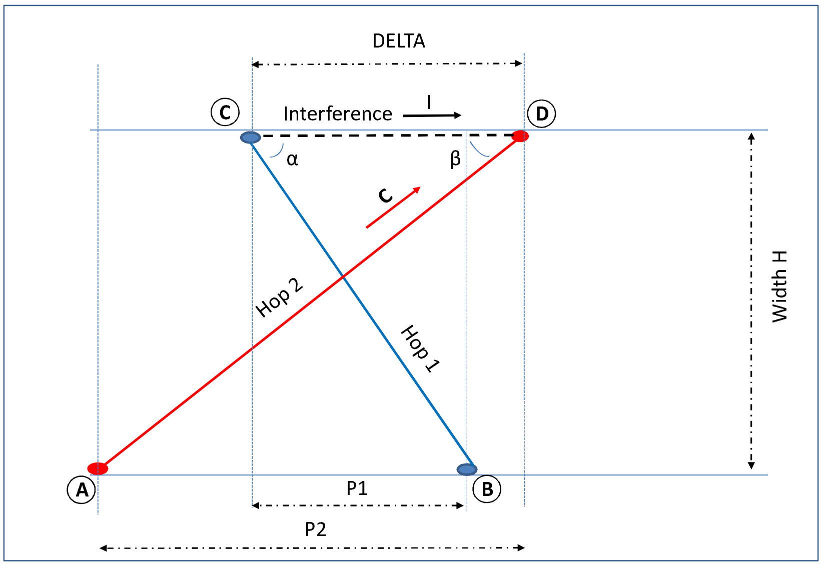

Figure 6.1.3.3

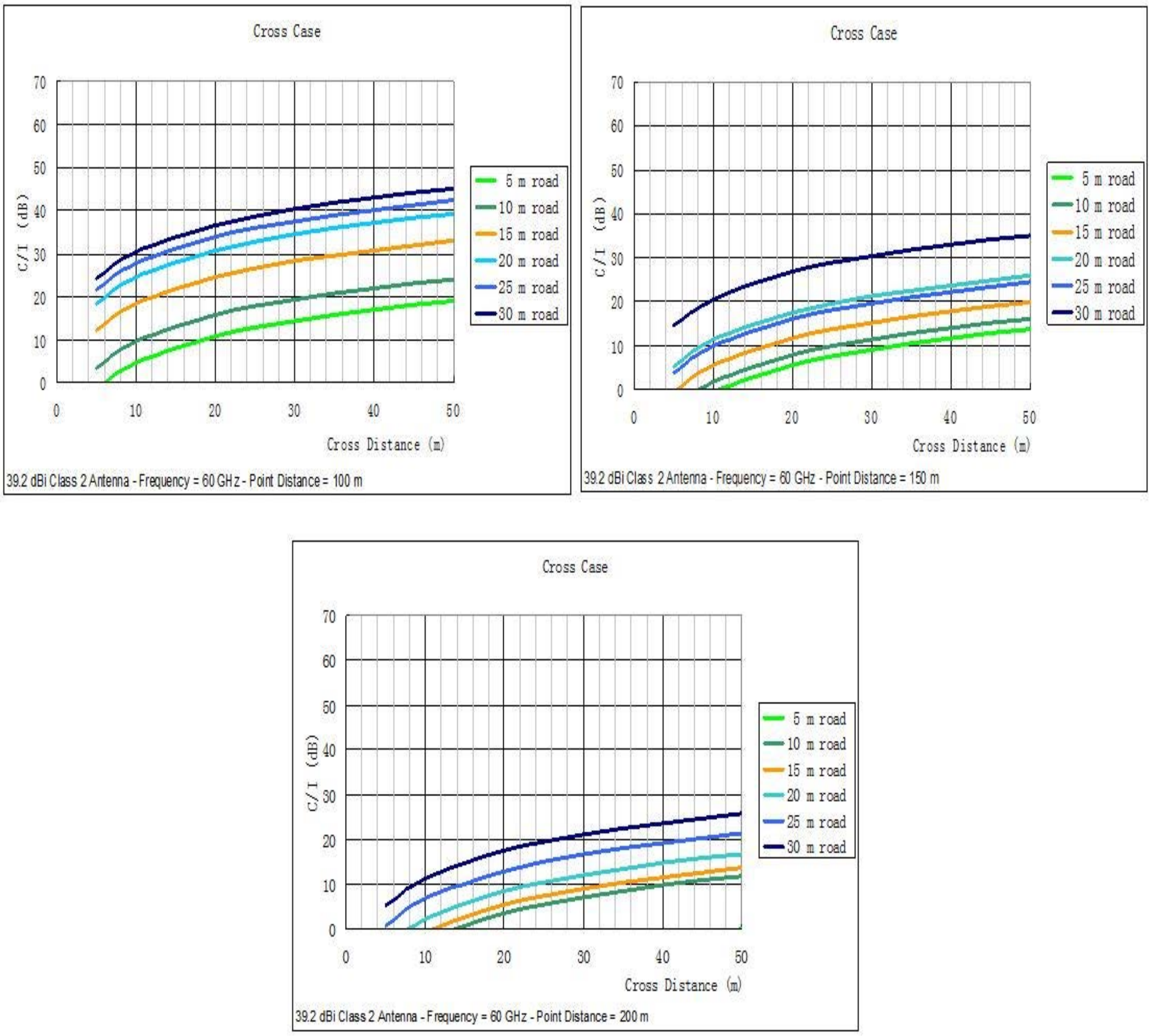

Figure 6.1.3.4 (a, b, c)

6.2 Conclusions on the geometrical approach

The results of simulations based on geometrical settings of interferer and victim links, using both the same channel, clearly shows that difficulties can be expected, especially for using high modulation schemes, due to the insufficient level of C/I values in relation with road geometry. In general, the limitation holds for modulations higher than 64QAM.

As such, sufficient level of performance can be reached on condition that more channels are available, with some migration mechanism in place, like Dynamic Frequency Selection (DFS). Adaptive Transmitter Power Control (ATPC) can help to reduce interference level.

7 Statistical models

7.1 Introduction

7.1.1 Simulation highlights

Simulation results consist in the collection of results of calculations of interference affecting a single "victim link" placed in an environment, containing one or more interfering links.

The tool used in the present document is SEAMCAT® [i.9] freely available, designed and supported by ECO within the frame of CEPT.

The collection of results is based on a repeating calculation process for a high number of "simulated trials".

Parameters and environmental setting possibilities for simulated trials:

- Interferers are placed in a circular area of which the centre is the victim receiver.
- Number of interferer links in simulated trials can be specified, once the network density is known.
- Their stations minimum distance from victim receiver can be fixed inside that circle.
- Equipment parameters and antennas can be defined separately for victim and interferers.
- Length of link can be specified by means of minimum and maximum range for victim and interferers.
- Rx filter is automatically set, based on Rx noise BW.

Calculation process: for each simulated trial following actions are performed:

- Length of the victim link is randomly fixed within the allowable range.
- Specified number of interferer transmitters is placed in circular area.
- Interferer links are randomly fixed (channel frequency, direction and length).
- In case of DFS, the frequency of the victim is randomly chosen, interferer analyses is carried on for each interferer in all channels, after that the best channel (the one giving the lowest level of interference) is chosen.
- RSL and total interferers power in receiver victim are calculated.
- Comparison with the acceptable degradation criteria (i.e. C/I threshold) is carried on.
- Results are collected.

After this process is finished, another simulated trial is planned and the process is repeated for the specified number of times.

At the end, the result of the percentage of cases where foreseen C/I threshold has been exceeded, is made available.

Provided that the number of iteration is sufficiently high, statistical validity can also be considered meaningful in real deployment.

Assumptions adopted in simulations:

- All links are assumed to be LoS.
- Interferers have been distributed in a circle of 113 m radius, corresponding to 1/25 km^2.
- Interferer density was agreed to be 200 link/km^2 (thus the number of interferer links in the simulated area becomes 8).
- 20 000 iterations have been used, corresponding to 160 000 interfering links.
- The number of available channels on which the links could be deployed is variable as function of available spectrum.
- Antenna height (h) is constant for either the victim link or the interferer.
- Link availability = 99,99 % evaluated with 60 mm/h rain rate.

Note that, due to the statistical nature of interference scenario in case of unlicensed or light license regime, it is not possible to design links/networks virtually without threshold degradation, as it can be in interference controlled environments. Therefore, only an acceptable percentage target of interference free cases should be considered.

As such, some degree of risk of threshold degradation cannot be avoided.

Although it is not possible at this stage to indicate a minimum target for universally acceptable threshold degradation percentage, since different targets could be adopted on case by case basis for different kinds of backhaul, it is in our assumptions ("high quality backhaul") a percentage of about 2 % that has been used as possible acceptable limit. It should be noted that the "full LoS" and "same antenna height" assumptions made could be considered close to the worst-case situation for urban environment.

Concerning the number of available channels over which the centre frequencies can be distributed, an indicative figure of 5 to 10 channels/operator, corresponding to 1 to 2 GHz BW allowing coexistence of few different operators in same geographical contest, is considered a realistic case.

An example of (one of 20 000) a simulated trial, showing the victim link and the disposition of interferer links, with Tx placed around victim Rx (yellow diamond) is shown in figure 7.1.1.1.

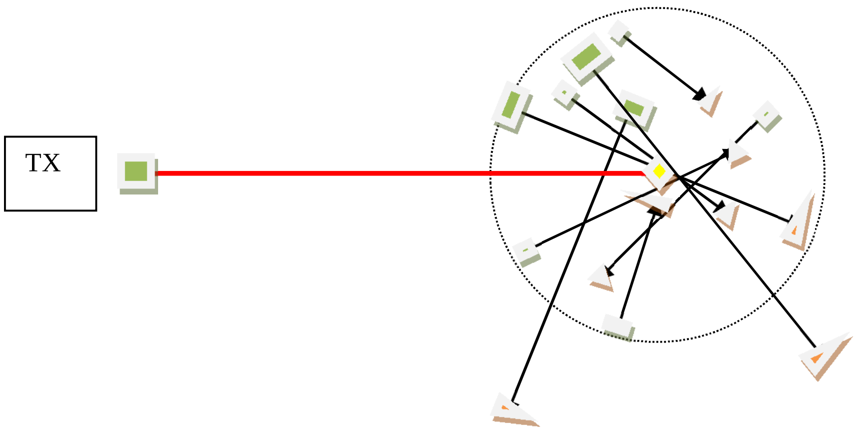

Figure 7.1.1.1: Example of simulated trial

7.1.2 Interference criteria

Three criteria to evaluate interference were considered, in accordance with the ECC Report 20 [i.3], C/I critical ratio, used when the expected degradation target can be evaluated at nominal Received Signal Level (RSL); conservatively, the critical C/I is here considered as the C/I for 3 dB sensitivity threshold degradation commonly found in the ETSI standard ETSI EN 302 217-3-1 [i.1]. It should be considered that when fading is not affecting the link, the link is properly working (i.e. without errors) even in presence of that C/I:

1) I/N, in order to evaluate the increase of noise power in the receiver BW resulting from multiple interferences. It is generally used when wanted and interfering paths attenuations are highly uncorrelated. E.g. an I/N = 0 dB, would correspond to 3 dB thresholds degradation.

2) C/(I+N), in case of higher sensitivity, degradation could be accepted (e.g. in dense networks) if performance and available objectives were met and the increase degradation can be compensated in the link budget (by reducing the fade margin). This is an intermediate situation between the above two.

Networks addressed in the current study are supposed to be carried on by means of links characterized by quite similar characteristics (limited length, similar equipment constraints and requirements, similar propagation characteristics). In particular, due to short distance and same frequency band used, rain attenuation is assumed to be highly correlated (see note) for victim and interferer, such as both tend to be attenuated by about same amount; therefore, the C/I ratio is considered practically constant (from propagation point of view) at any time.

NOTE: The diameter of a rain cell in Recommendation ITU-R P.452 [i.10] is assumed to be always larger than typical hop length in this band.

Due to this correlation, the critical C/I (assumed equal to C/I at 3 dB threshold degradation) will be assumed as the main degradation factor for this analysis. All links are then assumed designed with 3 dB extra-margin given to interference impact.

Table 7.1.2.1: Interference Criteria

Parameter	Value [dB]	
	64QAM	QPSK
Critical C/I (see note)	< 29	< 15
I/N	0	0
NOTE: For the present document the critical C/I is assumed equal to the C/I for 3 dB threshold degradation.		

7.2 Backhaul implemented by FS links only

7.2.1 Introduction

Results of simulations carried out by using the specific CEPT tool, and implementing the Monte Carlo analysis (SEAMCAT®), are presented, for following scenarios:

Backhaul is carried on by means of traditional FS Systems, compliant with ETSI EN 302 217 multipart standard [i.1] and [i.2]:

- Results are felt to be effective worst cases, since obstructions from obstacles and attenuation of reflected links are not considered.
- Reflected rays, although not directly simulated, are expected to be covered by the large spread of direction of arrivals of simulated interfering rays.

7.2.2 Simulations

Following conditions have been considered:

- Calculations for systems with QPSK and 64QAM modulation, with antennas of 32 and 38 dBi gain, according to ETSI EN 302 217-4-2 [i.2] Class 2.
- For the 32 dBi antenna, also DFS effect is considered. Results are summarized in table 7.2.2.1a to table 7.2.2.2.
- A further simulation with an antenna of 32 dBi gain, compliant with ETSI EN 302 217-4-1 [i.8] Class 1, generally not allowed in EU, was done, without DFS, to evaluate performance degradation compared to the mainly used class 2.

Difference between RPEs of the two classes for 32 dBi gain antenna are shown in figure 7.2.2.1.

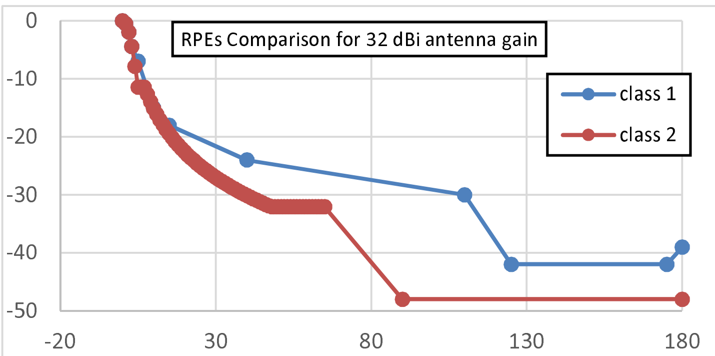

Figure 7.2.2.1: ETSI antennas RPE

Antenna gain =32 dBi (about 20 cm size, low visual impact); cases studied:

Case 1: P.out = +4 dBm; Mod. 64QAM; Thr = -55,5dBm; C/I = 29 dB; length = 150 m; - simulation also for a class 1 antenna

Case 2: P.out = +4 dBm; Mod. QPSK; Thr = -69,5dBm; C/I = 15 dB; length = 150 m

Table 7.2.2.1a: G = 32 dBi Class 2; Mod. 64QAM:-computed also with DFS

Case 1a) - 64QAM

CS Number	Prob. C/I [%]	
	DFS ON	***DFS OFF***
1	7,53	10,79
2	3,71	5,36
5	1,73	2,21
10	0,85	1,19
15	0,56	0,80
20	0,49	0,63
25	0,48	0,59
35	0,35	0,49
45	0,29	0,32

Table 7.2.2.1b: G = 32 dBi Class 1; Mod. 64QAM

Case 1b) - 64QAM

CS Number	Prob. C/I [%]	
	DFS ON	***DFS OFF***
1		26,54
2		13,20
5		5,75
10		2,92
15		2,03
20		1,58
25		1,44
35		1,01
45		0,90

Table 7.2.2.2: G = 32 dBi Class 2 Mod. QPSK:- same links as for table 7.2.2.1a

Case 2) -QPSK

CS Number	Prob. C/I [%]	
	DFS ON	***DFS OFF***
1	---	4,46
2	---	2,32
5	---	1,02
10	---	0,46
15	---	0,38
20	---	0,27
25	---	0,19
35	---	0,12
45	---	0,09

Result shows that the 2 % probability of C/I interference criterion can be achieved with 5 channels available, while with 10 channels available, less than 1 % interference probability is expected for the 64QAM system, with Class 2 antennas.

The use of class 1 antennas would result in about 3 times more spectrum needed for same low percentages of interference probability.

Antenna gain = 38 dBi (about 30 cm size, higher visual impact); cases studied:

Case 3: P.Out = +10 dBm; Mod. 64QAM; Thr = -55,5 dBm; C/I = 29 dB; length = 300 m

Case 4: P.Out = +10 dBm; Mod. QPSK; Thr = -69,5 dBm; C/I = 15 dB; length = 300 m

Table 7.2.2.3: G = 38 dBi Class 2; Mod. 64QAM

Case 3) - 64QAM

CS Number	Prob. C/I [%]	
	DFS ON	*DFS OFF*
1	1,01	2,48
2	0,58	1,23
5	0,21	0,57
10	0,11	0,26
15	0,10	0,25
20	0,08	0,21
25	0,03	0,11
35	0,03	0,07
45	0,02	0,07

Table 7.2.2.4: G = 38 dBi Class 2; Mod. QPSK:
- same links as for table 7.2.2.3

Case 4) - QPSK

CS Number	Prob. C/I [%]	
	DFS ON	*DFS OFF*
1	---	0,80
2	---	0,46
5	---	0,19
10	---	0,11
15	---	0,07
20	---	0,06
25	---	0,04
35	---	0,01
45	---	0,01
NOTE: GAnt = 38 dBi Class 2; Mod. QPSK: values for case 3) - same links as for table 7.2.2.3.		

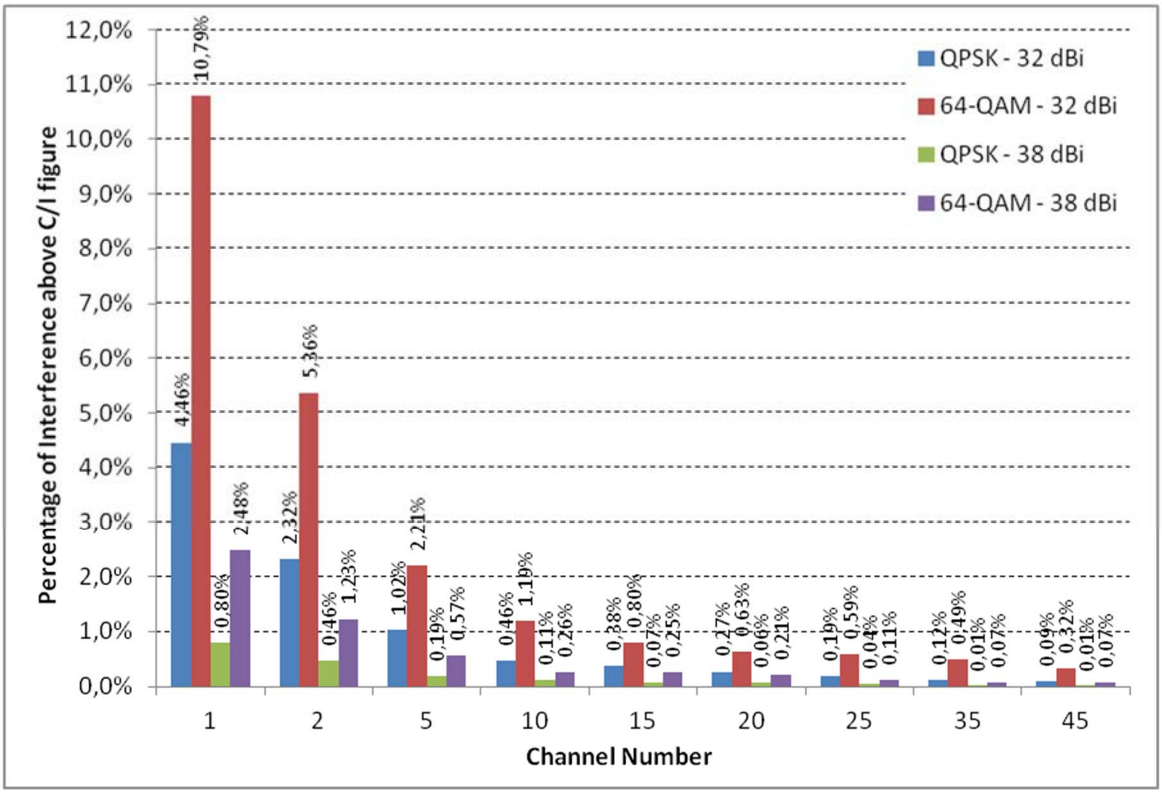

Figure 7.2.2.2: Summary of cases 1 - 4 with FS systems only - ETSI based- DFS off

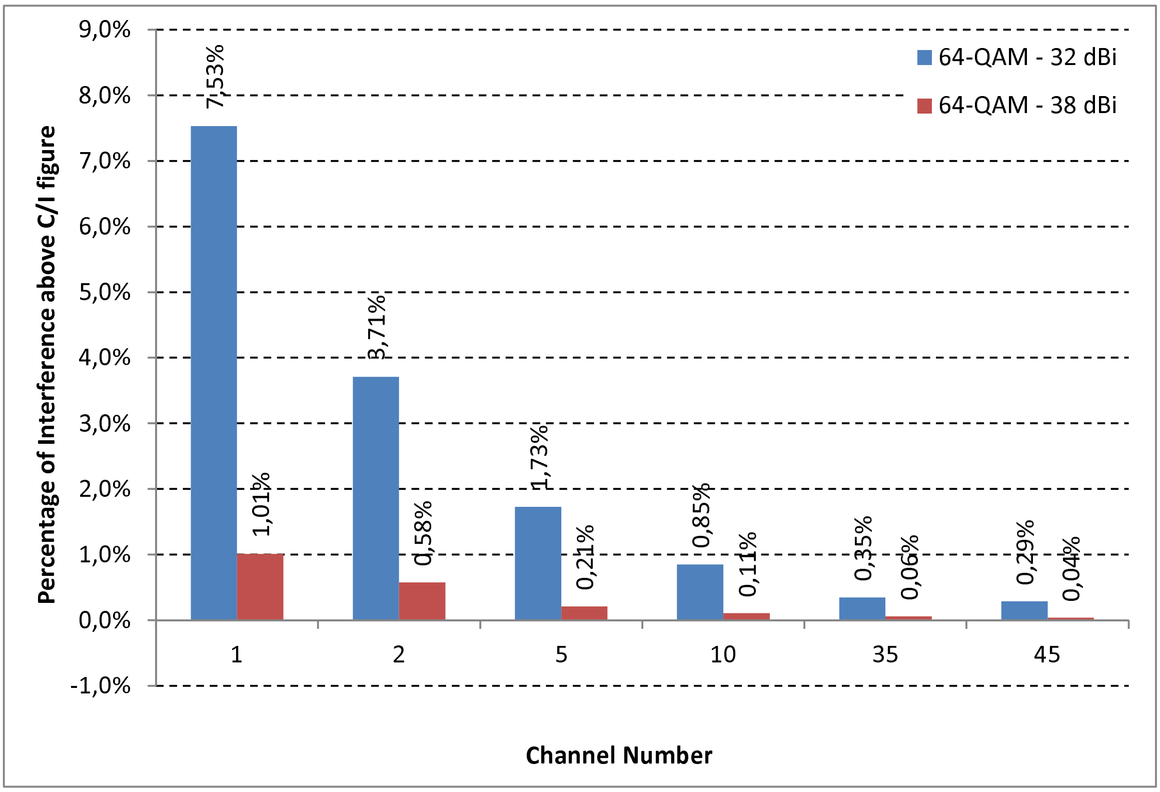

Figure 7.2.2.3: Summary of cases with FS systems only - ETSI based - 64QAM only- DFS on

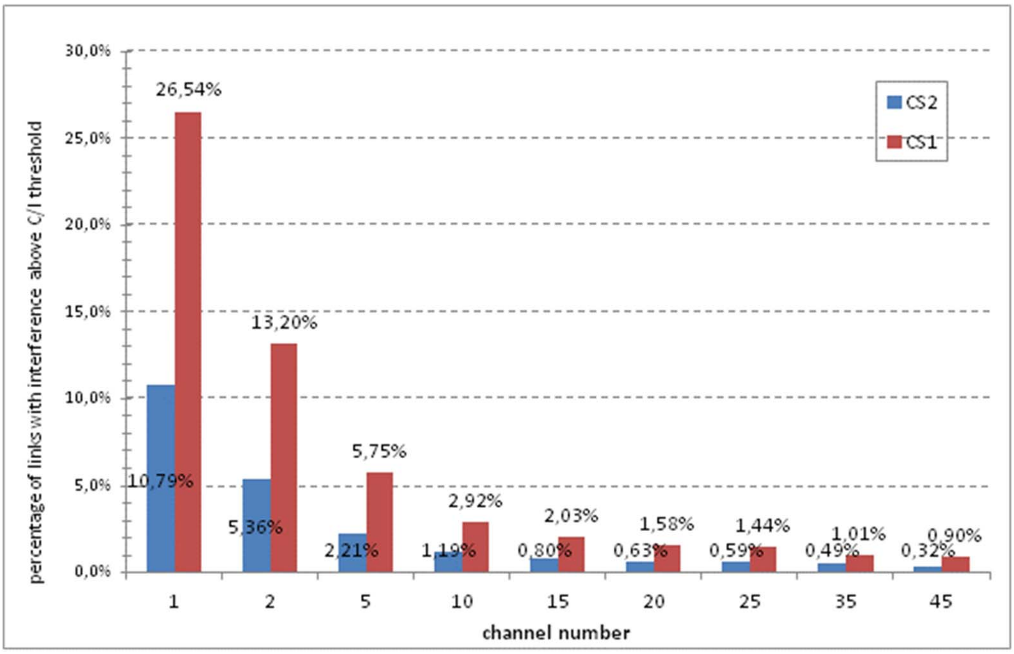

Figure 7.2.2.4: 32 dBi ETSI CS1 and CS2 classes comparison - 64QAM - DFS off

7.2.3 Conclusions on statistical simulation

The results for use of QPSK are available in the document, nevertheless, since the target is 1 Gbit/s per link, only the results for 64QAM are considered relevant in this conclusion:

- Increasing the number of available channels allows to quickly increase links density.
- With the assumed density of links (200 links / km^2), transmission of traffic capacity about 1 Gbit/s in a generic 200 MHz Channel (i.e. 64QAM modulation) with small form factor antenna, equivalent to about 20 cm in size (32 dBi gain), can be supported if 1- 2 GHz BW are available.

  This corresponds to 5 to 10 channels of 200 MHz BW (or 5 channels with 400 MHz BW).
- In the above conditions, 2 % target is close to be met with 5 Channels, without DFS (about 2,2 % 5 CH). In these condition, adoption of DFS allows to reduce overall interference, as target can be met with some margin (about 1,7 %).
- Analysis carried on give the possibility of a comparative evaluation when different antenna types are considered:
- Comparing data related to use of classes, it is shown that the use of 32 dB gain ETSI class 1 RPE antennas seem to require about 3 times more spectrum for the same % of interference probability than using class 2 RPE to reach the target (2 % interference).
- Comparing the same data , if a bigger antenna is possible (38 dBi gain), the percentage of interfered links drops to about 0,2 %, while even if just 1 channel is available, the interference probability already drops to about 1 % .
- Antennas realized to meet ETSI EN 302 217-4-2 [i.2] class 2 RPE requirements are felt appropriate.

In conclusion, the analysis confirms that ETSI requirements for equipment and antennas are appropriate to allow high transmission capacity with low probability of interference even in unlicensed regime, with the expected network density for today and in next mid future.

Annex A (informative): Bibliography

ECC Recommendation 09-01 (2009): "Use of the 57 - 64 GHz frequency band for point-to-point fixed wireless systems".

ECC/Recommendation 05-02 (2009): "use of the 64-66 GHz frequency band for fixed service".

Annex B (informative):
Authors & contributors

The following people have contributed to the present document:

Rapporteur:
Mr. Pietro Nava, Huawei

History

Document history		
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