ECC Report 288

Conditions for the coexistence between Fixed Service and other envisaged outdoor uses/applications in the 57-66 GHz range

approved 25 January 2019

0 EXECUTIVE SUMMARY

Analyses of interference potentially affecting Fixed Service (FS) applications in the 57-66 GHz band, derived from Multi gigabit wireless systems (MGWS) systems, have been accomplished.

Due to unknown location of interfering devices, consequence of unlicensed regime, traditional interference analyses for the protection of FS is in general not possible. However, proper mitigation mechanisms have shown to be effective in this band in reducing the probability of interference to a few percent of FS links.

A variety of methods and design practices are available to modern MGWS that would reduce interference to FS. Ranking these methods and practices in terms of effectiveness (i.e. maintaining performance of both MGWS and FS), complexity, and cost is generally case dependent.

Among dynamic mechanisms, Automatic Transmit Power Control (ATPC) and Dynamic Frequency Selection (DFS) are the most effective and cost-efficient mechanisms. ATPC is particularly important as MGWS equipment are naturally motivated to implement ATPC to control self-interference. Coordinated transmission based on a common (synchronised) time base is highly effective in minimising interference and helps with intra-system interference, especially planning takes into account local specific deployment environment.

High propagation loss for signals in 60 GHz band due to oxygen absorption (up to 15 dB/km) naturally improves interference immunity for both MGWS and FS. Results in Section 7 indicate that combination of ATPC and adaptive antenna beamforming on MGWS can be used to further improve coexistence between MGWS and FS.

Regarding Intelligent Transport Systems (ITS), conclusions derived from ECC Report 113 [20] are still considered valid.

The utilization of MGWS outdoor is compatible in the majority of cases with current use of FS in this band, provided that common technical conditions as follows are adopted:

- The establishment of a common set of technical conditions under which fixed service applications and other outdoor envisaged uses/applications may coexist within the 57-66 GHz range in the same uncoordinated deployment is considered feasible;
- Therefore the technical conditions described in Figure 1 are considered appropriate to manage the coexistence amongst any MGWS and FS applications intended to be used in this band;
- In addition, the adoption of interference mitigation technique such as ATPC/DFS is also highly beneficial.

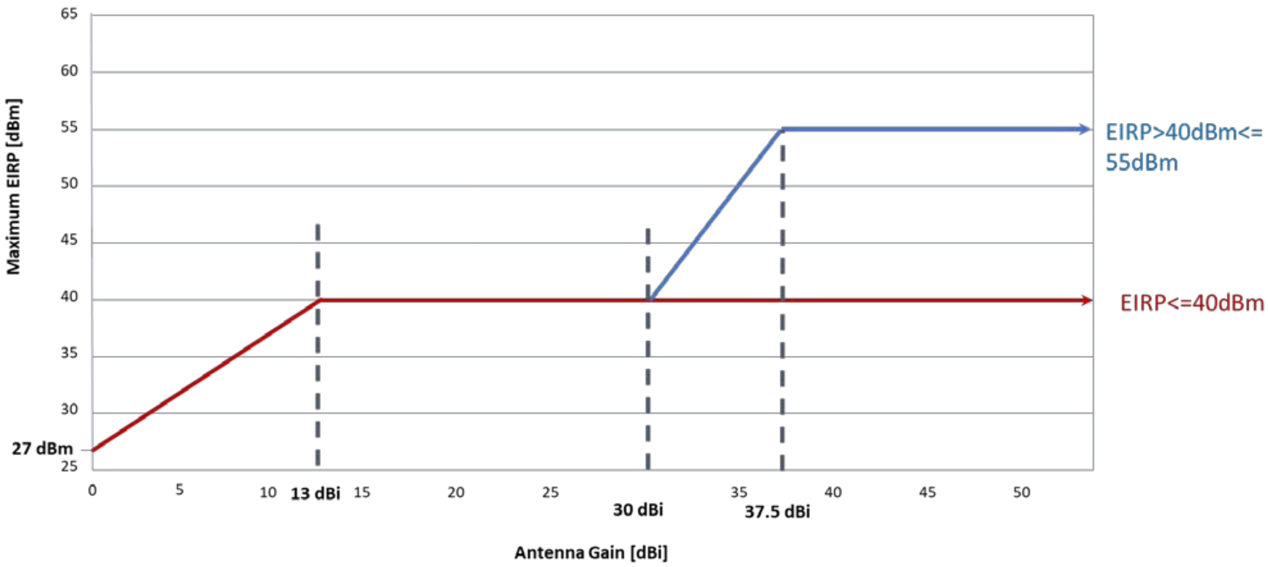

Figure 1: Maximum e.i.r.p. and antenna gain relationship

This could be implemented as:

For operation at e.i.r.p. ≤ 40 dBm:

- Maximum transmit power delivered to the antenna port or ports of 27 dBm and
- Maximum e.i.r.p.:
  - e.i.r.p.(max) = min (40, 40-(13-Gant)) dBm.

For operation at e.i.r.p. > 40 dBm:

- Maximum e.i.r.p.: 55 dBm
- The maximum e.i.r.p. shall be reduced by 2 dB for every 1 dB that the antenna gain is less than 37.5 dBi. This can be represented as:
  - e.i.r.p.(max) = 40 + 2*(Gant-30) dBm.

In this way, the e.i.r.p. is increased gradually with the antenna directivity.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
5G	Fifth Generation of Mobile Service
A-BFT	Association beam-forming training
AP	Access Point
ASK	Amplitude shift keying
(A)TPC	(Automatic) Transmission Power Control
BER	Bit error ratio
BPL	Building penetration loss
BS	Base Station
BW	Bandwidth
CCA	Clear Channel Assessment
CDF	Cumulative distribution function
C/I	Carrier to interference ratio
CN	Client Node
CPE	Customer Premises Equipment
CS	Channel spacing
DFS	Dynamic Frequency Selection
DL	Down Link
DN	Distribution Node
eCCA	extended Clear Channel Assessment
ED	Energy Detection (threshold)
e.i.r.p.	Effective isotropic radiated power
EMF	Electromagnetic field
EVM	Error vector magnitude
FBR	Front to Back Ratio (antenna parameter)
FCC	Federal Communications Commission
FLANE	Fixed local area network extension
FS	Fixed Service
FSK	Frequency shift keying
FWA	Fixed Wireless Access
Gant	Antenna gain
HOU	Home Outdoor Unit

HPBW	Half Power Beam Width
I	Interference (i.e. interference signal both single or aggregate)
IAP	Interferer Access Point
ITS	Intelligent Transport System
ITU	International Telecommunication Union
LBT	Listen Before Talk
LOS	Line Of Sight
MAC	Medium Access Control (Layer)
MCS	Modulation and Coding Scheme
MDU	Multi-Dwelling Unit
MGWS	Multi gigabit wireless systems
mmWV	millimetre wave
NFD	Net Filter Discrimination
nLOS	Near Line Of Sight
NLOS	Non Line Of Sight
OFDM	Orthogonal frequency division multiplexing
OOB	Out of band
PP	Point-to-Point
PMP	Point to Multipoint
PD	Power Detection (threshold)
PDF	Probability distribution function
PEC	Perfect Electromagnetic Conductor
POP	Point Of Presence
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RF	Radiofrequency
RPE	Radiation Pattern Envelope
RT	Remote Terminal
S	Signal (i.e. wanted signal)
SCM	Spatial Channel Model
S/I	Signal to Interference Ratio
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
SRD	Short Range Devices
TD	Threshold Degradation
TDD	Time Division Duplex
TPC	Transmission Power Control

TS	Time Slot
U	Number of interference links
UE	User equipment
UL	Uplink
UMi	Urban Micro
VHC	Very high capacity
WiGig	Wireless Gigabit Alliance

1 INTRODUCTION

The band 57-66 GHz is allocated to Fixed Service (FS) in ITU Region 1 on a primary basis, and it can be used in Europe by wideband data transmission devices according to the European Commission Decision 2013/752/EU [21]. This EC Decision imposes 40 dBm maximum e.i.r.p. to such devices and it does not allow the use of outdoor fixed installations. Regulatory aspects are covered by Annex 3 of ERC Recommendation 70-03 [8], which refers to ETSI EN 302 567 [9].

Point-to-point applications in the Fixed Service are regulated by ECC Recommendation (05)02 [22] and ECC Recommendation (09)01 [12] for regulatory aspects, and by ETSI Harmonised Standard EN 302 217-2 [4] for equipment. In the 57-64 GHz range (in some case equipment operates in the overall band 57-66 GHz), a maximum e.i.r.p. of +55 dBm is allowed and a 30 dBi minimum antenna gain is required. In the 64-66 GHz range, the usual e.i.r.p. requirement is used (up to 85 dBm maximum). In both cases, the output power (Pout) depends on antenna gain.

ECC started an action to review the conditions applicable to the band 57-66 GHz in order to ensure less restrictive, flexible and streamlined regulations for backhauling as well as for SRDs (WiGig), also taking into account ITS, in this frequency range (see CEPT Roadmap for 5G [23]).

FS has a primary allocation and incumbent deployments need protection based on the Radio Regulations, and SRD operates on a non-interference basis (required not to produce harmful interference). For this reason, proper studies are necessary to check conditions for coexistence.

Results of such studies, including proper mitigation effects allow final considerations to be developed in conjunction with knowledge of the effective use of the band.

2 DEFINITIONS

Term	Definition
V-band	57-66 GHz band
FLANE	Fixed Local Area Network Extension (presently included in the Fixed Service)
MGWS	In this Report, the term MGWS (presently identified as wideband data transmission systems in Annex 3 of ERC Rec 70-03) is used to indicate generic systems with wide band (in the order of 2 GHz, if not differently specified) including applications that are indicated as MGWS and/or FWA in the presented studies.

3 SCOPE

This Report is intended to analyse the compatibility of Multiple Gigabit Wireless Systems (MGWS) with the Fixed Service (FS) and other services in the 60 GHz band (V-band). It is to assess the feasibility of establishing a common set of technical conditions under which Fixed Service applications and other envisaged outdoor uses/applications may coexist within the 57-66 GHz range as described in the CEPT Roadmap for 5G [23].

4 BACKGROUND

This Report summarises a collection of studies related to use of 60 GHz by Fixed Service (FS) and Multiple Gigabit Wireless Systems (MGWS) in order to verify the opportunity to develop a common regulatory approach.

Some of the studies specifically address FS, others address intra- and inter-coexistence within other systems (MGWS, SRD and ITS).

Results of ECC Reports 113 [20] and 114 [13]are summarised in section 7.1 and 7.2. Such reports were developed a few years ago, and they addressed ITS and indoor MGWS compatibility with other services respectively. At that time, the acronym "FLANE" was used to indicate FS systems with a bandwidth of 200 MHz. These studies allowed determining protection distance as a function of the angles between main beams of the various applications, resulting in very long protection distances for small angles such as for mainbeam to mainbeam.

Due to unlicensed regime adopted by several administrations in this frequency band and with the consequent impossibility to know the exact location of the application, such approach is not applicable, so different approaches were deemed necessary to progress the work.

An initial study of coexistence of FS links and MGWS in the V-band was undertaken in 2016 by ETSI ISG mWT using SEAMCAT. This study assumes that Line of sight (LOS) links are used constituting a dense use scenario (200 randomly distributed links/km^2) as interferers and victims. Such analysis is summarised in section 7.3.

At that time, it was recognised that, in case unlicensed regime is adopted in this frequency band, which does not allow preliminary interference evaluation for actual uses, it is necessary to derive a possible limit for interference. The 2% percentage of links potentially affected by a critical C/I was indicated as threshold from FS network operators.

The value producing a 3 dB 10E-6 BER threshold degradation, was also chosen as a critical value according to the ETSI EN 302-217-2 [4].It was recognised that other applications could use another criterion as "critical condition", and a different, more relaxed percentage of interfered links could be tolerated in these cases.

Results of these simulations are given as the percentage of links which are expected to exceed a critical value of C/I. While the limit can be met if the equipment complies with the FS requirement, results show that such percentage grows significantly for less demanding system requirements and increasing channel bandwidth (BW); in particular, the result for MGWS showed percentage of interfered links higher than 50%.

Since the used method (LoS model) does not account for some important situations such as the presence of reflection and shielding of buildings, results were deemed not applicable (too pessimistic) to these kind of applications. It was agreed to perform a more detailed analysis, using 3D ray tracing tools applied to real world locations.

It should be noted that most of these methods apply to a specific situation where an accurate evaluation of interference is carried on and all parameters are fixed, while statistical models allow taking account of variability of some parameters within specified ranges. As such, simulation for more than one single case was considered advisable in order to increase confidence on wide applicability of results to real cases.

Studies carried on with such methods are addressed in sections 7.4 (Shanghai, China), section 7.8 (Washington D.C., USA) and section 7.9 (San Jose, California, USA) for several conditions and use cases.

Finally, a 3GPP method, capable of also applying statistical analysis to a 3D described environment is described and analysed in section 7.7.

Section 8 addresses mitigation mechanisms for interference reduction.

It should be noted that, due to different time of execution of studies, different companies providing studies and the evolving situation of the normative framework, especially related to MGWS, the technical characteristic used for these systems can be slightly different in the different studies. Nevertheless, the conclusions are considered not to be significantly affected by these differences.

It should also be noted that, although some considerations on the effectiveness of some interference protection mechanisms can be considered independent of frequency range, the results of these studies are strictly related to the specific conditions of propagation (such as the strong oxygen absorption) and authorisation regime in this band.

In this Report, the term MGWS is used to indicate generic systems with wide band (in the range of 2 GHz if not differently specified), and it includes applications which are indicated as MGWS and/or FWA in the presented studies.

Table 1 provides a summary and mitigation mechanisms used in each study.

Table 1: Summary of the studies presented in this Report

Doc. Sec-tion	Study	Sys-tem(s)	Channel	Deploy-ment	Output	Prot distance	Offset angle	Density	Ant gain	e.i.r.p.	ATPC	DFS	Beam steering
7.1	ECC Report 113	FS - ITS MGWS - ITS	Deterministic	MGWS (FLANE) roof top	**FS - ITS (RSU)** ITS as interferer: limit of unwanted emissions from ITS ITS as victim: ITS implements guard band **MGWS - ITS (RSU)** ITS as interferer to FLANE: min. protection distance ITS as victim from FLANE: min. protection distance ITS as interferer to WLAN: outdoor WLAN not studied ITS as victim from WLAN: maybe Detect And Avoid	X X	X X		**X**	**X**			
7.2	ECC Report 114	FS - MGWS (FLANE)	Deterministic	MGWS (FLANE) roof top	Protection distance and offset angles No Outdoor WLAN	X	X			X			
7.3	SEAMCAT STUDY (FS-FS)	FS	Statistical	Roof top	% interference vs BW, Antenna Gain and #channels		X	X	X		X	X	
7.3	SEAMCAT STUDY	MGWS - MGWS	Statistical	Roof top	% interference vs DFS and ATPC. Too pessimistic for new usage		X	X	X		X	X	
7.4	Shanghai (MGWS – MGWS)	FS - MGWS	3D Deterministic	MGWS roof top / nodal	Negligible thresh degradation (Includes self-backhaul)		X						X
7.5	1.5 km square	MGWS	Deterministic	Roof top	Low interference (offset angle)		X	X			X	X	X
7.6	Street-level	MGWS	Deterministic	Street level	Low occurrence C/I thresh crossing vs antenna		X						X
7.7	3GGP 3D model	FS - MGWS	3D Statistical	Below roof top	Max beam alignment angle, C/I CDF - FS unavailability %, as function of FS height, distance & angle	X	X						
7.8.2	Washington	MGWS	3D Ray Tracing	Street level	Operation with 1 channel possible, better with 2		X					X	X
7.8.3	Washington	MGWS	3D Ray Tracing	Street to roof top	LoS and NLOS (diffraction, reflection) ok in most conditions		X						X
7.9.2	San Jose – outdoor	MGWS	3D Ray Tracing	Street level	C/I CDF (with and without foliage)		X				X		X
7.9.3	San Jose - indoor located SRD	MGWS (FWA-SRD)	3D Ray Tracing	Below roof top	Low Interference from / to indoor application		X				X		X
7.9.4.5	San Jose – coexistence	FS - MGWS	Statistical	Street level	Low C/I exceedance, exclusion distance, antenna, angle, BW 200MHz, 2 GHz, several modulations		X		X		X		X
7.9.4.6	San Jose -Scen. 1 [long FS links]	FS - MGWS	3D Ray Tracing	Street level	C/I CDF - FS vs FS antenna gain, modulations, TPC		X		X		X		X
7.9.4.6	San .Jose -Scen.2 [short FS links]	FS - MGWS	3D Ray Tracing	Street level	C/I CDF - FS, vs distance & angle; Several modulations		X				X		X
7.9.5	FWA-SRD (nomadic application)	MGWS (SRD out FWA)	3D Ray Tracing	Street level	Distance for Co/ Adjacent channel Interference,						X	X	X

5 USE CASES

Use cases considered in this Report can be found in the relevant sections.

6 EQUIPMENT PARAMETERS

A list of technical parameters used in the interference studies addressed in this Report can be found in the relevant clauses.

7 AVAILABLE STUDIES

This section contains the results of studies available from recent or previous activities in relation to the 60 GHz use cases.

The studies available in ECC before the publication of this Report are contained in of ECC Reports 113 [20]and 114 [13] summarised in section 7.1 and 7.2.

Recent (specific) studies, not addressed by ECC deliverables, making use of SEAMCAT, 3D model, and 3D ray tracing are summarised in sections from 7.3 to 7.9.

7.1 ECC REPORT 113 (FS – ITS)

ECC Report 113 was developed in 2007 and revised in 2009. It was specifically addressed to study compatibility between ITS in the 63-64 GHz and other systems including MGWS.

MGWS included a specific class of devices named FLANE although they were considered as normal FS applications

Parameters utilised for MGWS including this FS application, are reported in Table 2.

Protection distances are calculated, with worst case scenario assumptions (main lobe to main lobe).

Table 3 provides a summary of the calculated separation distances with e.i.r.p. of 40 and 55 dBm.

Table 2: Technical parameters of MGWS

Parameter	Value / Characteristic	Comments
Maximum radiated power (e.i.r.p.)	+40 dBm (55dBm)	A variety of antennas may be used according to specific applications
Antenna aperture / gain	50° / 10dBi 7° / 27 dBi 2° / 38 dBi	Typical indoor distribution scenario connecting CPE to an access point with very little alignment effort. Both CPE and AP using the same antenna. Scenario studied in the project WIGWAM[1]. Indoor distribution system using half omni in combination with high directional CPE antenna. Study carried out by Fraunhofer Institute. Typical building to building LAN extension FLANE application[2]
Examples of typical modulation schemes	ASK, FSK, QPSK and OFDM	Modulation schemes currently used by broadband wireless air interfaces
Typical data rates	100 Mbps -10 Gbps physical layer	Depending on the channel size and modulation method
Typical channel bandwidth	0.15-2.5 GHz	Depending on desired data rate

[1] WIGWAM: System Concept Development for 1 Gbit/s Air Interface http://www.wigwam-project.com

[2] www.hubersuhner.com/sl60

Parameter	Value / Characteristic	Comments
Communication mode	Half Duplex, Full Duplex, broadcast	Duplex and broadcast are believed to be adequate for the applications considered to date
Typical maximum BER	$<10^{-6}$	Depending on the application
Typical Noise Figure	10 dB	
Noise/Interferer Threshold	10 dB	

Table 3: Minimum separation distances for 40 dBm e.i.r.p. and for 55 dBm e.i.r.p.

ITS	MGWS	
	FLANE e.i.r.p. of 40 dBm	FLANE e.i.r.p. of 55 dBm
Interferer	230 m	600 m
Victim	815 m	1310 m

It should be noted that results can be seen as interference from ITS to Wideband Systems (ITS as interferer) or interference from Wideband Systems to applications in the band (ITS as victim). This is due to the wide band characteristics of FLANE in this study, and being FLANE a FS application.

Although calculations should be calibrated to the FWA systems addressed in this Report to give accurate values, the order of magnitude of separation distances resulting from ECC Report 113 indicates that possible coexistence problems between ITS and FWA could not be excluded in principle if outdoor used is allowed. In such conditions, especially in urban environment, the possibility of main lobe to main lobe between applications not registered nor licensed cannot be excluded.

It should be noted that some technical characteristics of current equipment can be different from those used in developing ECC Report 113. Nevertheless, conclusions are still to be considered valid since no major technological change has occurred.

7.2 ECC REPORT 114 (FS-MGWS)

ECC Report 114 [13] was developed in 2007 and revised in 2009. This revision specifically studied compatibility between Multiple Gigabit Wireless Systems (MGWS) in the frequency range 57-66 GHz and other services and systems, excluding the 63-64 GHz band which was studied by ECC Report 113 [20].

Technical characteristics of FLANE, which can be considered similar to the MGWS studied in this ECC Report 114, are given in Table 4.

Table 4: MGWS FLANE parameters

Parameter	Value / characteristic	Comments
Maximum mean e.i.r.p.	+40 dBm +55 dBm	
Maximum OOB noise floor e.i.r.p.	–24 dBm/MHz	Evaluated from Figure 2 for a 250 MHz FLANE bandwidth

Parameter	Value / characteristic	Comments
Antenna aperture/gain	2° / 38 dBi	Typical building to building FLANE application
Gain in side lobes (>~5º)	< 18	Evaluated on typical Recommendation ITU-R F.699 [5] radiation patterns
Gain in side lobes (>~15º)	< 8 dBi	Evaluated on typical Recommendation ITU-R F.699 radiation patterns
Examples of typical modulation schemes	ASK, FSK, QPSK and OFDM	Modulation schemes currently used by broadband wireless air interfaces
Typical data rates	100 Mbps -10 Gbps physical layer	Depending on the channel size and modulation method
Channel bandwidth	From 150 MHz to 2.5 GHz	Depending on desired data rate and modulation. Channel spacing is not formally defined but assumed to be equal to at least channel bandwidth
Communication mode	Half Duplex, Full Duplex	FDD is considered to date. TDD was not envisaged up to date, but is not excluded
Typical maximum BER	$<10^{-6}$	Depending on the application
Typical Noise Figure	10 dB	
Protection criterion	I/N= -10 dB	Generic interference protection criterion

Emission mask of MGWS transmitter is given below in Figure 2 (Source is Figure B.3 of TR 102 555 [19]).

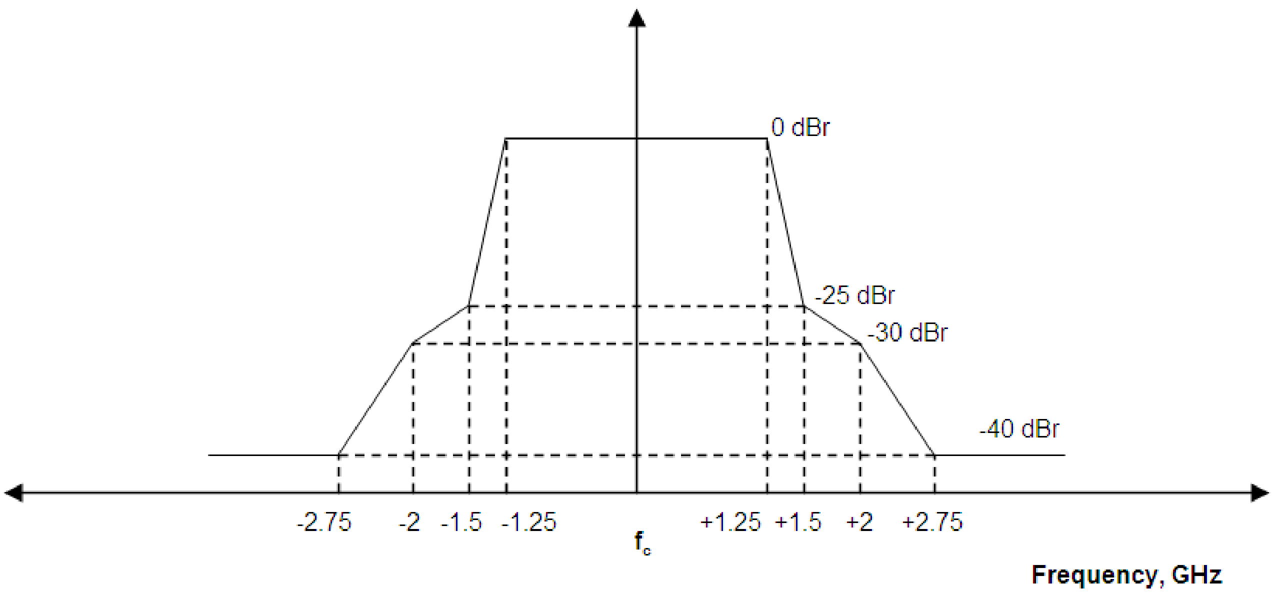


Figure 2: MGWS emission mask

Two sets of technical parameters were used to describe point-to-point (PP FS) links in the band 57-59 GHz (Table 5) and in the band 64-66 GHz (Table 6).

The study was limited to worst case scenarios such as the one shown in Figure 3.

Table 5: Parameters of PP FS links in 57-59 GHz used in compatibility studies

Parameter	Value/characteristic
Tx output power	+10 dBm
Transmitter e.i.r.p.	+55 dBm
Maximum OOB noise floor e.i.r.p.	–5 dBm/MHz
Assumed (typical) antenna gain	45 dBi
3 dB Beamwidth (°)	0.9
Gain in side lobes (>~5º)	< 15 dBi
Gain in side lobes (>~15º)	< 4 dBi
Channel bandwidth	100 MHz
Communication mode	TDD currently used today
Typical maximum BER	$<10^{-6}$
Receiver noise figure	13 dB
Protection criteria	I/N = -10 dB
Minimum C/I (co-channel equivalent on co-located routes)	C/I ≥ 25 dB

Table 6: Parameters of PP FS links in 64-66 GHz used in compatibility study

Parameter	Value / characteristic		Comments
	Conventionale	Very High Capacity PP FS	
Assumed e.i.r.p.	+45 dBm(*)	+67 dBm (*)	(*) Higher e.i.r.p. is possible if higher antenna gain is used (with consequent higher directivity)
Maximum OOB noise floor e.i.r.p.	-2 dBm/MHz	-2 dBm/MHz	
Assumed antenna gain	30 dBi (*)	41 dBi (**)	(*) Assumed suitable for ITS infrastructure links (**) Higher value (up to 50 dBi) might be possible for conventional PP links
3 dB beamwidth	5.4°	1.5°	Evaluated on typical Recommendation ITU-R F.699 radiation patterns
Gain in side lobes (>~5º)	<18 dBi	<18 dBi	Evaluated on typical Recommendation ITU-R F.699 radiation patterns
Gain in the side lobes (>~15º)	<12 dBi	<7 dBi	Evaluated on typical Recommendation ITU-R F.699 radiation patterns
Examples of typical	QPSK, 16QAM	AAK, FSK,	Modulation schemes currently used

Parameter	Value / characteristic		Comments
modulation schemes		PSK, QPSK	by broadband wireless air interfaces
Typical data rates	100 Mbps – 1 Gbps physical layer	STM-1 ÷ 1.25 Gbps	Depending on the channel size and modulation method
Typical channel bandwidth	350 MHz (*)	Up to 2 GHz (**) Typical assumption 1 GHz (***)	Depending on desired data rate and modulation: (*) 400 Mbps @ min.QPSK (**) STM16 Gbps @ min QPSK (TDD) (***) STM4 @PSK (TDD)
Communication mode	Full Duplex	TDD (FDD lower capacities)	
Typical maximum BER	$<10^{-6}$	$<10^{-9}$	Based on IP protocol transport
Typical Noise Figure	10 dB	10 dB	
Protection criteria	I/N=-10 dB	I/N=-10 dB	
Minimum C/I (co-channel equivalent on co-located routes)	C/I ≥ 25 dB	C/I ≥ 25 dB	

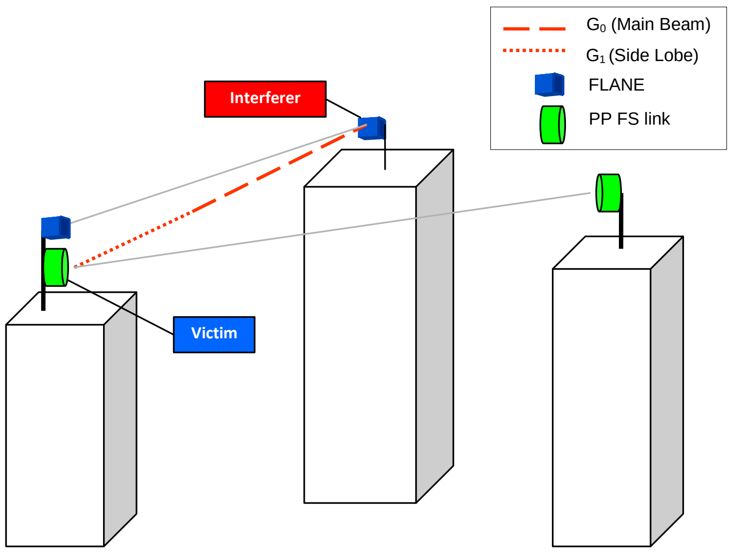
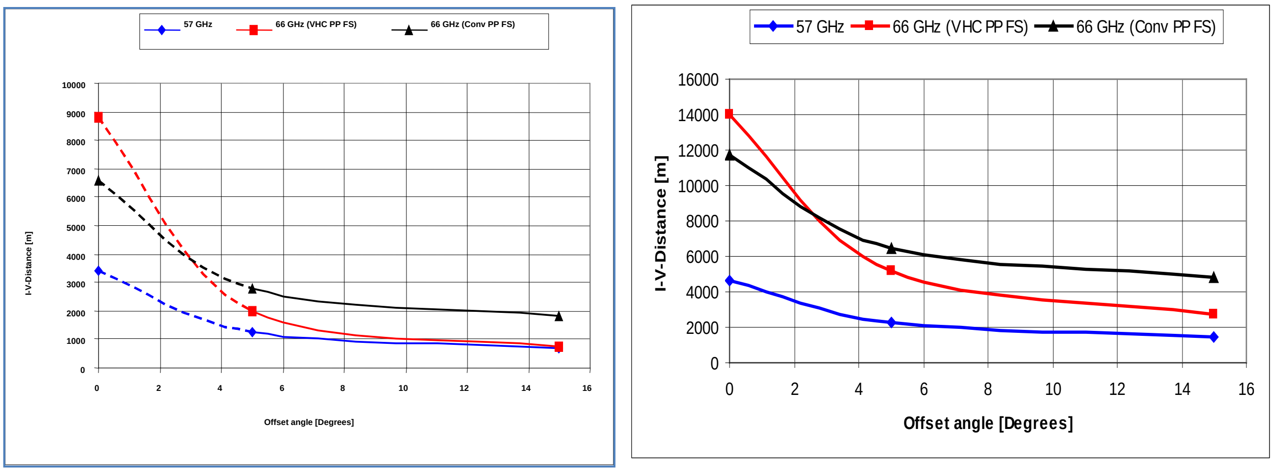


Figure 3: Protection distance evaluation scenario

Calculations were carried out for cases of e.i.r.p. of 40 dBm and e.i.r.p. = 55 dBm.

The result of these studies is shown in Figure 4 and in Table 7.



e.i.r.p. of 40 dBm e.i.r.p. of 55 dBm

Figure 4: Required separation distances: FLANE Tx main beam to PP FS Rx as a function of offset angle between the links for 40 dBm and 55 dBm e.i.r.p.

As shown, the required separation distance increases when e.i.r.p. is increased from 40 dBm to 55 dBm for all the offset angles. A comparison of the required separation distance for an e.i.r.p. of 40 dBm and 55 dBm is presented in Table 7.

Table 7: Comparison of the required separation distances (m) for an e.i.r.p. of 40 dBm and 55 dBm

-	Offset angle (°)					
-	0		5		15	
Band	e.i.r.p = 40 dBm	e.i.r.p = 55 dBm	e.i.r.p = 40 dBm	e.i.r.p = 55 dBm	e.i.r.p = 40 dBm	e.i.r.p = 55 dBm
57 GHz	3400	4600	1250	2250	700	1500
66 GHz (VHC PP FS)	8800	13950	2000	5200	750	2650
66 GHz (Conv PP FS)	6600	11600	2800	6500	1800	4800

It should be noted that some technical characteristics of current equipment can be different from those used in developing ECC Report 114 [13]. Nevertheless, conclusions are still to be considered valid, since no major technological change has occurred.

7.2.1 Conclusion of ECC Report 114 for MGWS co-existence with Fixed Service links

At offset angles between 5-15°, the study found that the required separation distances between MGWS and FS links, are in the order of 700-2800 m (with a FLANE e.i.r.p. of 40 dBm) and 1500 to 6500 m (with a FLANE e.i.r.p. of 55 dBm) for MGWS FLANE applications and in the order of 18-670 m for MGWS WPAN and WLAN applications; see section 4.1.5 of ECC Report 114 for details.

As an overall conclusion for MGWS-FS coexistence, it appears that indoor WLAN and WPAN applications of MGWS may be deployed in 57-59 GHz and 64-66 GHz without significant risk of interference to PP FS links, whereas deployment of FLANE may require taking some precautionary provisions in both considered bands to ensure co-existence with the PP FS links.

7.3 SEAMCAT STUDY (FS-FS)

This section summarises the studies undertaken in ETSI ISG mWT in 2016, using SEAMCAT 4.1.0. It is intended to study interference effects in a 60 GHz unlicensed environment on a generic equipment designed according to the requirements for FS. Analyses have been extended to other equipment types including some FWA equipment as currently foreseen.

Equipment characteristics:

- FS: according to ETSI EN 302 217 -2, BW 200 MHz;
- Antenna: ETSI class 2;
- Antenna gain: 32 and 38 dBi;
- FWA:
  - Antenna height (h): 30 m;
  - Ptx = 4/10 dBm without/with ATPC;
  - Antenna RPE according to Recommendation ITU-R F.699 (main lobe up to -10 dB;
  - Antenna gain: 25 dBi;
  - Side lobe Level: -10 dB;
  - QPSK & 64-QAM;
  - CS = 2 GHz;
  - Network density: 200 link/km^2.

Interference analysis was accomplished in three cases:

- All equipment complies with requirement of FS;
- All equipment complies with more relaxed criteria “WiGig – like”;
- Mixed use of two kinds of equipment.

In the case of coexistence with only FS equipment and adopting the interference criteria as the C/I needed to give 3 dB threshold degradation, a low percentage of possible interfered links (<= 7%) is obtained even for high modulations (64-QAM), with only 1 RF channel available (Figure 5 below).

Effects of DFS on the percentage can be seen in Figure 6, where the effects of ATPC is seen, reducing the percentage by at least a factor of two, for percentages not too high. Simulation also shows that interference increases with network density and decrease with reduced channel BW.

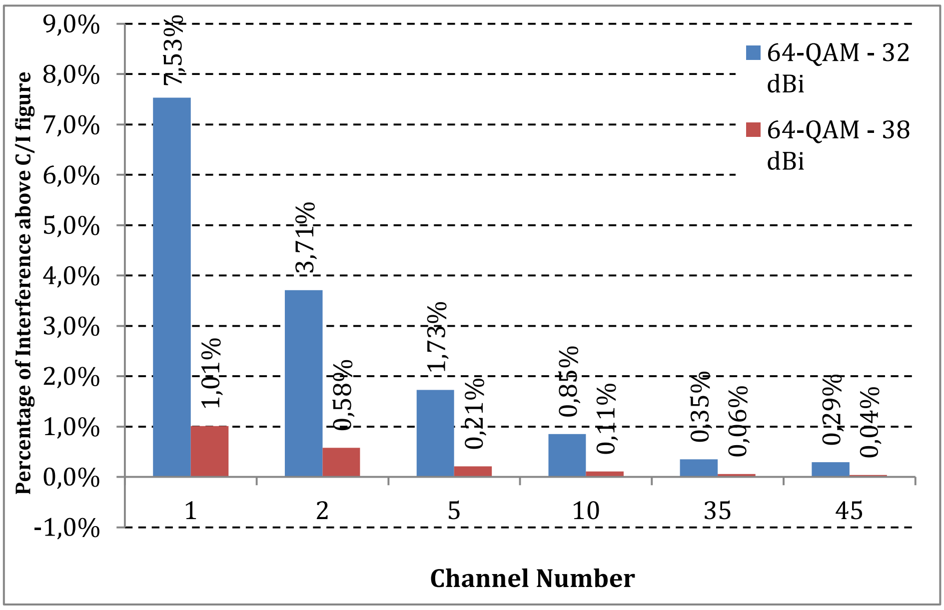


Figure 5: Open air % FS vs channel number

Same simulation applied to systems with 2 GHz channels and less stringent characteristics (such as an antenna with lower side lobes) provides significantly higher values for percentage. An example is given in Figure 6) where the effect of DFS and ATPC is also shown.

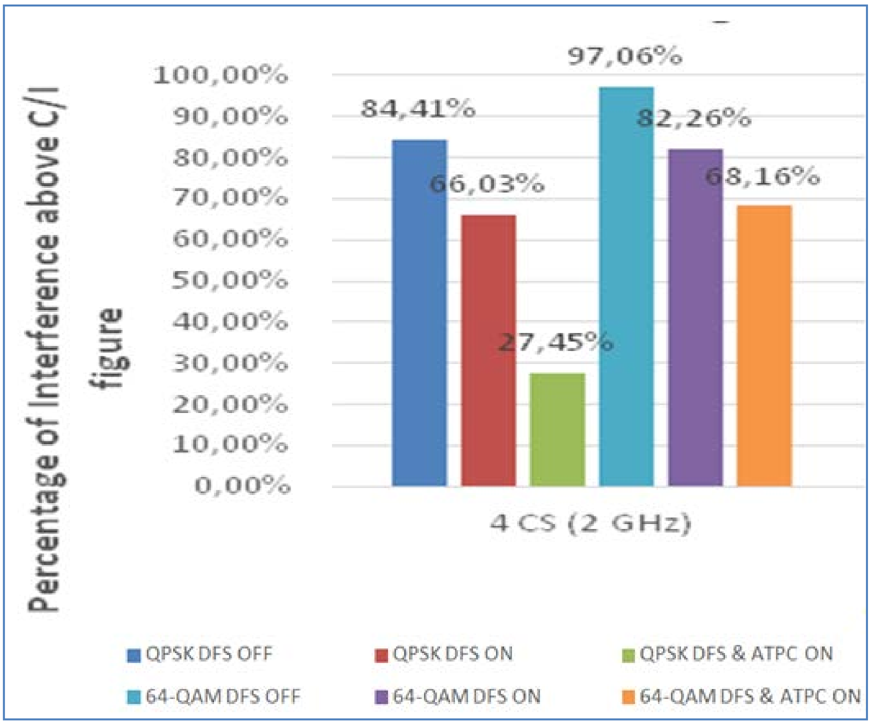


Figure 6: Open air %-FWA vs channel number

Working conditions adopted in statistical simulation could represent a reasonable approximation of a roof-to-roof use case, where LoS longer links (low density) are used with more performing antennas. However, these conditions seem to be not appropriate to describe MGWS deployed in cities at street level, which are expected to be a significant use case for this application.

Effects of shielding of buildings and the possible presence of reflection cannot be taken into account with this method, so the result is considered too pessimistic at least using the SEAMCAT version available when the study was conducted.

In order to gain better confidence of real network performance, specific tools designed to allow more accurate simulations of real environments were necessary.

7.4 3D SIMULATION IN SHANGHAI (MGWS-MGWS)

7.4.1 Shanghai roof-to-roof

A simulation of an area in Shanghai, China, has been completed based on a roof-to-roof network configuration as shown in Figure 7.

Figure 7: Roof-to-roof configuration in Shanghai, China

Interference analysis assuming equipment characteristics of a real 60 GHz PP equipment was performed, followed by a simulation assuming a WiGig based equipment.

Equipment characteristics are shown in Table 8, while results of simulations are shown in Table 9 in terms of threshold degradation (TD).

Table 8: Equipment characteristics

	PP equipment characteristics	PMP equipment characteristics
Duplex mode	TDD	TDD
Frequency	60875 MHz	60875 MHz
Bandwidth	2000 MHz	2000 MHz
Polarisation	Horizontal	Horizontal
Tx power	5.5 dBm	24 dBm
Antenna gain (Tx/Rx)	34.5 dBi	16 dBi
HPBW	1.9	HPBW: 15

Table 9: Results of simulations

Victim Link (DL)	Interfering Link	RSL(dBm)	Interference (dBm)	RSL(dBm)	Interference (dBm)	TD (dB)
		PP		PMP		
Link 2	Link 27 - DL	-32.8	-99.8	-51.5	-99.8	0.01
Link 5	Link 22 - DL	-36.7	-86.7	-55.3	-87.3	0.18
Link 5	Link 27 - DL	-36.7	-101.3	na	na	0.01

Victim Link (DL)	Interfering Link	RSL(dBm)	Interference (dBm)	RSL(dBm)	Interference (dBm)	TD (dB)
Link 6	Link 14 - DL	-40.2	-98.9	-59.1	-96.7	0.01
Link 13	Link 28 - DL	-37.3	-91.4	-56.2	-98.3	0.06
Link 13	Link 27 - DL	-37.3	-100.4	-56.2	-96.8	0.01
Link 21	Link 24 - DL	-43.0	-84.5	-61.8	-85.9	0.3
Link 21	Link 28 - DL	-43.0	-98.8	-61.8	-92.8	0.01
Link 26	Link 19 - DL	-39.2	-100.2	-57.7	-95.3	0.01
Link 27	Link 17 - DL	-42.1	-97.5	-60.9	-95.9	0.02
Link 14	Link 6 - UL	-40.2	-99.8	-58.9	-96.7	0.01
Link 12	Link 28 - UL	-45.0	-99.6	-63.1	-98.1	0.01
Link 17	Link 27 - UL	-41.6	-97.5	-59.8	-95.9	0.02
Link 19	Link 26 - UL	-42.7	-100.2	-61.9	-95,3	0.01
Link 22	Link 5 - UL	-38.2	-86.7	-56.7	-87.3	0.2
Link 24	Link 21 - UL	-38.2	-84.5	-58.4	-85.9	0.3
Link 27	Link 2 - UL	-42.1	-99.8	-60.9	-100.5	0.01
Link 27	Link 3 - UL	-42.1	-100.4	-	-	0.01
Link 27	Link 5 - UL	-42.1	-101.3	-	-	0.01

7.4.2 Shanghai nodal specific case

A specific nodal study, including two "self-backhauling" links (Link 1 and Link 2 in Table 10), was also undertaken.

Two sets of equipment, with two steerable antennas, are placed in the concentration node of this scenario.

When the system operates as "self-backhaul", only Link 1 and Link 2 are active, due to simulated antenna steering range.

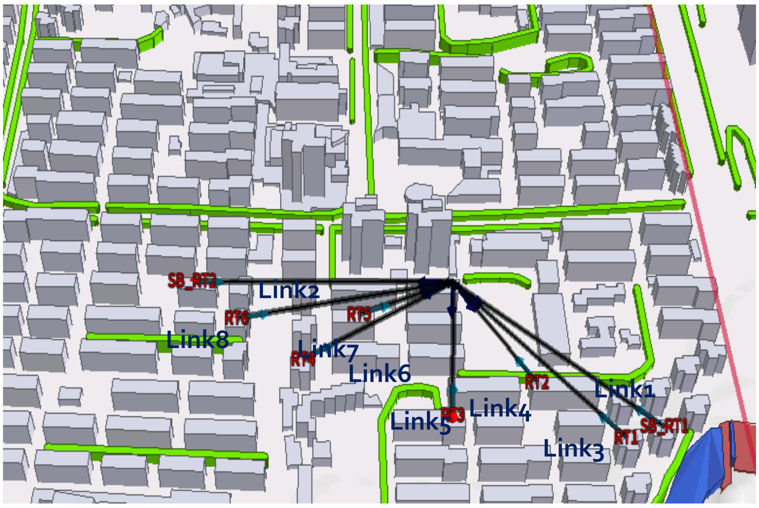


Figure 8: Nodal setup

Table 10 shows interference levels towards “self-backhaul” links during downlink and uplink and the sensitivity threshold degradation (a single channel is used).

Table 10: Downlink and Uplink interference results

Victim Link (DL)	RSL (dBm)	Interfering Link	Interference (dBm)	TD (dB)	Total TD (dB)
Link 1	-60.5	Link 5 – DL	-84.7	0.3	< 0.4
		Link 8 – DL	-96.8	0.02	
		Link 4 – DL	-97.5	0.02	
		Link 2 – DL	-102.2	0.01	
Link 2	-62.2	Link 7 – DL	-80.4	0.7	< 0.8
		Link 6 – DL	-81.2	0.6	
		Link 5 – DL	-88.9	0.1	
		Link 1 – DL	-90.3	0.1	
		Link 3 – DL	-91.6	0.06	
		Link 4 – DL	-92.1	0.05	
Link 1	-60.5	Link 5 – UL	-79.4	0.9	< 1
		Link 7 – UL	-88.3	0.1	
		Link 2 – UL	-90.3	0.08	
		Link 8 – UL	-91.8	0.06	
		Link 6 – UL	-94.5	0.03	
Link 2	-62.2	Link 5 – UL	-75.6	1.9	< 2
		Link 1 – UL	-102.2	0.01	

Interference calculations for the access links provide comparable results with both types of antennas with negligible threshold degradation.

A further check made using two adjacent channels confirmed the practical condition of no threshold degradation.

7.5 ROOFTOP SCENARIO IN A 1.5 BY 1.5 KM SQUARE AREA (MGWS - MGWS)

The simulation model used in this rooftop scenario is based on unplanned deployment where multiple uncoordinated sites are deployed using a license exempt model. The deployment is based on the use of multiple PMP beam-steering sectors, where each sector includes a single instance of PMP beam-steering base station (BS[3]) with several beam-steering terminals.

The aim of the simulation is to check the expected performance as well as get a feeling for the effect of various parameters on interference probability. Such parameters include the use of dynamic frequency selection (DFS), automatic transmit power control (ATPC), the overall density and the effect of terminals-per-BS density. The system operates in TDD mode and the antenna pattern is selected per the pointing angle of

[3] In this section, the term Base Station (BS) is used with the same meaning of Access Point (AP).

the link in the sector. Each interference scenario between any two links is described by angles and distances as shown in Figure 9.

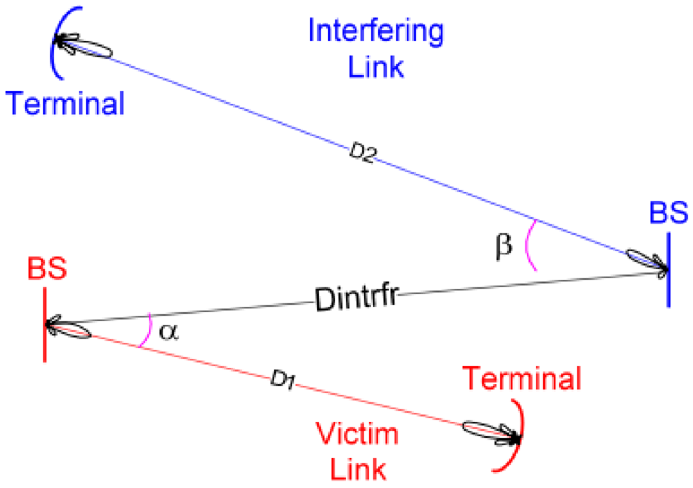


Figure 9 : Interference scenario

The simulation assumes a certain area of operation, in which a certain base station sector density per square km is used. Each sector is 120° wide where coverage area spans from 20 m to 200 m. In each sector, a certain terminal per base station density is assumed, which may be fixed or normally distributed. The simulation used a certain number of frequency channels where 20 dB of adjacent channel rejection assumed (i.e. net filter discrimination, NFD). The propagation model is LoS propagation (including oxygen absorption). The simulation results are captured by observing signal to interference ratio (S/I) distribution over about 10000 simulation trials. These results are visualised in a histogram with S/I bins from 0 to 20 dB. S/I values above ~4 dB are considered possible to operate with using robust modulations such as coded QPSK. An example of a simulation scenario is shown in Figure 10, where the sector density of 40 base stations per square km is considered and the area being analysed is of dimension of 1.5 km by 1.5 km. Each base station (i.e. AP) serves 4 terminals, where the blue slices represents the base station sectors nominal coverage area while the red circles represent terminals (i.e. RT). No coordination or ordering is used and the position of base station is taken from a random uniform distribution over the simulation area while the position of the terminals is taken from a random uniform distribution in the respective base station sector coverage area.

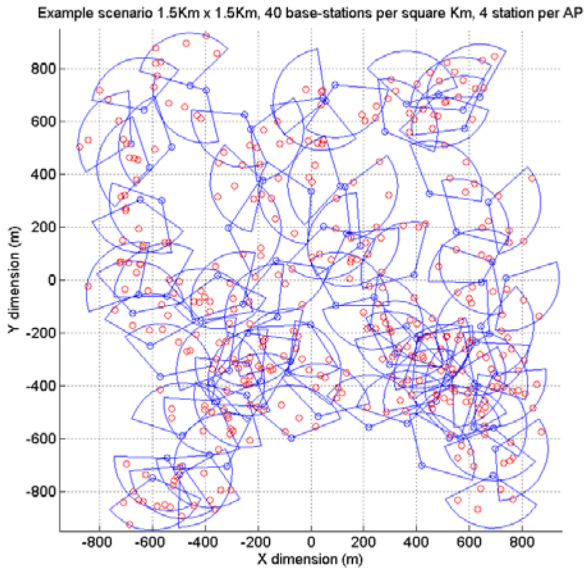


Figure 10: Scenario example

Figure 11 and Figure 12 depict examples of simulation results in various conditions. Typically the base station density is being varied and ATPC is being deployed. The simulation cases include:

- Fixed four terminals per base station using two frequency channels;
- Fixed four terminals per base station using four frequency channels;
- Random N(4,2) distributed number of terminals per base station using two frequency channels;
- Fixed node density by adjusting terminal to base station ratio using two frequency channels;
- Fixed four terminals per base station using two frequency channels and no ATPC;
- Deployment of a DFS mechanism.

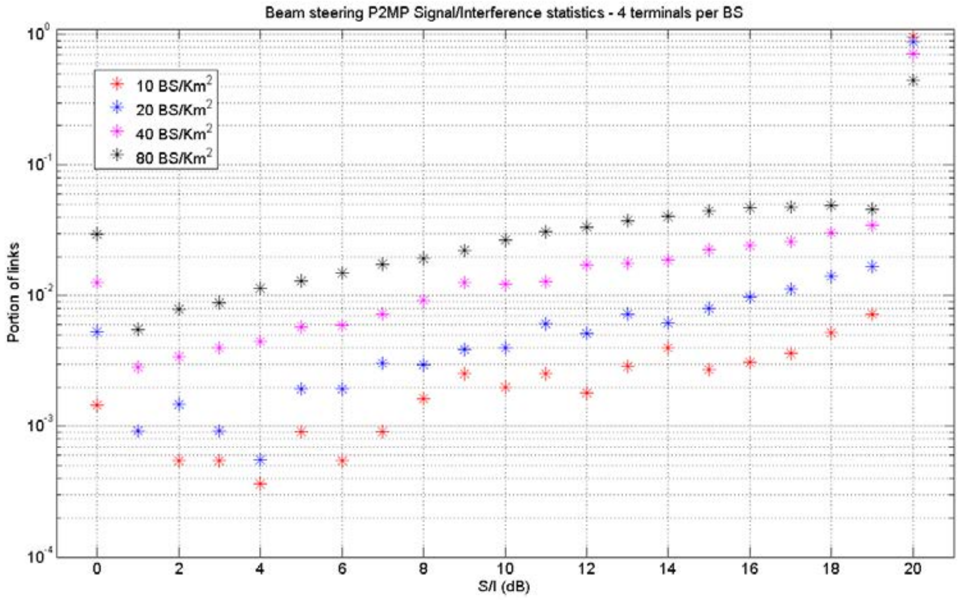


Figure 11: Fixed four terminals per base station using two frequency channels

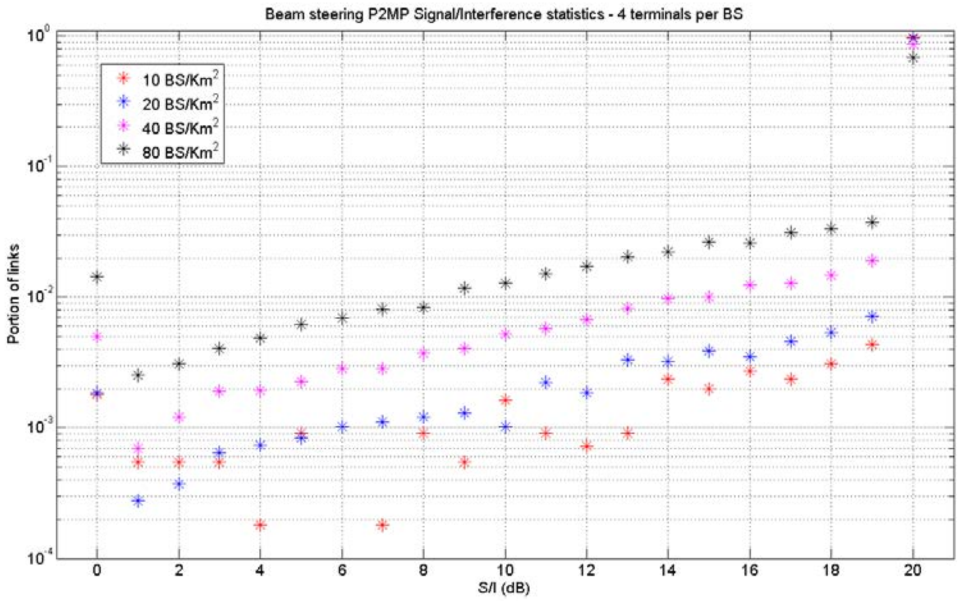


Figure 12: Fixed four terminals per base station using four frequency channels

The above results all demonstrate very robust performance in view of the high densities and lack of any planning. The percent of nodes that remain blocked by interference even at their most robust modulation (which is assumed to S/I less than 4 dB) is typically in the order of 1%.

As expected the use of more frequency channels improves the chances for lack of interference.

It is expect that real-life scenarios will provide even better results due to factors not considered in this analysis such as obstacles to pure LoS propagation as well as such as rooftop height being non-uniform across the deployment area and foliage height often exceeding the rooftop height.

7.6 MANHATTAN GRID STREET-LEVEL SCENARIO (MGWS - MGWS)

The street level deployment scenario assumes a Manhattan grid of buildings in which wireless links are deployed across the streets. In the specific analysed scenario, block size is taken as 90 m and street width is taken as 15 m. The simulation examines the chances for interference between a collocated pair of links using the same frequency channel. The link distance for both links ranges from 20 to 300 m. The distance between the interfering links to the interfered link also ranges from 20 to 300 m. The simulation consists of generating 10000 random configurations per interfering to interfered distance. The frequency simulated is 61.5 GHz, and co-channel interference thresholds are taken from ETSI EN 302 217-2 [4]. A graphical depiction of the simulation scenario is shown in Figure 13 where the blue lines represent the victim link whereas the red lines represent the interfering link.

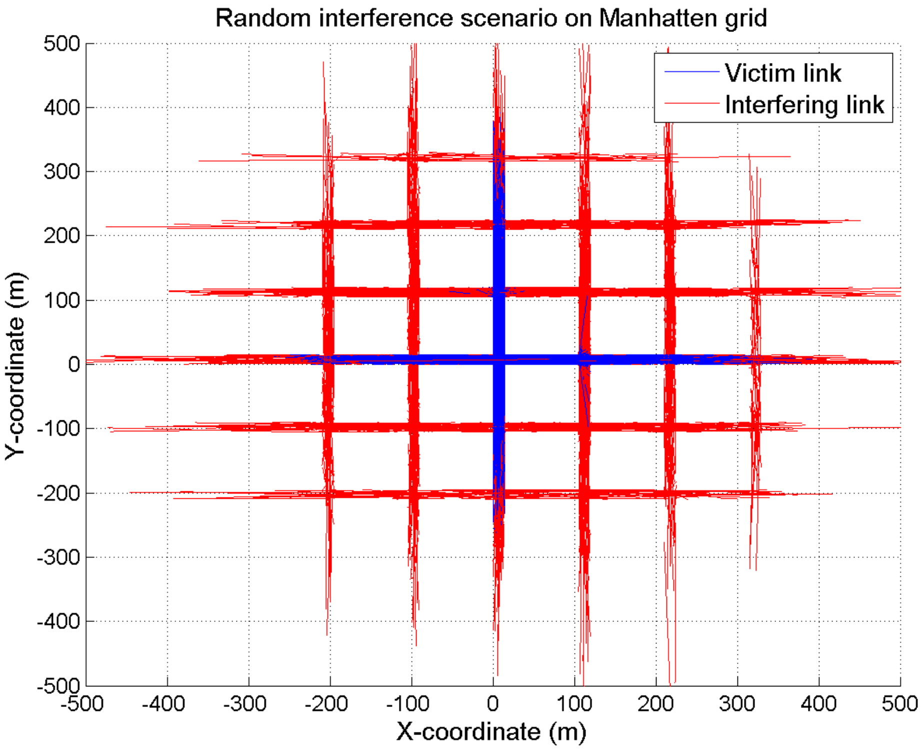


Figure 13: Street level interference scenario depiction

Figure 14 shows the simulated probability of interference shown when using a 30 dBi regular antenna with radiation pattern envelope (RPE) conforming to Recommendation ITU-R F.699 [5]. No polarisation discrimination is assumed. It shows that the interference probability is moderate within the same block, but it drops rapidly at more than one block distance.

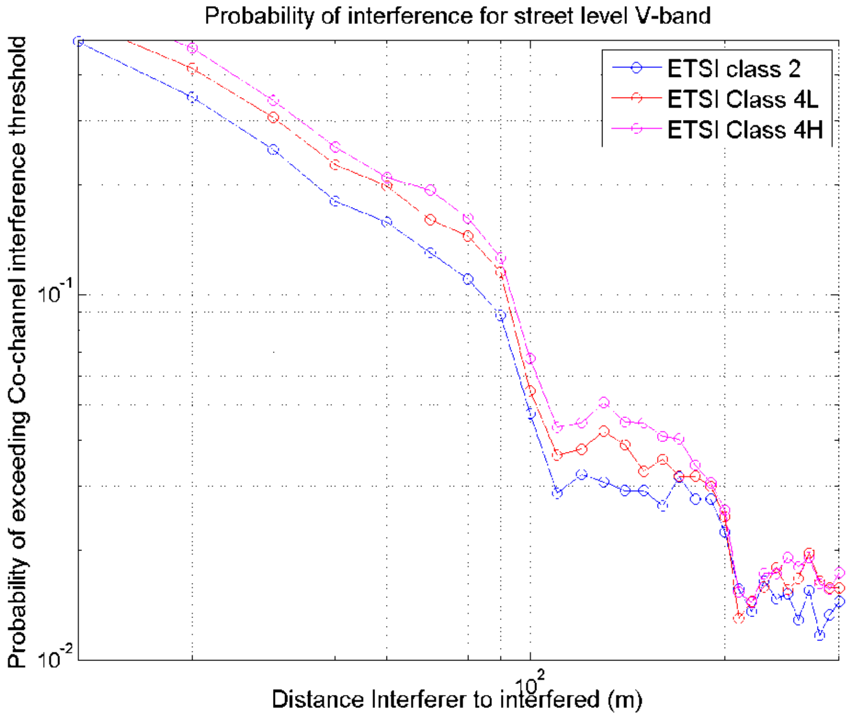


Figure 14: Regular antenna probability of interference as a function of interferer distance

The same simulation is repeated with the use of a beam-steering antenna and the result is shown in Figure 15.

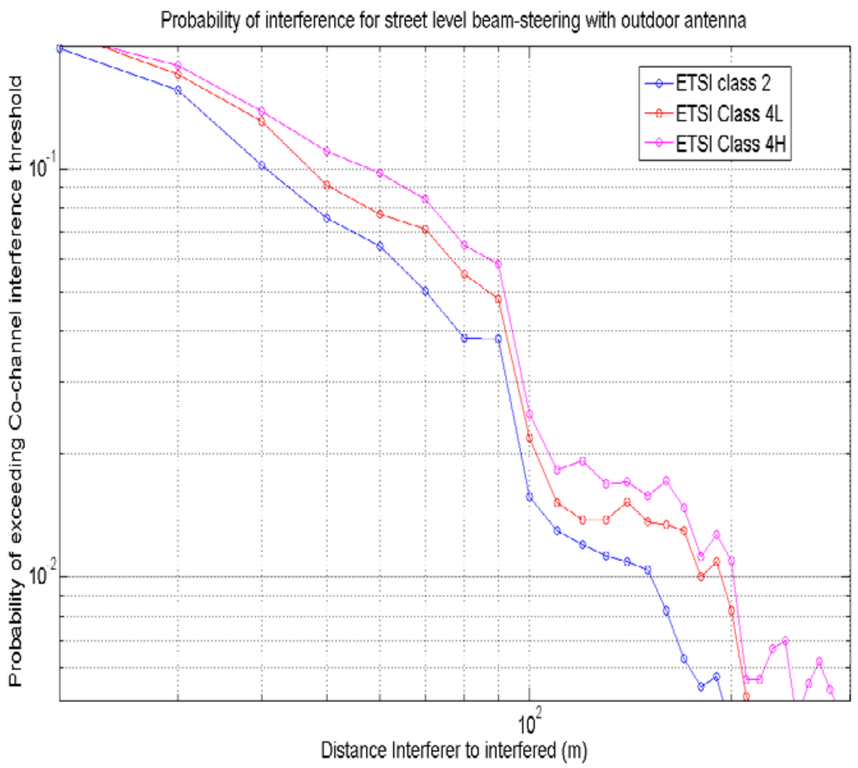


Figure 15: Beam-steering antenna probability of interference as a function of interferer distance

The street level analysis is performed on a simplified grid, but results should be valid to a general urban grid. In any such grid, the street structure (i.e. buildings) isolation is the main isolator, and the antenna pattern contribution is secondary. This happens because the antennas are forced to be aligned to the streets directions, which implies that antennas are either on the same street, non-isolated, and pointing more or less to the same direction, or on parallel or orthogonal streets, isolated by building. The oxygen absorption plays an insignificant role at such short distances.

The most relevant observation from this analysis is that the beam-steering antenna results are the same as a regular antenna. Other than that, it is expected that use of more than one frequency channel with a DFS mechanism should enable uncoordinated use also in this case, even with low gain beam-steering antennas.

7.7 3GPP MODEL APPLIED TO A 3D SCENARIO (FS AND MGWS)

7.7.1 Methodology

Complementing the ray tracing analysis applied in previous sections, the following coexistence study between FWA and FS considers the statistical 3D Spatial Channel Model developed by the 3rd Generation Partnership Project (3GPP) in [17].

The development of realistic channel models is one of the greatest challenges in the characterisation of wireless communications systems. The quality is crucial for accurately predicting the system performance and propagation behaviour of wireless systems. Channel models can be broadly divided into two categories, deterministic and statistical.

7.7.1.1 Comparison

Ray tracing

As all deterministic methods, ray tracing is targeted at describing the channel for a specific propagation environment between a transmitter and a receiver. In more detail, ray tracing is based on ray optics, which solves the Maxwell's equations in the high frequency regime.

Thus, the ray tracing method is a general propagation model that provides estimates of both large- and small-scale parameters (e.g. path loss, angle of arrival/departure, multi-path fading and time delays).

Unlike statistical models, ray tracing does not provide simple formulas for the calculation of the channel gain. It is a computer program based on a numerical method to solve Maxwell's equations. Ray tracing can provide very accurate predictions, but it is also computationally intensive, and thus not suitable for very large scenarios.

The accuracy of the predictions also depends on the quality of the description of the scenario (e.g. terrain, buildings and vegetation) and the properties of the materials in it (e.g. conductivity, permittivity and refractivity).

A ray tracing prediction is inaccurate if not adequately calibrated. Thus, real measurements are always needed to calibrate the ray tracer and optimise its performance in the particular scenario of study.

Overall, ray tracing can provide very accurate predictions for specific small scenarios, if an accurate data base describing is available, and if the tool is properly calibrated. Its computational complexity makes it prohibitive to study many scenarios.

3GPP statistical 3D Spatial Channel Model (SCM)

To strike a better balance between accuracy and complexity, the 3GPP has introduced a statistical 3D Spatial Channel Model (SCM). This model represents scatters through statistical parameters without being physically positioned.

It is also known as a geometric stochastic model, which separately defines large-scale parameters (e.g. shadow fading, delay spread, and angular spreads) as well as small-scale parameters (e.g. delays, cluster powers and arrival-and-departure angles).

Both sets of parameters are derived based on large number of measurement campaigns, and they are randomly drawn from tabulated distributions.

In contrast to ray tracers, statistical models do not need to solve Maxwell´s equations, which lower their complexity.

The large-scale parameters incorporate the geometric positions of the base stations (BSs) and the user equipment (UEs), which are also used to parameterise the statistics of the small-scale parameters.

Then, the channel behaviour is defined based on the power delay profile and the angular profile.

The 3GPP 3D SCM model includes a number of different scenarios each of them representing a unique environment.

Overall, this channel model:

- has a much lower complexity than ray tracing and accounts for a large range of frequencies including the 60GHz of interest;
- is based on large measurements campaigns, which allows to provide general statements in an ensemble of environments such as the Urban Micro considered in this coexistence study;
- has been adopted by a large number of companies within the 3GPP which allows to compare results among different sources.

SEAMCAT

The ECC tool uses also a statistical approach, but it lacks the Urban Micro (UMi) – Street Canyon channel model plug-ins for the 60 GHz band, as introduced in earlier in the comments of section 7.3 In the version in force at the time when the study was undertaken, the tool allows to choose from either Recommendation ITU-R P.452-12 [24] model or the WINNER path loss models[4], that is:

- Recommendation ITU-R P.452-12 model extends to high frequency bands, but it lacks an urban micro model;
- the WINNER model implements an urban micro model, but it only covers sub 6 GHz bands.

7.7.1.2 Description

All the communication links in the considered scenarios are assumed to experience line of sight (LOS) propagation and follow the UMi - Street Canyon propagation model.

These parameters are defined as a compromise of the results derived from a multiplicity of company measurements in different street canyons, i.e. they do not correspond to a specific street. The propagation characteristics of this street canyon setup are different from those experienced in open field deployments and should be captured accordingly in the specific values of the different parameters used in the channel model.

It should be highlighted that this channel model also captures the impact of the non line of sight (NLOS) multipath components of the propagation, and therefore accounts for time-and-frequency correlated fast fading.

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[4] https://www.cept.org/eco/eco-tools-and-services/seamcat-spectrum-engineering-advanced-monte-carlo-analysis-tool/training

The main characteristics of the channel model are summarised in Table 11.

Table 11: Characteristics of the 3GPP TR 38.901 [17]channel model

3GPP TR 38.901 channel model characteristics	
Shadow fading (Note 1)	Spatially correlated with standard deviation (σ) as per Table 7.4.1-1 (σ = 4 dB)
Path loss	Frequency-dependent as per Table 7.4.1-1
Oxygen absorption	As per Table 7.6.1-1 (e.g. 15 dB/km for f = 60 GHz), which is consistent with [3] [10]
K-factor*	Log-normal distribution with mean (μ) and σ as per Table 7.5-6 for WPON links (μ = 9 dB and σ = 5 dB)
Antenna element pattern	Identical vertical and horizontal cuts of the radiation power pattern as per Table 7.3-1
Delay spread (Note 1)	Log-normal distribution as per Table 7.5-6
Angular spreads of arrival and departure (Note 1)	Log-normal distribution as per Table 7.5-6
Note 1: The specific values of the large-scale channel parameters highlighted in the table above, a number of parameters used for fast fading generation (e.g. per cluster shadowing, angles of arrival/departure) and the traffic dynamics (e.g. scheduled users per TTI, packet times of arrival for the FTP3 scenario) vary per simulation drop since independent realizations of the random variables involved in their definition are generated per drop. The aggregation of results of many drops is used to build the CDFs.	

One simulation (i.e. see Cumulative Density Function (CDF) graphs) is composed by multiple drops where each drop is the realisation of the statistical channel model. Each drop is built as a time evolution series with a given traffic pattern. The initialisation of the channel model and traffic variables is based on random seeds which are chosen based on the Monte Carlo method.

The CDF results are composed by a relative low amount of drops i.e. 15. Whereas statistical analysis usually demands a further level of iteration, the high amount of Access Point (AP) and Home Outdoor Unit (HOU) units, and the smoothness of the results indicates that this assumption is correct. Where links are static (as result of the fixed position of the units), the nature of the scenarios, , reduces the randomness of the channel as usually it is the mobility characteristic that creates the biggest variance in wireless environments.

7.7.2 FS and MGWS access systems

The main characteristics of the considered systems are detailed in the following tables.

7.7.2.1 MGWS

Each AP and HOU is comprised of phased array antennas that provide 180° field of view.

Each AP solely provides downlink/uplink access to one HOU at a time.

Table 12: MGWS characteristics

MGWS characteristics	
Transmission power	16 dBm
Maximum e.i.r.p.	35 dBm
Maximum antenna gain per panel	19 dBi
Receiver noise figure	7.5 dB

MGWS characteristics	
Number of antennas elements	100
Antenna polarisation	Vertical
AP mechanical tilting	15º upwards
Data transmission bandwidth	1.76 GHz [15]
Analog beamforming	Codebook-based beamforming
Traffic model 1	Full buffer
Traffic model 2	FTP3 with: - Offered traffic = 10 Mb/s (each dir. UL and DL) - File size = 16 Mb

7.7.2.2 Fixed Service

Table 13: Fixed service characteristics

Fixed service (FS) characteristics	
Equivalent isotropic radiated power (e.i.r.p.)	48 dBm [12][13]
Transmission power	10 dBm [12][13]
Maximum antenna gain	38 dBi [13]
Antenna polarisation	Vertical
Receiver noise figure	10 dB [12][13]
Receiver signal level thresholds (dBm/MHz) for $\mathbf{BER} =$	4-QAM = -88.5 dBm/MHz [7][14] 16-QAM = -81.5 dBm/MHz [7][14] 64-QAM = - 75.5 dBm/MHz [7][14]
Limits of Carrier to Interference ratio (C/I) for 1 dB degradation of the receiver input signal level (RSL) thresholds for $\mathbf{BER} =$	4-QAM = 23 dB [7][14] 16-QAM = 30 dB 64-QAM = 37 dB [7][14]
Centre frequency	60.48 GHz [15]
System bandwidth	200 MHz [13]
Noise spectral density	- 174 dBm/Hz
Allowed interference to noise ratio (I/N) (Note 1)	-10 dB [13]
Allowed signal to interference ratio (C/I)	≥ 25 dB [13]
Traffic model	Full buffer
Note 1: The I/N criterion is necessary for links where fading is uncorrelated. Standing the shortness of the links, this might not be the case.	

Regarding the antenna pattern of the FS ends, a methodology similar to that described in [7] will be considered, i.e. the antenna pattern in the main lobe (≤ 5º) follows [7], and the Reference Pattern Envelope (RPE) outside the main lobe will be obtained as a compromise between Recommendation ITU-R F.699 [5] and ETSI EN 302 217-4-2 [16] since the latter does not provide values for the main lobe.

7.7.3 Simulation results

7.7.3.1 Sub-urban

Scenario definition

The sub-urban scenario consists of an AP site in the centre of the street (reference point 0 for Y-axis) e.g. mounted in a lamp pole, utility pole, street signage or street furniture. This site is composed by two APs, with a field of view of 180° each. The AP site serves single dwellings in both sides of the street, where the HOU is mounted outdoors, at a regular height and in LOS conditions to its serving AP.

The distribution of APs and HOUs is even throughout the street.

This set up defines several locations for the FS link.

FS Rx takes two locations in the X-axis i.e. in the left side of the street, where interference is present in one side of the receiver only; and somewhere in the middle of the street, to account for interference coming from both sides of the receiver.

In each of those locations the FS Rx is placed at two different heights i.e. 15 m and 20 m.

For every position described above FS, Rx is oriented in two directions i.e. facing east and facing south. According to each position and orientation of the FS Rx, the FS Tx is aligned at 500 m distance.

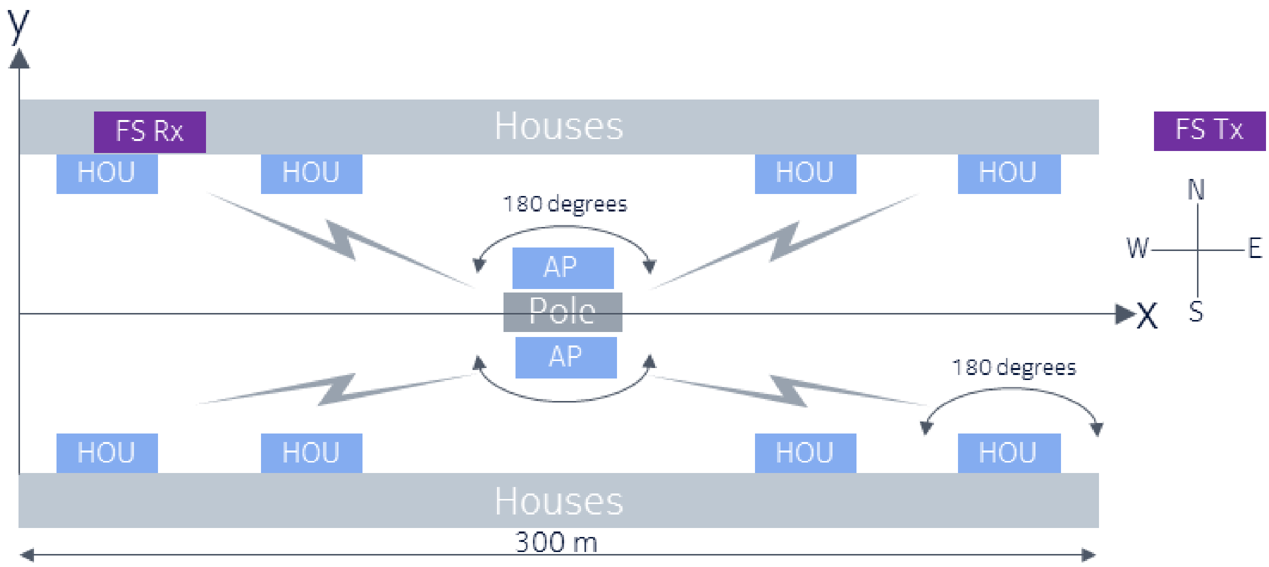


Figure 16: Scenario for the sub-urban case

Table 14: MGWS deployment for sub-urban scenario

MGWS deployment	
Number AP sites	4 locations
AP sectorisation	360º sector coverage
AP inter-site distance (x-axis)	120 m
AP heights	6 m
Distance AP-façade	5 m
Number of associated HOUs per AP	8 HOUs per AP
HOU heights	6 m
HOU deployment	Uniform 2D distribution with 15 m inter-HOU distance at y = $\pm$5 m

Table 15: FS deployment for sub-urban scenario

FS deployment	
FS Rx locations	x = -7.5 m and x = 112.5 m, y = 5 m
FS Rx heights	15 m and 20 m [11]
FS Rx antenna orientations	0° (pointing East) and -90° (pointing South)
FS Rx-Tx distance	500 m
FS Tx location	2D location: In the segment with initial point of the receiver location and direction given by its antenna orientation. Height: same as receiver.
FS Tx orientation	Antenna aligned with receiver

Performance

Configuration of FS Rx: orientation 0°, x = -7.5 m, h = 15 m

<u>Time domain analysis with FTP3 traffic model</u>

This represents around 29% of the MGWS channel occupancy.

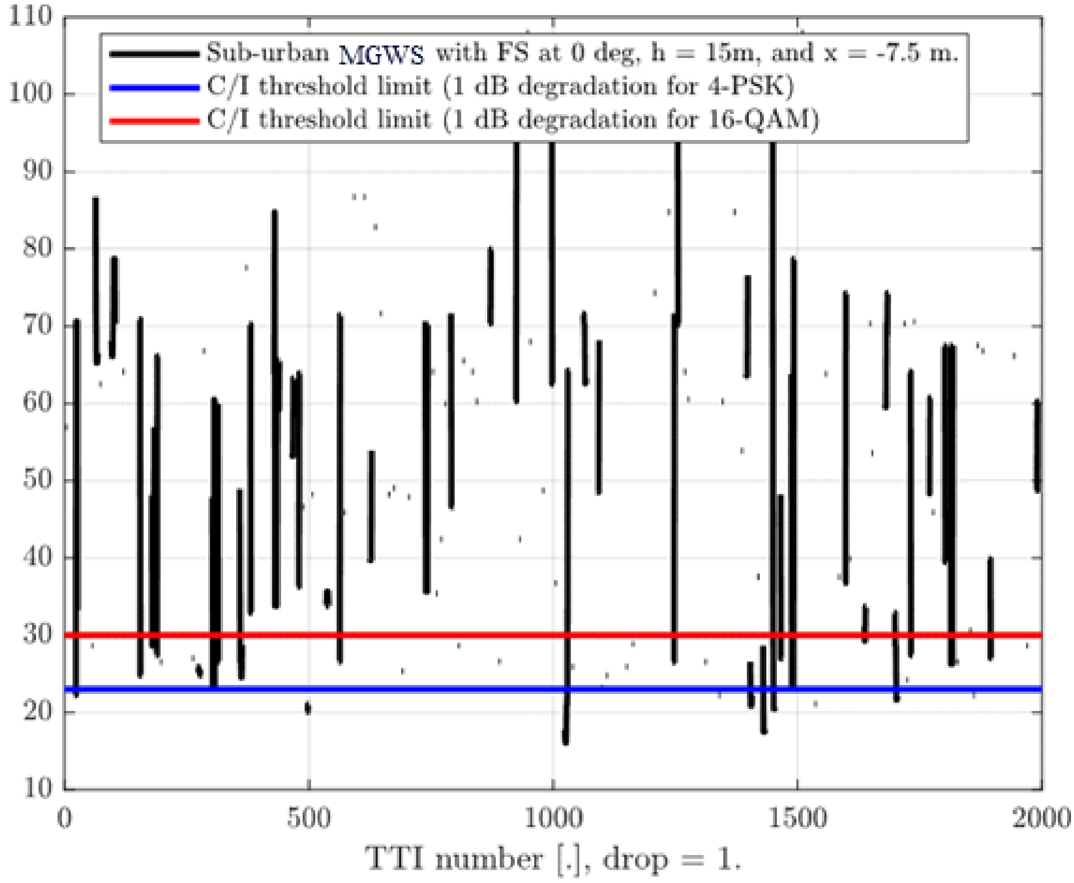


Figure 17: FS downlink C/I (dB) for the sub-urban scenario

Observe some deep spikes that go below the 4-PSK threshold. These worst cases occur when MGWS HOUs steer their beams towards the serving AP aligning their beams with FS receiver (e.g. θ=6°) and generating significant interference as a result.

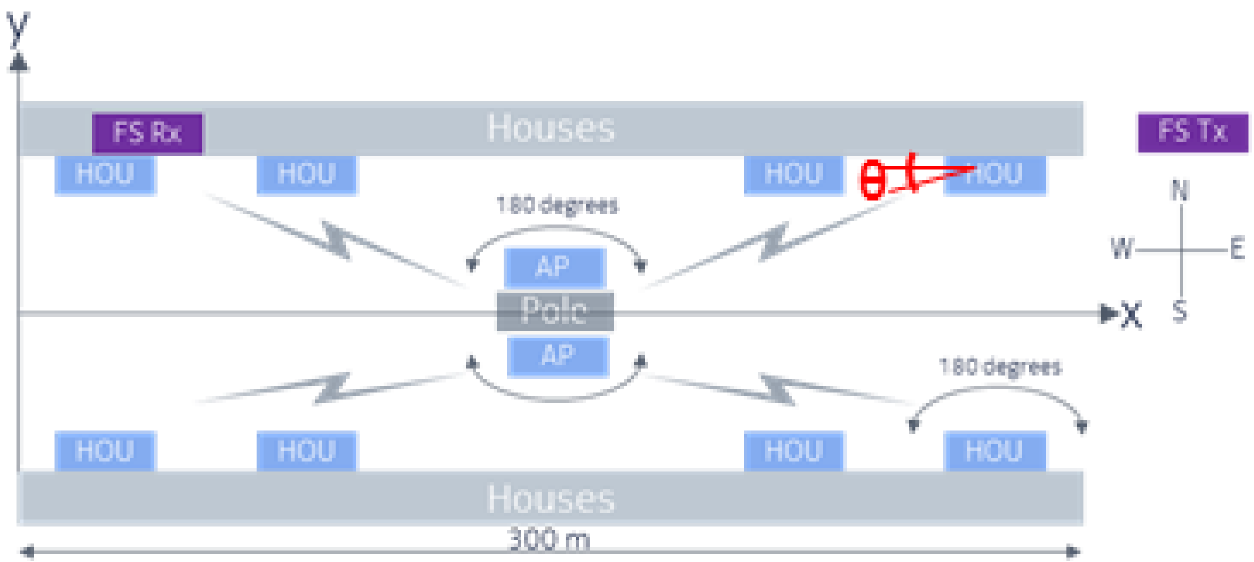


Figure 18: Scenario for the sub-urban case

CDF of the carrier-to-interference (C/I) ratio

The CDF shows results for the worst case of FS Rx position and orientation combination, and it is with respect to all the APs and HOUs deployed in the street.

Notice also that 1 dB threshold degradation is considered to emphasise the worst case.

In this worst case, the C/I ratio is 2% of the time below 4-PSK limit.

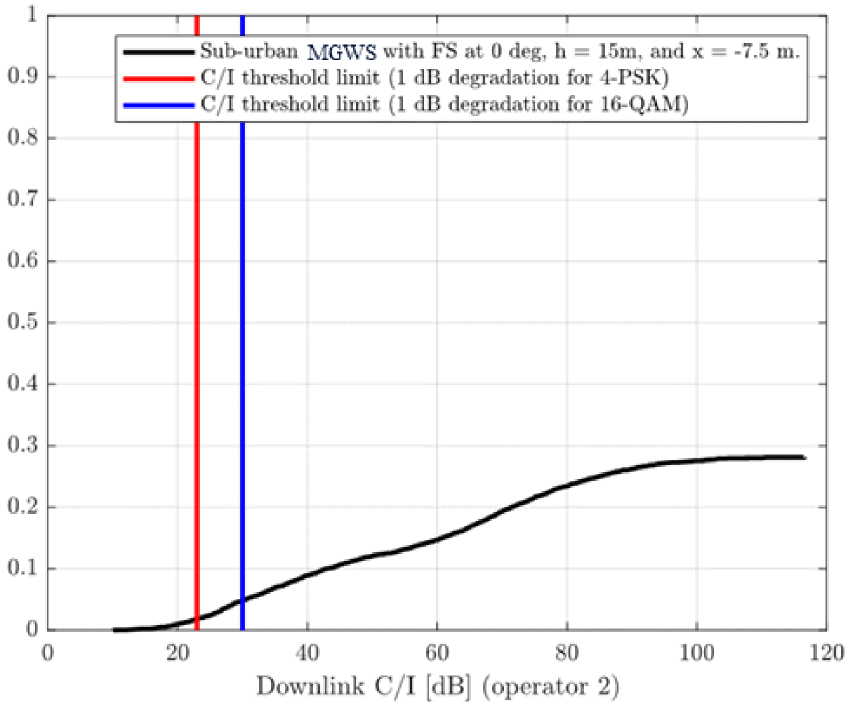


Figure 19: CDF of the C/I ratio for the sub-urban scenario

7.7.3.2 Urban

Scenario definition

The urban scenario consists of an AP site in the side of the street (reference point 0 for Y-axis) e.g. mounted in the building facade, a lamp pole, utility pole, street signage or street furniture. This site is composed by one AP, with a field of view of 180°. The AP site serves multi dwellings in the opposite side of the street, where the HOUs is mounted outdoors, at three different heights and in LOS conditions to their serving AP.

The distribution of APs and HOUs is even throughout the street.

This set up defines several locations for the FS link.

FS Rx takes two locations in the X-axis: in the left side of the street, where interference is present in one side of the receiver only, and somewhere in the middle of the street, to account for interference coming from both sides of the receiver.

In each of those locations, the FS Rx is placed at two different heights i.e. 15 m and 20 m.

For every position described above FS Rx is oriented in two directions i.e. facing East and facing South. According to each position and orientation of the FS Rx, the FS Tx is aligned at 500 m distance.

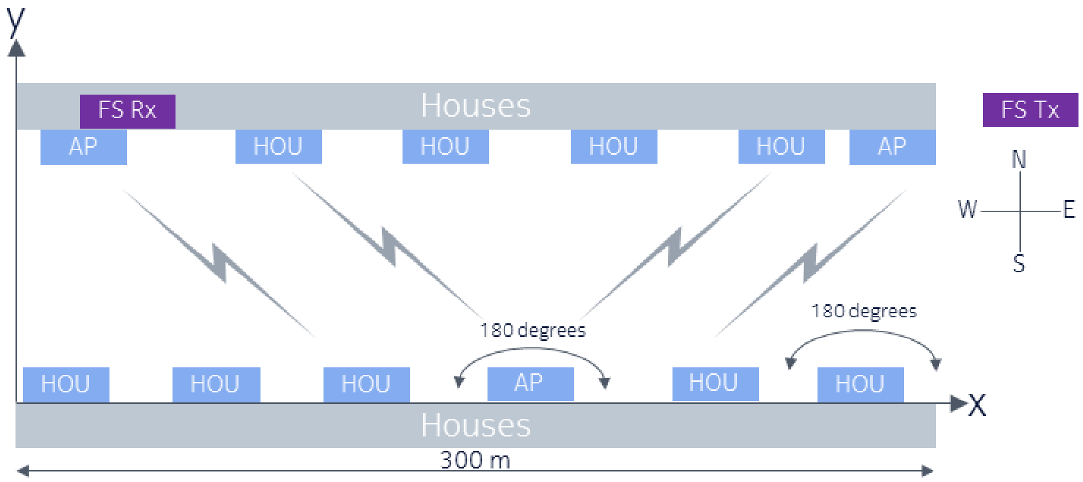


Figure 20: Scenario for the urban case

Table 16: MGWS deployment for urban scenario

MGWS deployment	
Number AP sites	10 locations
AP sectorisation	180º sector coverage
AP inter-site distance (x-axis)	30 m
AP heights	4 m
Distance AP-façade	10 m
Number of associated HOUs per AP	12 HOUs per AP (three height levels with 4 HOUs each)
HOU heights	4, 6, and 10 m
HOU deployment	Uniform 2D distribution with 15 m inter-HOU distance at y = 0 and 10 m

Table 17: FS deployment for urban scenario

FS deployment	
FS Rx locations	x = -7.5 m and x = 112.5 m, y = 10 m
FS Rx heights	15 m and 20 m
FS Rx antenna orientations	0° (pointing East) and -90° (pointing South)
FS Rx-Tx distance	500 m
FS Tx location	2D location: in the segment with initial point of the receiver location and direction given by its antenna orientation. Height: same as receiver.
FS Tx orientation	Antenna aligned with receiver

Performance

Configuration of FS Rx: orientation 0°, x = -7.5 m, h = 15 m

Time domain analysis with full buffer traffic model

Results are much better than in sub-urban case because HOUs do not need to steer their beam too much towards the AP which entails a reduced interference at the FS.

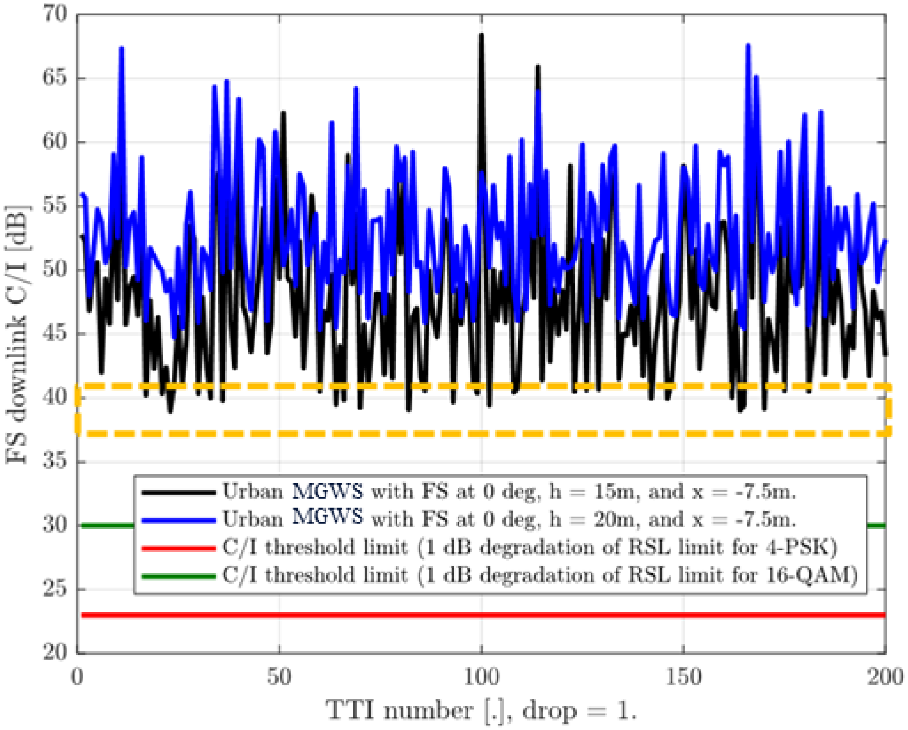


Figure 21: FS downlink C/I (dB) for the urban scenario

CDF of the carrier-to-interference (C/I) ratio

The denser AP deployment leads to a reduced beam alignment among the FS receiver and the MGWS nodes.

Increased height difference among MGWS APs (h=4m in urban vs. h=6m in sub-urban) and the FS receiver also contributes to an enhanced coexistence.

C/I ratios are substantially enhanced when compared to the sub-urban scenario.

Notice also that 1 dB threshold degradation is considered to emphasise the worst case.

Worst case 0.2% of the time below the C/I limit for 4-PSK.

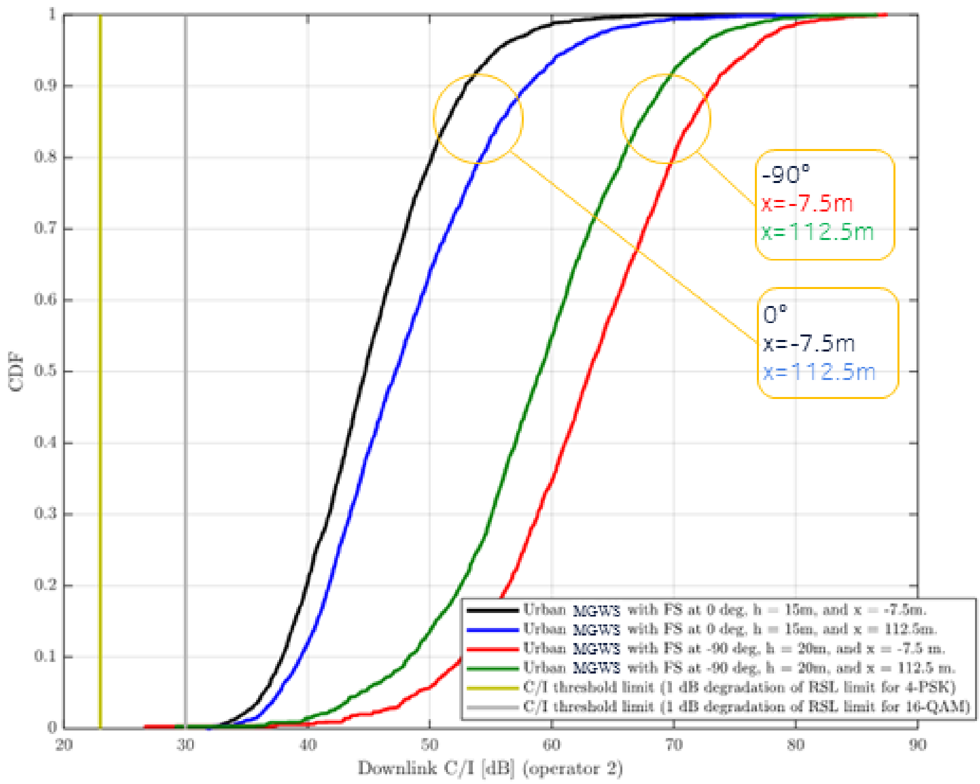


Figure 22: FS downlink C/I (dB) for the urban scenario

7.7.4 Conclusions

Height separation among MGWS and FS systems contribute to minimise inter-system interference to a level of the 2-5 % of links potentially interfered (i.e. C/I exceeding a specified threshold), already adopted for first SEAMCAT study for this band (see section 4).

Beam alignment prevention between MGWS and FS systems guarantees enough isolation between both systems. MGWS system might consider restricting the use of certain beam steering angles to prevent interference towards the FS at the expense of performance degradation.

7.8 3D SIMULATIONS IN WASHINGTON D.C., USA (MGWS - MGWS)

7.8.1 Washington D.C. USA, simulation scenario

The simulation procedure, which has been performed for various scenarios, is based on a 3D map, where set of network elements are analysed on each transmission directions (i.e. both DL and UL) to evaluate the received signal, noise and interference levels.

AP (Access Point) and RT (Remote Terminal) nodes are considered. In each AP, node two sectors (or directions) can be covered.

Systems operate in TDD mode and simulations are executed in absence of rain (i.e. clear sky).

Two different frequency arrangements have been used: the former with a single channel frequency and the latter with two channels available.

The e.i.r.p. value is fixed at 40 dBm as maximum value allowed by ECC[5] in Europe and FCC for non-fixed PP application in USA.

The steerable antenna is simulated as a phased-array antenna with 60 elements (a 12 x 5 array was used, with phase shifters for each element) with 6.5 dBi gain/element.

In Table 18 the main characteristics of the simulated systems are shown and in Figure 23 two simulated RPE diagram examples are reported in two steering directions (i.e. 0° and 45°).

Receiver sensitivity values and MCS from IEEE 802.11ad standard are reported in ANNEX 2:.

Table 18: Main system characteristics

Parameters	Value
e.i.r.p.	40 dBm
Tx power level	17.5 dBm
Noise figure	7 dB
Bandwidth	2160 MHz (WiGig RF Channel)
Front to back separation	90 dB
Adjacent channel separation	20 dB (NFD)
Receiver sensitivity	-61 dBm (for IEEE 802.11ad MCS 8)
Antenna main lobe gain	22.5 dBi
Max steering angle (range)	45° only on azimuth plane
HPBW azimuth	± 5°
HPBW elevation	± 10°
Installation height	3 m except otherwise specified
Reference modulation and coding scheme	MCS 8
SINR (BER 10^{-6})	7 dB (Table 29)

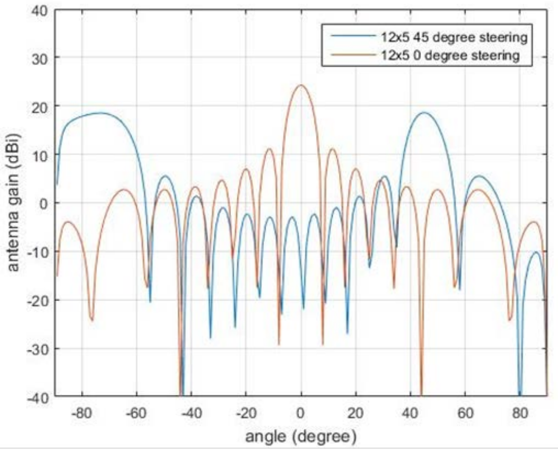


Figure 23: Antenna RPE diagram at 0° (boresight) and 45° pointing directions

[5] At current moment only for indoor application and for non-fixed outdoor application

7.8.2 Street to street

The considered area is a portion of Washington D.C. (USA), a typical dense urban clutter. Equipment with antennas is placed at height ranging from 3 to 5 m.

Mesh and linear network topologies have been considered.

7.8.2.1 Mesh network topology at street level

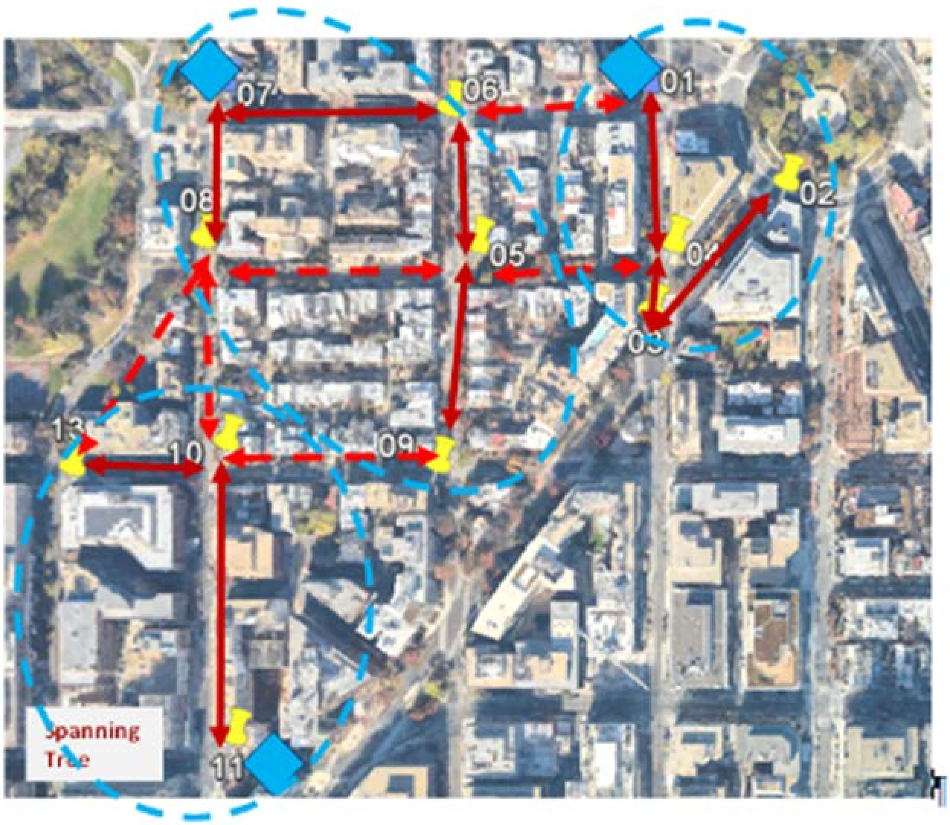


Figure 24: Specific portion analysed

In Figure 24, the basic arrangement for mesh network topology is shown. In the simulated network model there are:

- 3 fibre Points of Presence (PoP), depicted as blue diamonds (node 1, 7 and 11);
- 9 Access Points (AP), depicted as yellow placeholders (nodes);
- Other 3 APs are placed in same positions of PoPs.

A specific graph has been selected to connect PoPs and Aps, and it is depicted with solid arrows. Furthermore, each PoP is assumed to reach some APs by means of a preferential path resulting in 3 different “network island” (blue dashed ellipses).

The three different network islands are based on network topology in relation with simulated traffic flow through network nodes (such as spanning tree).

Possible alternative paths are represented by dashed arrows.

Simulations have been carried on only for the preferential path (i.e. solid connection lines).

Transmission direction from each PoP onwards is assumed as “downlink” (DL) and the opposite is considered as “uplink” (UL) in the whole Report.

7.8.2.2 Simulation method and results

For each link and for each direction (UL/DL), the wanted received signal (S) and the aggregated level of interference coming from all other links in the network (I) are computed by means of a 3D ray tracing tool.

Results are shown in terms of Signal to Interference Noise Ratio (SINR) and Signal to Noise ratio (SNR).

Table 19: One single channel or two channels used

AP	AP	Length (m)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)	SINR_UL (dB) – 2 channels	SNR (dB) – 2 channels
AP02	AP03	140	22.6	18.4	22.6	22.5	22.6
AP10	AP11	221	4.88	9.07	9.07	9.07	9.07
AP08	AP07	118	21.5	21.6	21.6	21.6	21.6
AP09	AP05	167	13.1	10.1	14.3	14.2	14.3
AP06	AP05	105	20.1	19.6	24.3	24.2	24.3
AP06	AP07	161	8.28	12.5	12.5	12.5	12.5
AP01	AP04	120	9.94	11.7	14.1	14.1	14.1
AP03	AP04	51.6	13	14.1	18.3	18.2	18.3
AP10	AP13	117	19.1	15	19.1	15	19.1

Table 19 shows that the availability of a single channel in the network is sufficient to guarantee the use of MCS 8, while the addition of a second channel exhibits a SINR improvement on average of 2 or 3 dB.

7.8.3 Street to roof network topology

In this simulation scenario, already addressed in Figure 24 the network elements density has been increased by adding some more RT nodes as access terminals on the rooftop corners of buildings (such as in a FWA use case), as shown in Figure 25. Antenna vertical HPBW characteristic only (Figure 26) is used to access the roof terminals (no steering capability assumed in elevation plane). As usual, direction towards the access point is referred as uplink (UL) and the opposite is downlink (DL).

Results for the simulated links are shown in case the buildings and the streets are realised by a partial reflecting material (concrete) or by a perfectly reflecting one.

Figure 25: Simulation scenario

Figure 26: Antenna vertical HPBW

Table 20 shows results in case material constituting buildings and road are not reflective.

Result show that most links can have SINR much higher than 10 dB by reaching values up to about 38 dB. Such links are in LOS conditions. For other links, where LOS condition is not met, the propagation is dominated by diffraction, and the SINR appears much lower. These links, AP07-RT10 and AP11-RT03, cannot operate according to the target.

Table 20: AP/Node to/from RT, concrete buildings and concrete street

AP	RT	Length (m)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)
AP11	RT02	39	29.7	29.7	29.7
AP10	RT04	55	29.2	29.4	29.4
AP10	RT05	61	17.5	17.5	17.5
AP10	RT06	30	34.3	34.3	34.3
AP10	RT07	65	27	26.8	27
AP08	RT08	42	27.4	28.5	28.7
AP08	RT09	67	11.9	12.1	12.1
AP08	RT11	48	30.7	30.7	30.7
AP07	*RT10*	*89*	*-6.48*	*-7.82*	*-6.48*
AP11	*RT03*	*78*	*-12.7*	*-12.9*	*-12.7*

Table 21 shows the results when perfect reflective (PEC) material is used in simulation. The figures for links where the LOS condition is met do not change significantly with respect to the previous case. Instead, for one NLOS links, reflection becomes prevalent over diffraction and the SINR improves. In this condition the link AP07-RT10 can operate.

Table 21: AP/Node to/from RT, perfect reflecting material for buildings and street

AP	RT	Length (m)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)
AP11	RT02	39	29.7	29.7	29.7
AP10	RT04	55	29	29.4	29.4
AP10	RT05	61	17.5	17.5	17.5
AP10	RT06	30	34.2	34	34.3
AP10	RT07	65	27	26.6	27
AP08	RT08	42	27.7	28.8	29
AP08	RT09	67	16.8	15	16.9
AP08	RT11	48	30.7	30.7	30.7
AP07	RT10	89	16.8	15	16.9
AP11	*RT03*	*78*	*-10*	*-10*	*-10*

It is shown that the reflections can become the dominant effect for some specific links (i.e. NLOS links), where diffraction appears to be a significant propagation mechanism with non-reflecting material.

In presence of sufficiently reflecting materials (PEC case), figures of some NLOS links can improve significantly for SINR values allowing expected transmission traffic.

7.8.3.1 Additional WiGig interferers

A further simulation has been done by adding three WiGig interferers (IAP 1, 2 and 3) in the same road where network access points AP7, AP8, AP10 and AP11 are placed. The three new elements are at street level, at same height from ground, fixed to building walls and on both sides of the road.

Interferer Access Point (IAP) equipment characteristics:

- Tx power: 23.5 dBm;
- Antenna gain: 13 dBi;
- Horizontal HPBW: ~90 °;
- Vertical HPBW: ~10 °.

Table 22 shows that addition of such elements produces negligible (around 0.2 dB) or no SINR changes.

Table 22: AP/Node to/from RT, concrete buildings and concrete street, IAP at street level

AP	RT	Length (m)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)
AP11	RT02	39	29.7	29.7	29.7
AP10	RT04	55	29.2	29.4	29.4
AP10	RT05	61	17.4	17.5	17.5
AP10	RT06	30	34.2	34.2	34.3
AP10	RT07	65	26.8	26.7	27
AP08	RT08	42	27.4	28.5	28.7
AP08	RT09	67	11.9	12.1	12.1
AP08	RT11	48	30.7	30.7	30.7
AP07	*RT10*	*89*	*-6.83*	*-7.83*	*-6.48*
AP11	*RT03*	*78*	*-12.7*	*-12.9*	*-12.7*

7.9 SAN JOSE, CALIFORNIA USA

FWA systems can be used to implement point-to-point (PP) backhaul and point-to-multipoint (PMP) backhaul/access mesh networks.

7.9.1 FWA link characteristics

A FWA system operating in the V-band (57–66 GHz) using the IEEE 802.11ad physical (PHY) layer with modulation and coding scheme (MCS) limited to 16-QAM rate-3/4 is considered in this section. This system provides a throughput of 1.9 Gbps uplink plus 1.9 Gbps downlink using a single 2.16 GHz channel. It is designed to operate in both line-of-sight (LoS) and near-LoS (NLoS) environments.

Distribution nodes (DNs) are assumed to be mounted on street light poles. Each DN has four phased array antenna panels, one on each side. Each panel is capable of generating a single beam which can be scanned ±45°. PMP operation is enabled by sequentially pointing an electronically steered beam in the direction of each of the receive antennas. Client nodes (CNs) have a single antenna panel and are typically mounted on the sides of buildings.

The FWA systems antenna panels provide approximately 31 dBi peak gain and 40 dBm maximum average e.i.r.p. The signal bandwidth is 1.76 GHz. The terminals use automatic transmit power control (ATPC) and rate adaptation to minimise interference and compensate for variations in the propagation environment.

- The FWA use cases are illustrated in Figure 27.

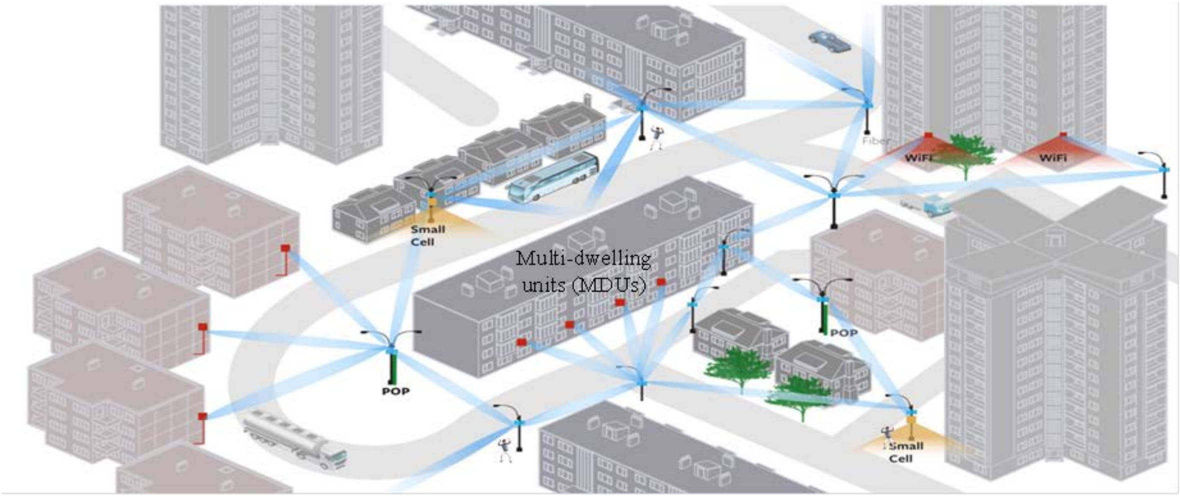


Figure 27: mmWV distribution network scenario

7.9.2 FWA - FWA

FWA self-coexistence is studied to understand whether FWA will be able to operate in presence of interference originating within the system in a single frequency deployment. This sections studies if mechanisms such as ATPC, synchronisation and proper placements and orientation of FWA nodes alone are adequate to meet the per link C/I requirements when the entire system/network of nodes is operating.

To study self-coexistence, a simulation is carried out based on a proper subset of a FWA deployment at San Jose, California, USA (Figure 27) and will be used to validate the assumptions on coexistence. The locations of buildings, foliage and FWA nodes are accurately modelled in the simulation. Detailed database of measurements (signal power and other logs) is also available for each node pair and compared with the simulations.

The deployment is based on careful network planning. The nodes are synchronised using GPS and the topology (connected links) and the polarity (Tx-Rx cadence/phase of each node) of the network are followed strictly.

Figure 28: Scenario used for San Jose simulations

The FWA nodes uses 36x16 phased arrays (with G ~ 31 dBi) that beam steer in the horizontal plane to transmit an average e.i.r.p. of 40 dBm in the steered direction when no power backoff is applied (ATPC off). PMP operation is enabled by electrically steering the antenna pattern in the direction of the receiver. Links are LOS/nLOS (near line of sight) and span a distance less than or equal to 250 m. Link throughput of 2 Gbps up + 2 Gbps down is achieved (highest MCS: 16QAM ¾) with a bandwidth of 2.16 GHz using single carrier transmission mode of IEEE 802.11ad standards. Automatic transmit power control is used for CNs/DNs links to compensate for the dynamics of the environment to support the highest MCS.

The C/I statistics of all the FWA links are captured by the cumulative distribution function (CDF) show in Figure 29. Based on the CDF, the probability of not meeting the MCS12 (16QAM ¾) threshold of 18 dB is ~5% with ATPC turned off and around 1% with ATPC on. Simulation was performed with and without foliage. Foliage reduces signal as well as interference largely independently leading to a probability distribution function (PDF) different from the one where no foliage is considered.

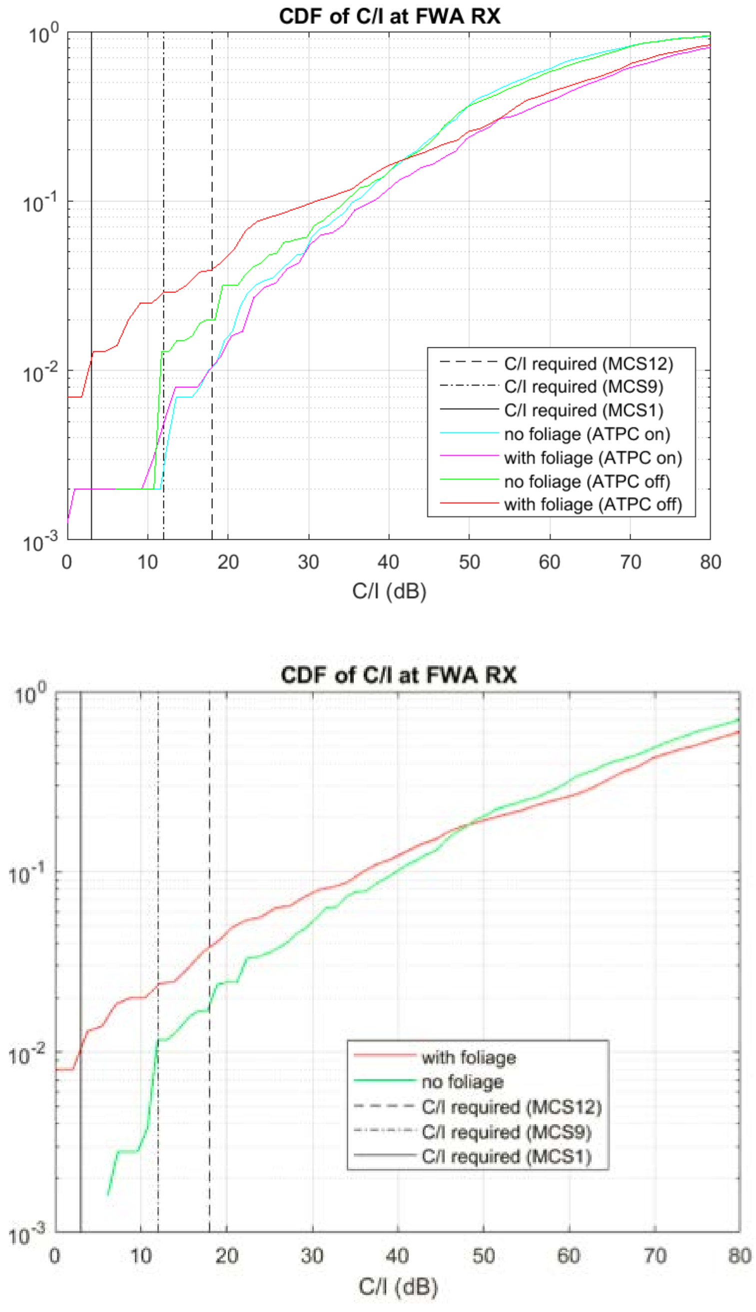


Figure 29: C/I CDF – FWA suitability

7.9.3 FWA with indoor SRD

This section explores the potential for sharing spectrum between this FWA system and indoor short range devices (SRD) which operate in the same V-band spectrum. SRD are assumed to be IEEE 802.11ad compliant. The FWA nodes, both DNs and CNs, are assumed to be located 4 m above ground level.

Two interference cases are considered. Both involve building penetration (outdoor-to-indoor) from FWA nodes to SRD. First transmissions from DNs to CNs, and second transmissions from CNs to DNs. The potential interference model is shown in Figure 30. Each DN is modelled as serving 8 to 16 CNs with time multiplex, i.e. 6% to 12% duty cycle for each DN to CN link. The potential interference is to SRDs located indoor behind the windows.

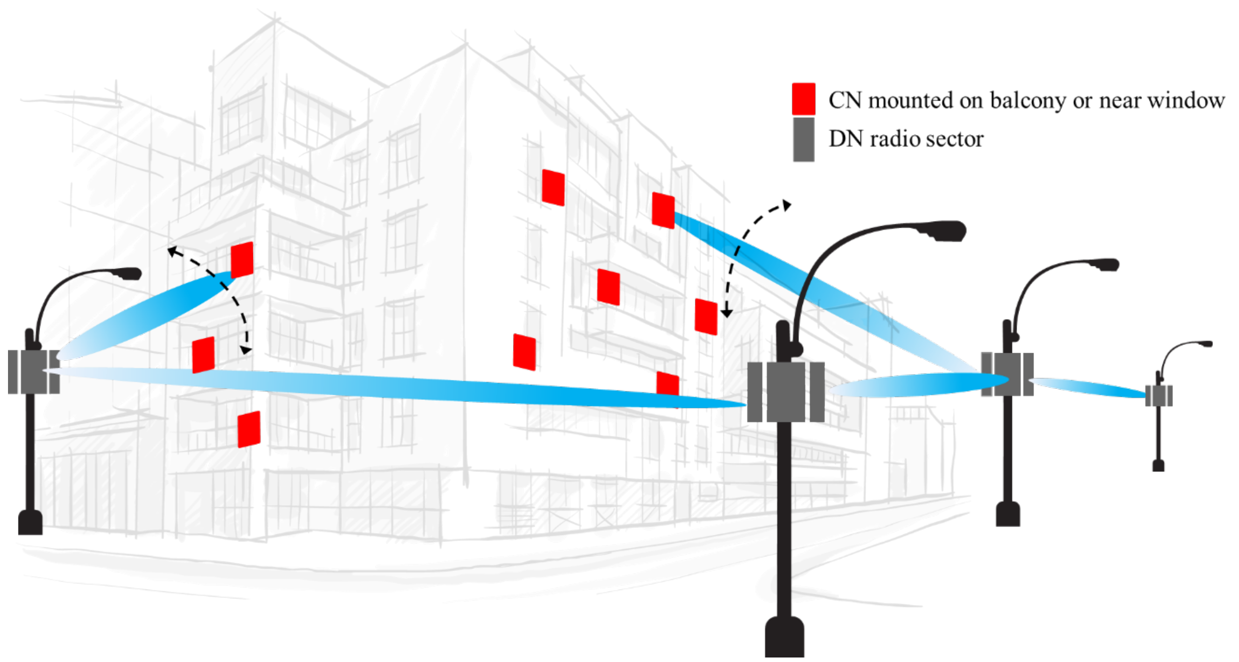


Figure 30: Potential Interference Scenario

The DN to CN transmission scenario is illustrated in Figure 31.

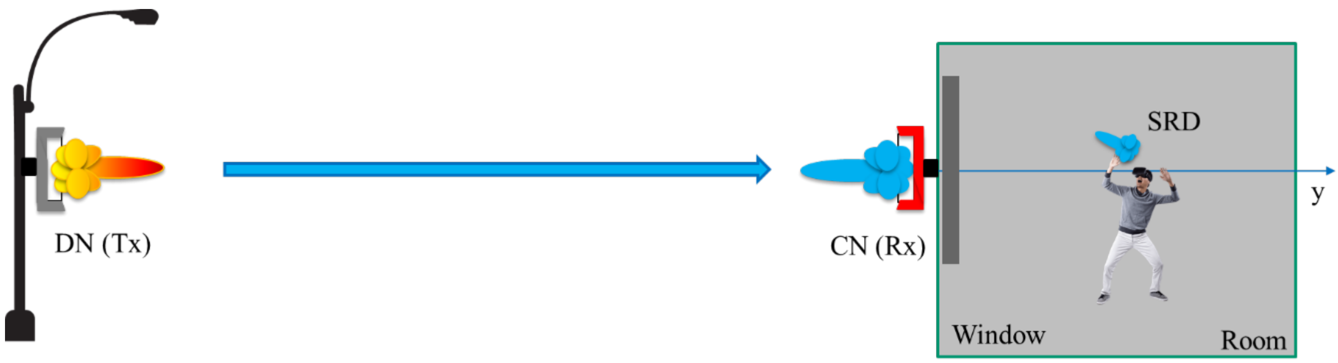


Figure 31: DN to CN Transmission Scenario

The interference power received by a SRD inside the room is given by:

I (dBm) = SNRTARGET (dB) – GR (dBi) + N (dBm) – BPL (dB) + GSRD (dBi)

Where:

- e.i.r.p. is the CN e.i.r.p. (40 dBm max);
- SNRTARGET is the target SNR at the CN (18 dB for MCS12), assuming that the DN uses ATPC;
- GR is the CN receive antenna gain (30 dBi);
- N is the CN thermal noise (-72 dBm) assuming a 1.76 GHz bandwidth and 10 dB noise figure;
- BPL is the building penetration loss (3.6 dB) for a single pane of window glass;
- GSRD is the gain of the SRD in the direction of the CN (0 dBi).

With these assumptions, the receive interference power is -87.6 dBm, almost 20 dB below the Clear Channel Assessment (CCA) threshold of -68 dBm for SCPHY/CPHY. Thus, SRD in the room will not experience any channel access impacts.

It has been shown that DN transmissions do not block SRD transmissions. The next question is, do DN transmissions interfere with SRD reception? Figure 32 shows the interference power level at each location within a 5 m on a side room behind the window. The interference power received by the SRD depends on the SRD antenna pattern and pointing. The SRD antenna pattern is modelled as shown in Figure 33 with a 19 dBi peak gain and a conservative front-to-back ratio of 20 dB. The worst-case orientation would be pointing directly towards the window.

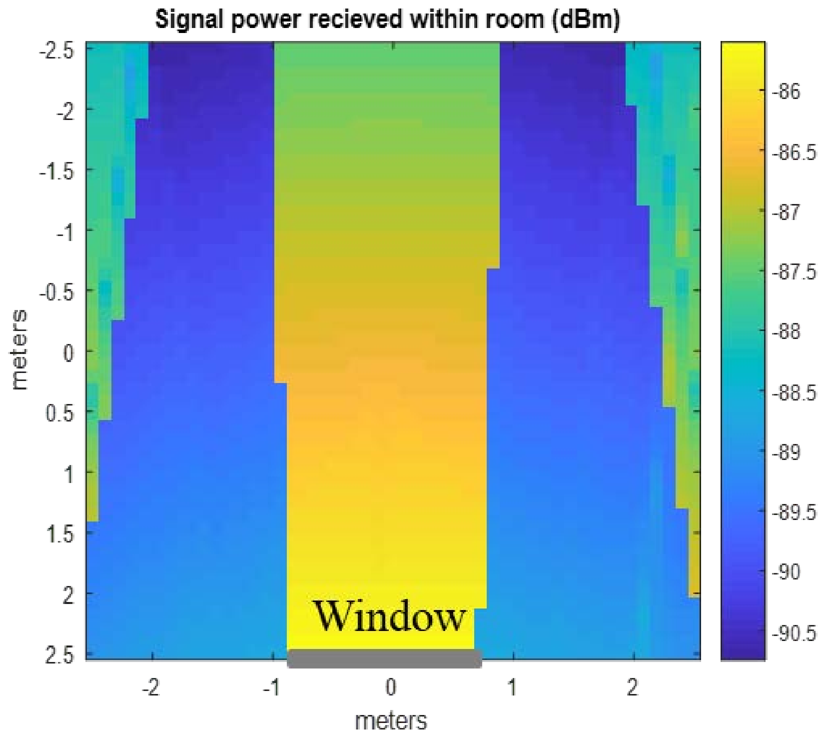


Figure 32: Interference power map inside room due to DN transmission

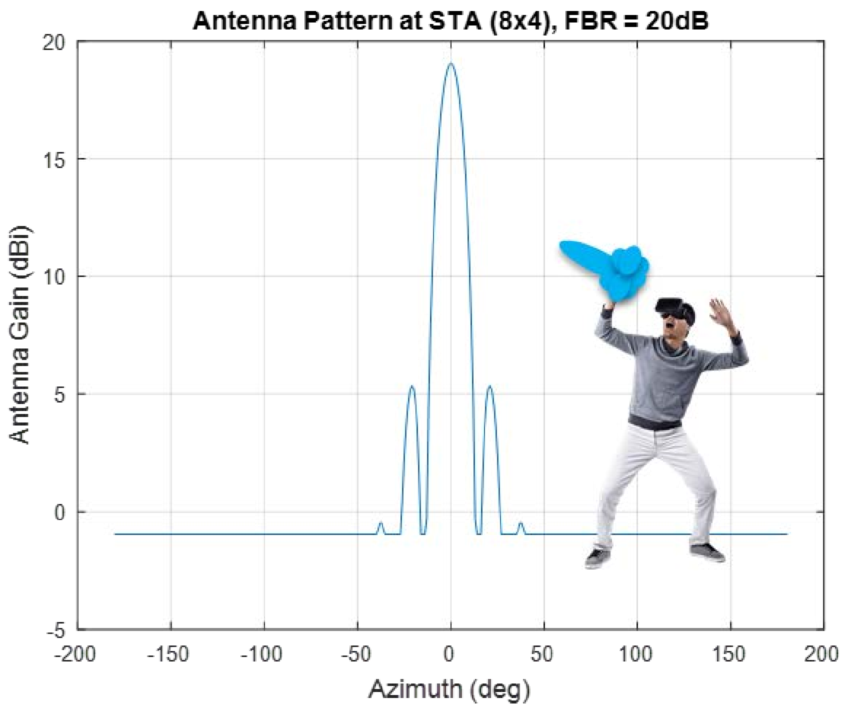


Figure 33: SRD antenna pattern

Figure 34 shows the CDFs of interference power received by the SRD and resulting SINR assuming that the SRD AP is transmitting at 40 dBm e.i.r.p.. The DN to CN duty cycle of 6% to 12% would further reduce interference.

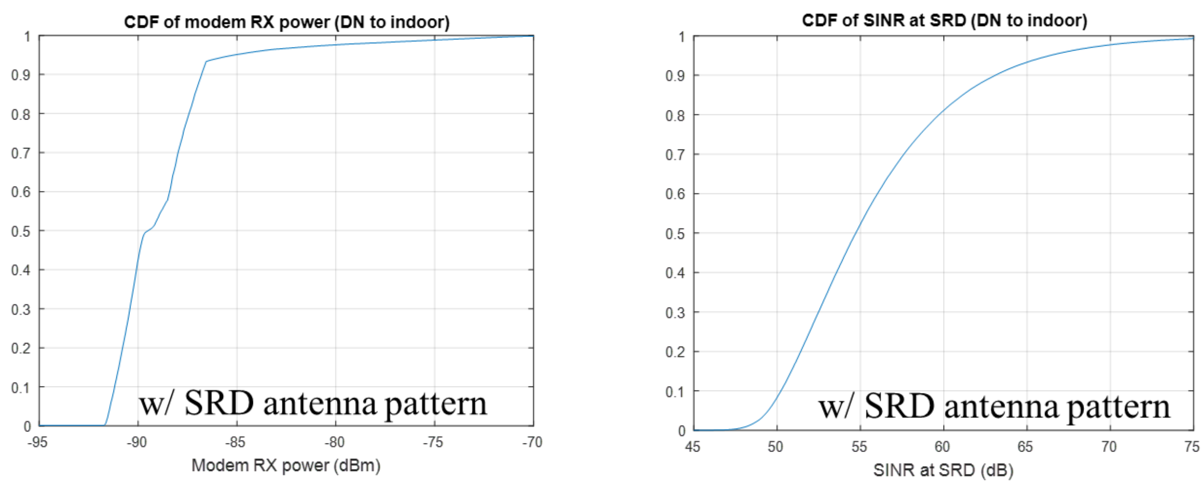


Figure 34: CDFs of interference power at output of SRD antenna and SINR

The previous analysis assumed that the DN signal was perpendicular (normal) to the window. Figure 35 shows the interference power in the room for 45° and 25° angles of arrival relative normal incidence. These shallower incidence angles result in a slight increase in interference power within the room. Still, as shown in Figure 36, CCA is not triggered anywhere in the room.

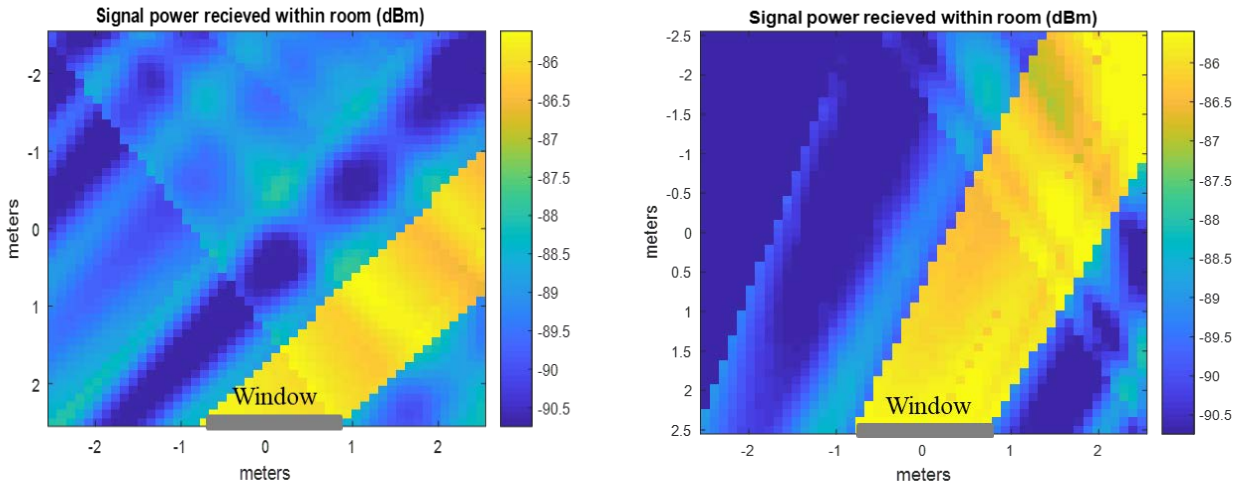


Figure 35: Interference power level inside the room

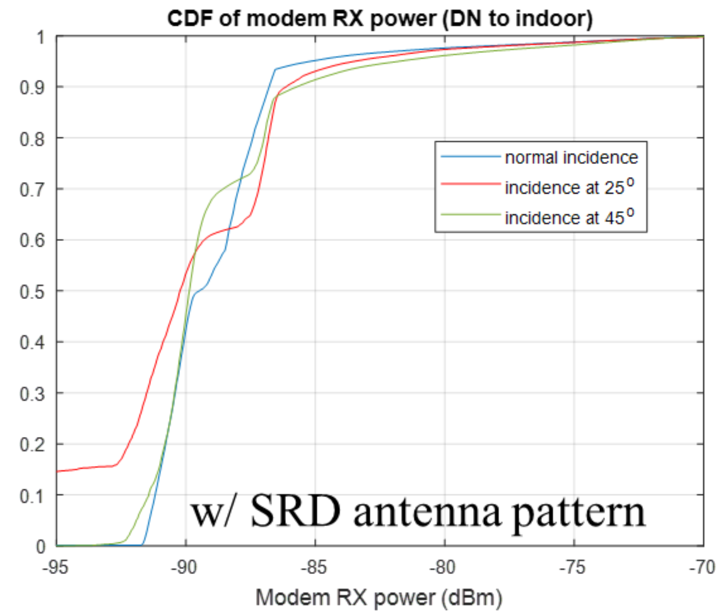


Figure 36: CDF of interference power at output of SRD antenna for various incidence angles

The CN to DN transmission scenario is illustrated in Figure 37.

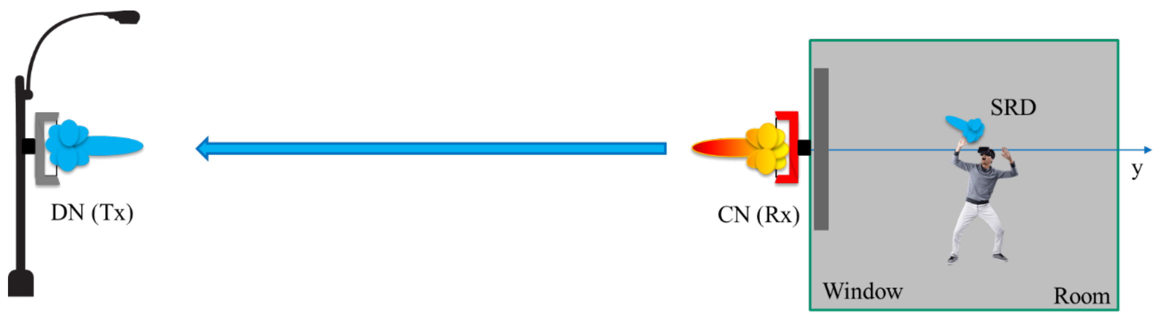


Figure 37: CN to DN transmission scenario

The interference power received by a SRD inside the room is given by:

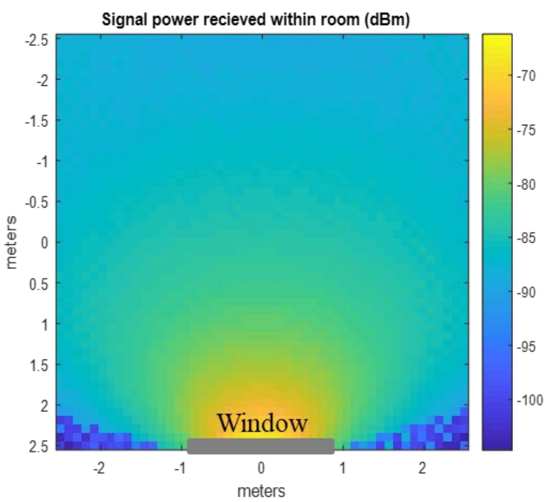
I (dBm) = e.i.r.p. (dBm) – FBR (dB) – FSL (dB) – BPL (dB) + GSRD (dBi)

Where:

- e.i.r.p. is the CN e.i.r.p. (40 dBm maximum);
- FBR (dB) is the front-to-back ratio of the CN antenna plus isolation of CN housing box (50 dB)[6];
- FSL is the free space propagation loss from the CN to the SRD (68 dB) assuming minimum 1 m separation ;
- BPL is the building penetration loss (3.6 dB) for a single pane of window glass;
- GSRD is the gain of the SRD in the direction of the CN (0 dBi).

With these assumptions, the interference power is -81.6 dBm, which is 13.6 dB below the SRD CCA threshold for SCPHY/CPHY. Thus, CN operation will not impact channel access for SRD devices.

Figure 38 shows the interference power level at each location within a 5 m room behind the window and the associated interference power CDF. The SRD CCA is only triggered within a few centimetres directly behind the window with the SRD antenna pointed at the window. This occurs less than 0.1% of the time. CCA is not triggered regardless of distance, when the SRD antenna is pointed away from the window.



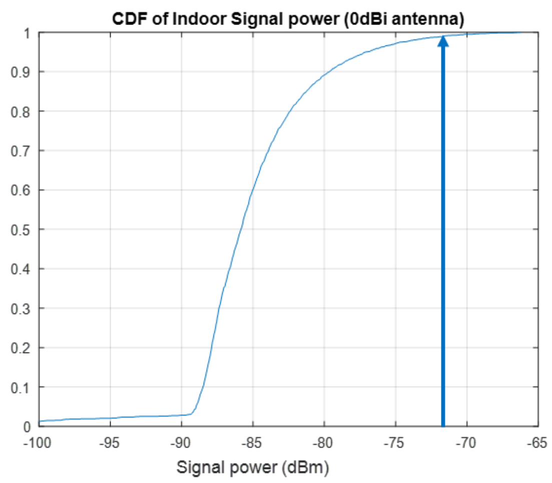


Figure 38: Interference power map and CDF

Figure 39 shows the SRD received power CDF assuming the SRD AP is transmitting at 40 dBm e.i.r.p., and the resulting SINR CDF. Clearly, the CN transmissions are not interfering with the SRD links even without taking into account the duty cycle of DN to CN communication is only 6% to 12%.

[6] Other studies have assumed 90 dB.

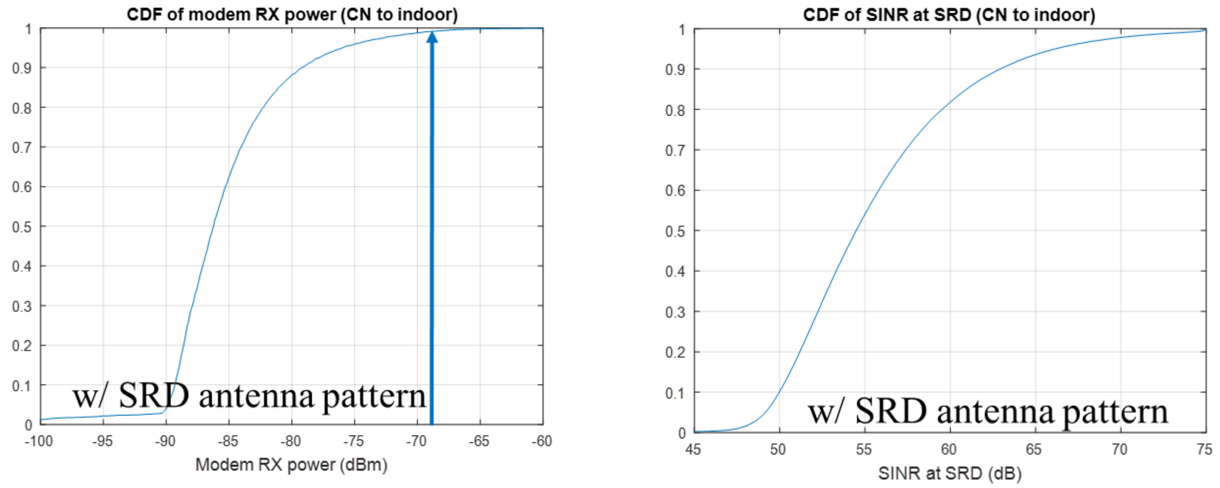


Figure 39: CDFs of interference power at output of SRD antenna and SINR

The potential interference from FWA systems to indoor SRDs resulting from outdoor to indoor penetration has been evaluated. An aggressive scenario consisting of a FWA client terminal mounted on the window glass of a room in a multi-dwelling unit (MDU) was considered. Even with the relatively small loss through the window, the results confirm that FWA operations do not harm indoor SRD. They are summarised in Table 23.

Table 23: Summary of results

Scenario	CCA trigger (PD @ -68 dBm)	Min. SINR at SRD
DN => CN	Never	45 dB
CN => DN	<0.1% (SRD mounted to window, pointing outside (not realistic))	45 dB

7.9.4 FS and FWA coexistence

There are several hundred European deployments of fixed service (FS) point-to-point (PP) links operating in the 57-66 GHz band (V-band). Proposed FWA systems can operate in either PP or point-to-multipoint (PMP) configurations in the same band.

This section explores the potential for sharing spectrum between these two types of systems. Three approaches are explored:

- exclusion zone analysis;
- statistical analysis;
- ray tracing simulations intermixing FS-PP links with a trial FWA deployment in San Jose, California.

7.9.4.1 FS characteristics

FS-PP links use high-gain antennas with narrow-beamwidths. Typical V-band antenna patterns are shown in Figure 40.

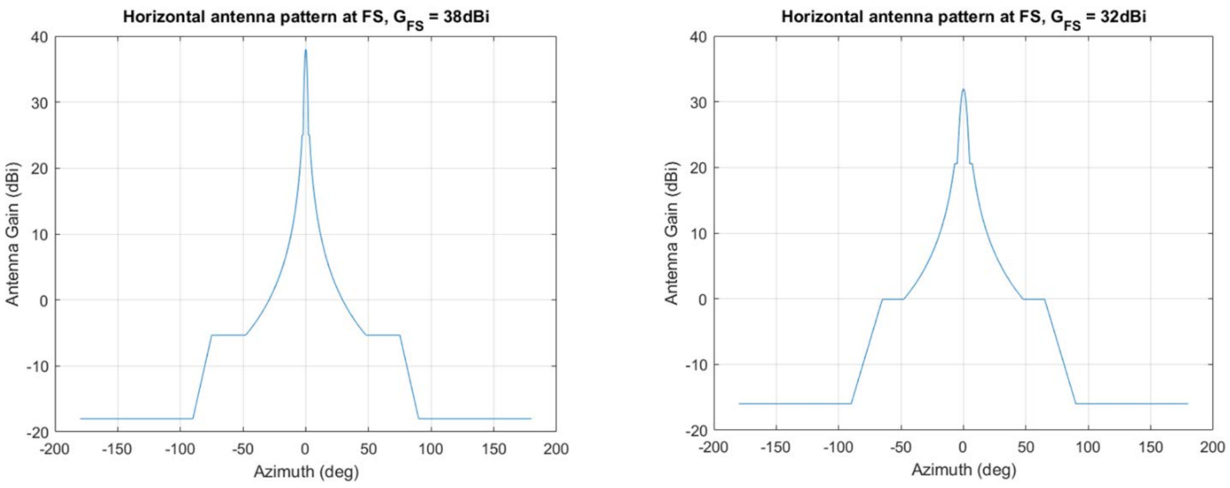


Figure 40: FS horizontal antenna patterns (32 dBi and 38 dBi gain) [5]

Typical FS-PP channel bandwidths are multiples of 50 MHz, N x 50 MHz, for N equal 1 to 40 [26]. Required C/I depends on the spectral efficiency class/modulation, as shown in Table 24. It ranges from 19 dB for 2-PSK to 36.5 dB for 256-QAM. Two cases are considered for analysis: 1 Gbps (64-QAM over 200 MHz channel) and 4 Gbps (8-PSK over 2 GHz channel). Full, 100%, duty cycle is assumed.

Table 24: FS-PP C/I requirements [4]

Spectral Efficiency Class	Modulation	C/I for BER ≤ 10-6 RSL degradation of 3 dB
1	2PSK	19
2	4QAM	19
3	8PSK	21
4L	16QAM	23
4H	32QAM	26
5L	64QAM	29.5
5H	128QAM	33
6L	256QAM	36.5

7.9.4.2 FWA characteristics

FWA systems can operate in PP and PMP configurations. The system modelled for this analysis utilises phased array antennas with approximately 31 dBi peak gain and 40 dBm maximum average e.i.r.p.. Each FWA terminal has four antenna panels, one on each side. Each panel is capable of generating a single beam which can be scanned ±45°. PMP operation is enabled by electronically hopping a beam in the direction of the receive antennas. FWA channel bandwidth is 2.16 GHz and the signal bandwidth is 1.76 GHz. A 100% duty cycle is assumed.

The FWA system is designed to operate in both line-of-sight (LOS) and near-LOS (nLOS) environments. Its physical (PHY) layer is based on IEEE 802.11ad with Modulation and Coding Scheme (MCS) limited to 16- QAM rate-3/4. This provides a maximum throughput of 1.9 Gbps up plus 1.9 Gbps down using a single 2.16 GHz channel. The FWA terminal performs automatic transmit power control (ATPC) and rate adaptation to minimise interference and compensate for variations in the propagation environment.

The FWA system phase array antenna allows the implementation of nulling. This can be used to provide around 10 dB of transmit beam suppression in the direction of a known FS-PP terminal. Doing so would provide an additional 10 dB of C/I protection. This additional protection is not included in the following analysis.

7.9.4.3 FWA impact on FS-PP

Typically, the FS-PP bandwidth is significantly less than the modelled FWA signal bandwidth. This mitigates the impact of FWA emissions on FS-PP links. The effective interference power reduction is shown in Table 25. However, it is important to note that lower bandwidth FS-PP links tend to operate at higher spectral efficiency, requiring higher C/I, as shown in Table 24.

Table 25: Effective reduction of interference power

FS-PP BW (MHz)	Interference power reduction (dB)
50	-15.47
100	-12.46
200	-9.44
400	-6.43
800	-3.42
1200	-1.66
1600	-0.41
>1760	0.00

7.9.4.4 Exclusion Zone Analysis (with and without power control)

Exclusion zones around FS-PP terminals are considered as a potential mechanism to mitigate interference. Exclusion zones are areas around a FS-PP terminal defined by azimuth angle and distance that are free of any potential interferers. They are specified to meet the C/I requirements. The modelled FWA terminals are assumed to be mounted at lamp post level, so there will be reflections from buildings, ground, and foliage. These reflections may reduce the effectiveness of exclusion zones.

Figure 41 shows interferers at the extremity of the exclusion zone. FWA terminals would only operate outside of the exclusion zones (away from the boresight).

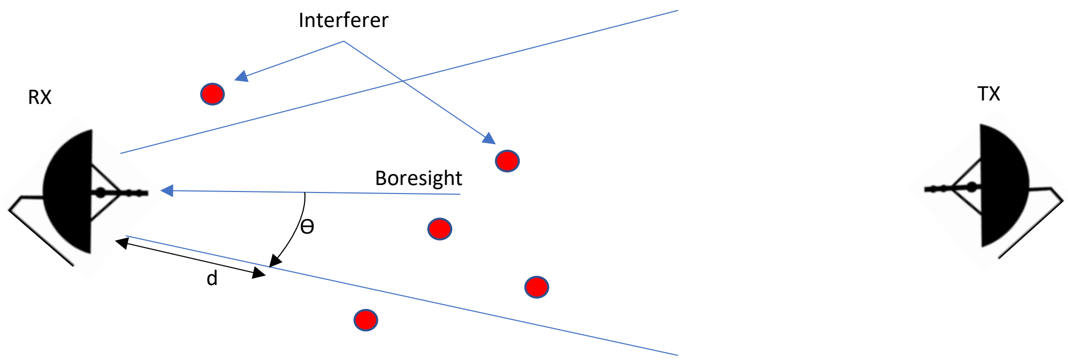


Figure 41: Exclusion zone for FS

Note that while exclusion zones guarantee interference free operation in free-space propagation scenarios, they are not sufficient protection in actual outdoor deployments where reflections can bring back some of interfering transmissions from outside of exclusion zone.

Figure 42 shows the exclusion zones for FS-PP terminals with 38 dBi and 32 dBi antenna gains, respectively. It is assumed that the FS-PP links operate over a 200 m distance and that the C/I thresholds in Table 24 are the acceptable interference levels. The curves define the exclusion zones by distance as a function of off-boresight angle for various bandwidth/spectral efficiency pairs. With a 10° off-boresight exclusion angle, the exclusion distances are 30 m and 150 m for 38 dBi and 32 dBi antenna gains, respectively.

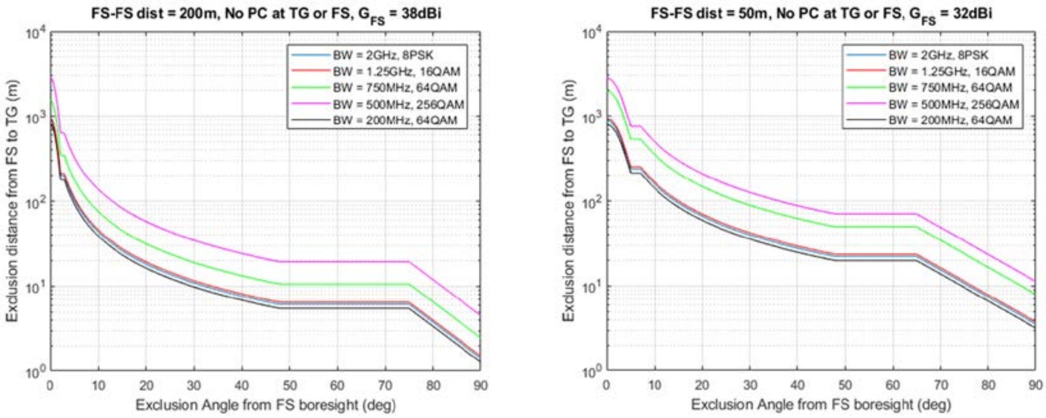


Figure 42: FWA exclusion zone for 32 dBi FS-PP terminal

7.9.4.5 Statistical analysis

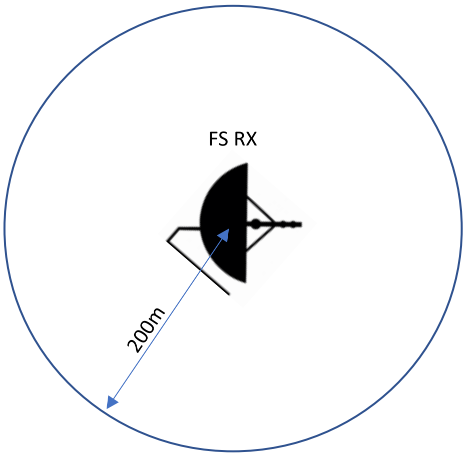


Figure 43: Statistical model scenario

Statistical analysis was performed to evaluate the potential for FWA to FS-PP coexistence. A FWA terminal is randomly placed with a 200 m radius of the FS-PP receiving terminal. The FS-PP link is assumed to be operating over a 200 m distance at max e.i.r.p. with no power control. Two FS-PP link channel bandwidths are considered: 2 GHz and 200 MHz. The FWA link operates at 40 dBm max average e.i.r.p. with a 2.16 GHz channel bandwidth. The FWA terminal is operated in PMP mode with each of its panels randomly pointing a beam to serve multiple receive terminals.

The CDF of C/I at the FS-PP receiving terminal is shown in Figure 44 for the 2 GHz and the 200 MHz FS-PP channels.

Curves are provided for both the 38 dBi and the 32 dBi FS-PP terminal antenna gains. Vertical lines denoting the required 3 dB degradation C/I for the various modulation formats are also shown.

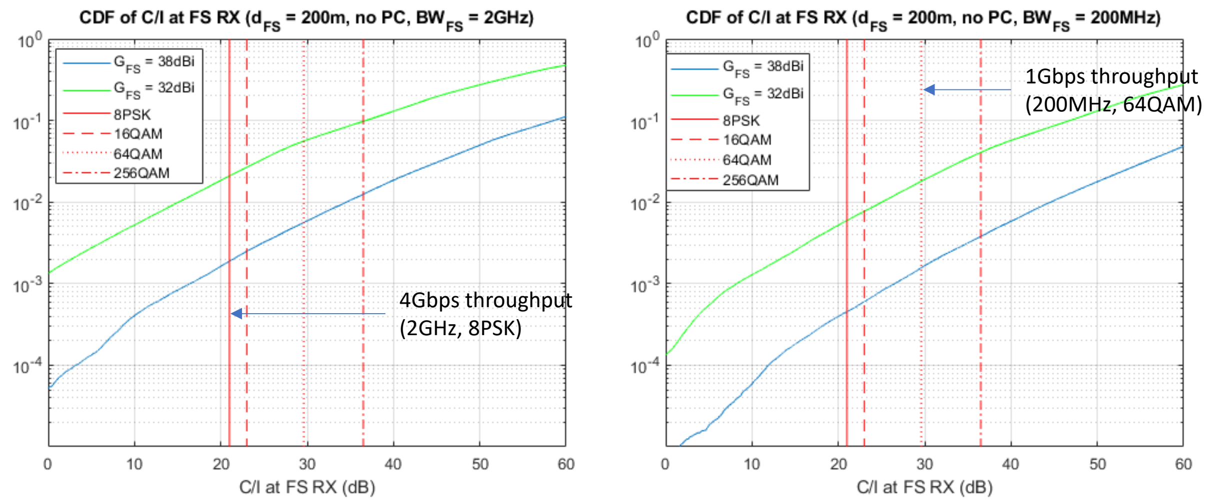


Figure 44: Statistical analysis results

Results of analyses, reported in Figure 44 show that C/I threshold for FS link not met in less than 10% in all cases.

7.9.4.6 San Jose Deployment Scenario

A PMP FWA system deployment has been modelled in San Jose, California consisting of several hundred FWA terminals in a mesh network. Ray tracing simulations were used to evaluate the potential for coexistence with FS-PP in this environment. Two PP-FS deployment scenarios were considered: Scenario 1 – replacing selected FWA links with FS-PP links and Scenario 2 – adding building-to-building FS-PP links.

Long links (FS - MGWS)

Scenario 1: Replacing selected FWA links with FS-PP links.

This ensured that FS-PP and FWA terminals were not collocated on the same lamp pole. Only FWA links that span a distance of over 100 m were considered as candidates for replacement.

Two sub-scenarios were considered:

- 1a) random beam pointing from FWA terminals;
- 1b) FWA beam pointing only to other FWA terminals.

The San Jose deployment is shown in Figure 28. Adjacent terminals were identified based on received power. FWA terminal pairs were randomly replaced by FS-PP terminal pairs and C/I computed. The presence of foliage was seen to degrade the C/I at the FS-PP receivers giving poorer results compared to the statistical modelling.

Figure 45 and Figure 46 and show CDF of C/I assuming randomised FWA beam pointing for the strongest 3 FWA links replaced with FS-PP links and the strongest link replaced with a FS-PP link respectively; the latter is considered for two different channel bandwidths, i.e. 200 MHz and 2 GHz. Curves are provided for both 38 dBi and 32 dBi FS-PP terminal antenna gains. The vertical lines are the C/I thresholds for the various modulations.

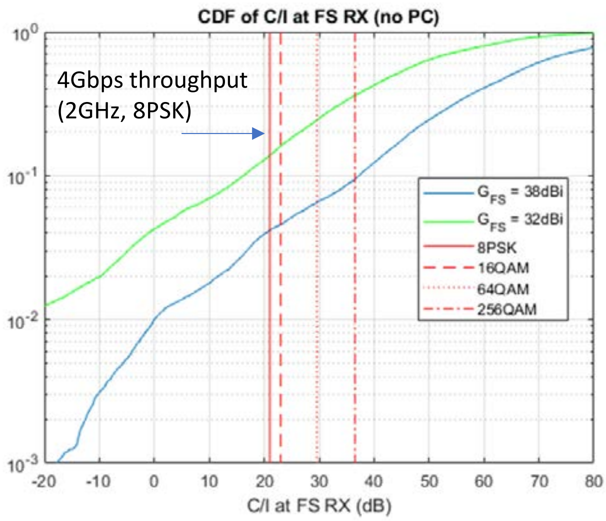


Figure 45: Sub-scenario 1a (Randomised FWA Pointing) results for the strongest 3 FWA links replaced with FS-PP links

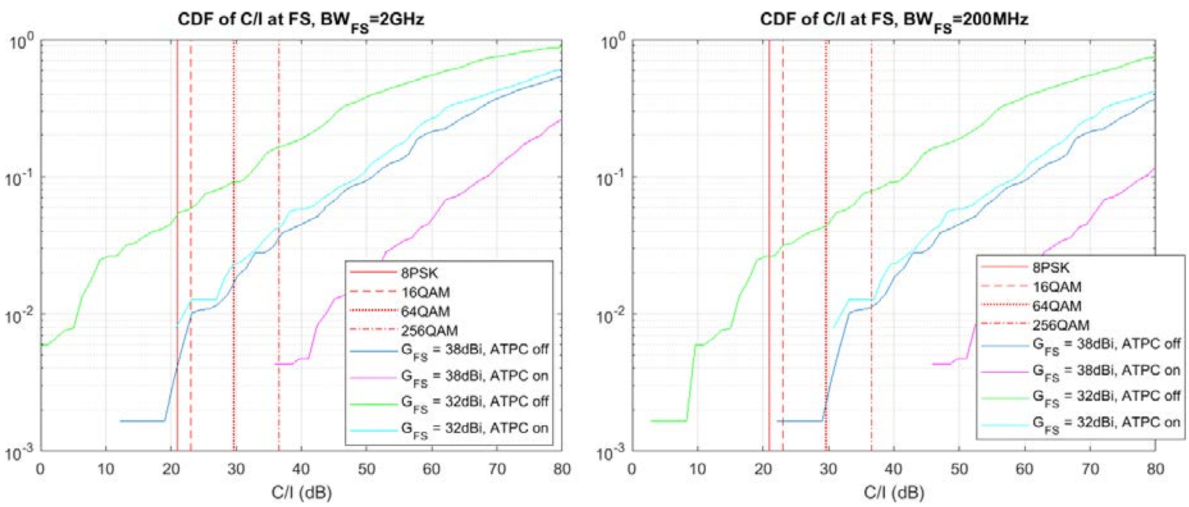


Figure 46: Sub-scenario 1a (Randomised FWA Pointing) results for the strongest link replaced with a FS-PP link, considering two different channel bandwith

Figure 47 and Figure 48 show C/I CDF with directed beamforming for all four combinations of 2 GHz and 200 MHz bandwidth and 38 dBi and 32 dBi FS-PP antenna gain. The vertical lines are the C/I thresholds for the various modulations. Directed beamforming was modelled with FWA client nodes (CNs) on building walls every 20 m, and FWA distribution terminal beamforming limited to server client terminals and adjacent distribution terminals. A FWA scheduler was modelled to randomly serve CNs and distribution nodes (DNs) while enforcing DN/CN polarity and transmit/receive cadence of a single frequency network (SFN).Two sub-scenarios were simulated: no foliage blockage of FS-PP links (typical case) and FS-PP link foliage blockage. Curves are provided in the figures for each of the cases. Foliage blockage was assumed for FWA links in both cases.

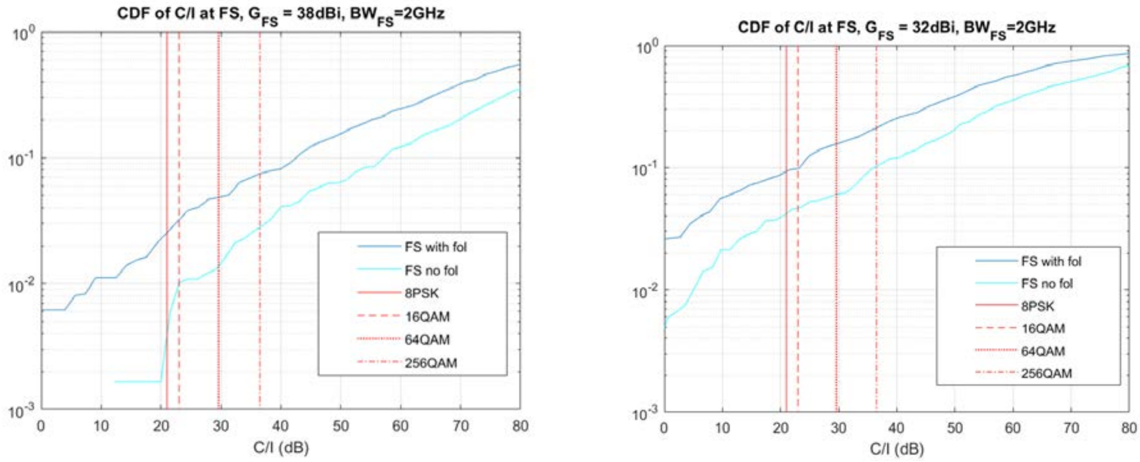


Figure 47: Directed beamforming, 2 GHz FS-PP channel, 38 and 32 dBi FS-PP antenna gain

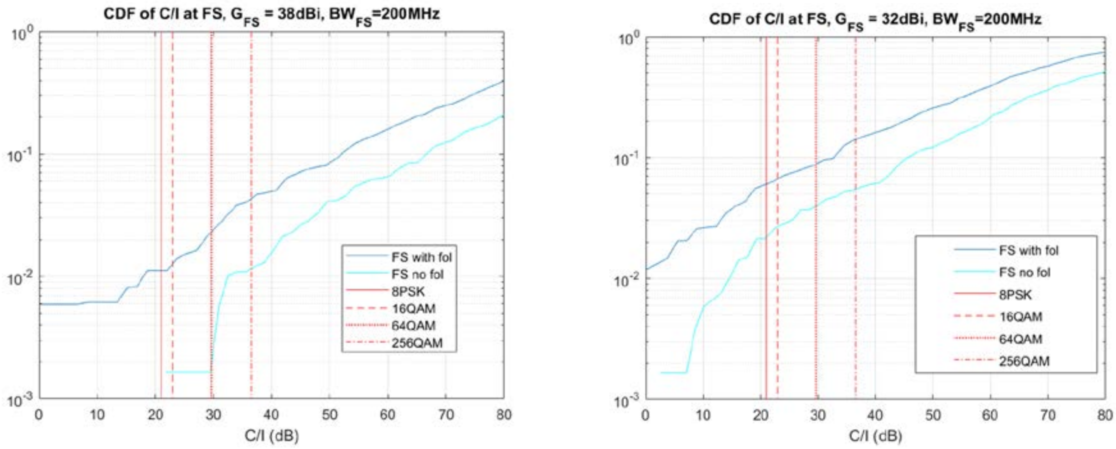


Figure 48: Directed beamforming, 200 MHz FS-PP channel, 38 and 32 dBi FS-PP antenna gain

Short links (FS - MGWS)

Scenario 2: Adding building-to-building FS-PP links

In this scenario, short (~50 m) building-to-building (perpendicular to street) FS-PP links were added to the ray tracing model of the San Jose, California deployment. FS-PP links that are perpendicular to the street have better C/I due to the narrow beamwidths and the shorter distances. Whereas, links along the streets tend to see more interference and have less received signal power due to the distance.

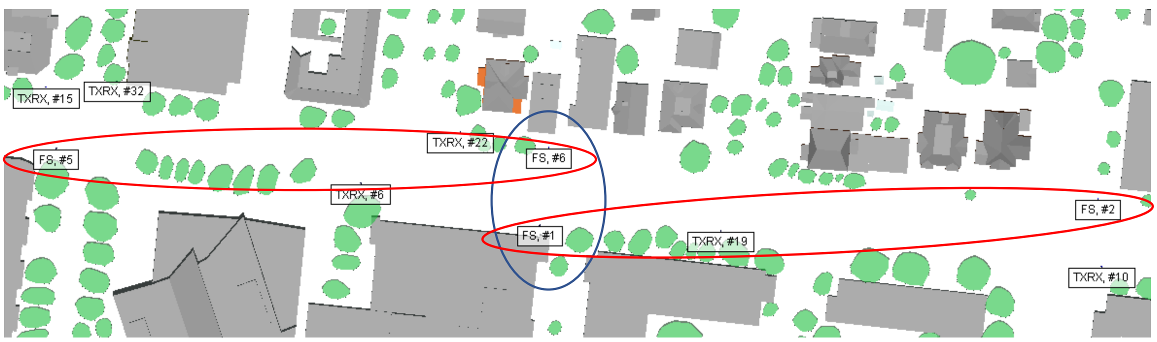


Figure 49: FS link perpendicular to street

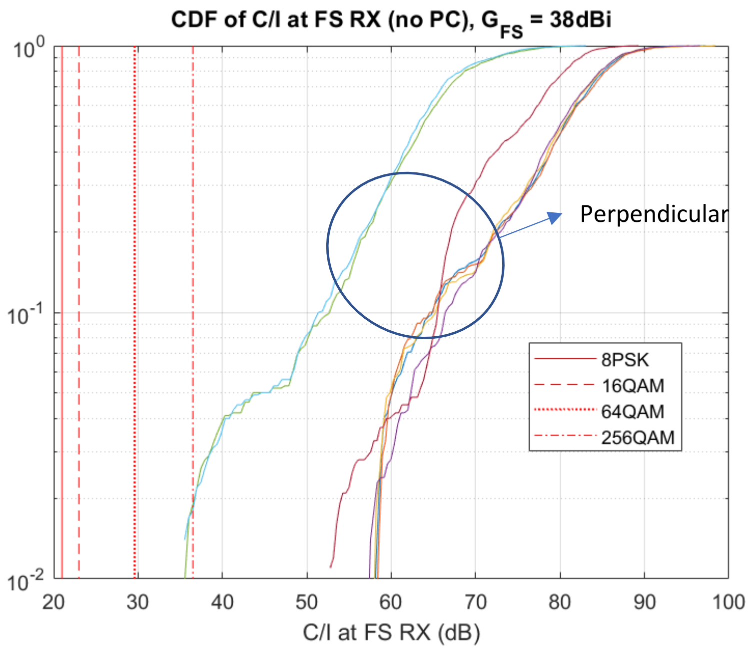


Figure 50: FS links perpendicular to street simulation results

The exclusion zone analysis showed that with a 10° exclusion angle, a 64-QAM, 200 MHz FS-PP link would not be impacted by FWA terminals operating at exclusion distances of 30 m and 150 m for 38 dBi and 32 dBi FS-PP antenna gains, respectively. However, for street level deployments, reflections from outside of the exclusion zones can bring interfering signal back to the receiver, rendering them ineffective.

The statistical analysis showed that only 0.2% and 2% of the FS-PP links failed to meet the C/I threshold for 38 dBi and 32 dBi FS-FF antenna gains, respectively.

In the San Jose, California deployment scenario, foliage causes significant degradation of C/I for the FS-PP links, as the links were modelled at the level of the foliage. Better FS-PP C/I would be obtained if only typical FS-PP links, those with clear LOS, were modelled. FS-PP links perpendicular to the street were shown to be less susceptible to FWA interference than those along the street.

These results suggest that FWA coexistence with FS-PP in V-band is possible and that interference to incumbent FS-PP deployments would be so rare that interference could be addressed on a case-by-case basis.

7.9.5 FWA - SRD

This section is intended to study coexistence between an IEEE 802.11ad based Short Range Devices (SRD), which has to be considered as a nomadic application, and distribution network for Fixed Wireless Access (FWA).

Ray tracing simulation performance for impact of FWA on outdoor SRDs and real measurement for both indoor and outdoor scenarios have been executed.

7.9.5.1 Equipment specifications

SRD:

- 8x2 antenna elements, ~17 dBi antenna gain;
- e.i.r.p. ~ 25 dBm;
- 1 Gbps (unidirectional) offered traffic;
- Automatic MCS selection.

FWA:

- 36 horizontal x 8 vertical elements, ~30 dBi antenna gain;
- Automatic Tx power control (TPC) with maximum average e.i.r.p. = 40 dBm;
- TCP 1 Gbps + 1 Gbps bidirectional offered traffic;
- Automatic MCS selection.

7.9.5.2 Simulation environment

Ray tracing has been used to compute the interference levels received by SRD, I order to evaluate the areas where the CCA mechanism could be activated, with or without power control. Measurements have been operated in a real environment, with architectural characteristics similar to the simulated one.

The simulated area is shown in Figure 52

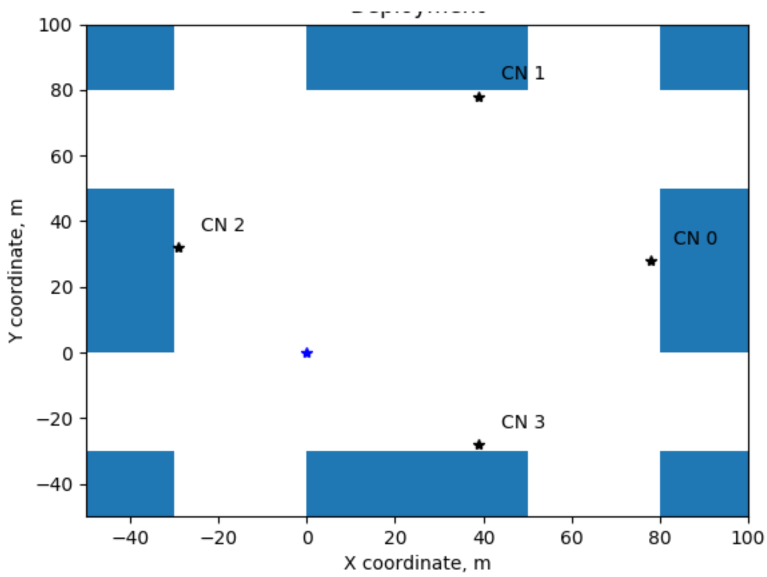


Figure 51: 3D ray tracing scenario

Figure 52 shows the results of simulations on the probability of CCA activation obtained at nominal Tx power. While Figure 53 show the interferer levels with power control. Figure 54 shows the CDF with and without TPC.

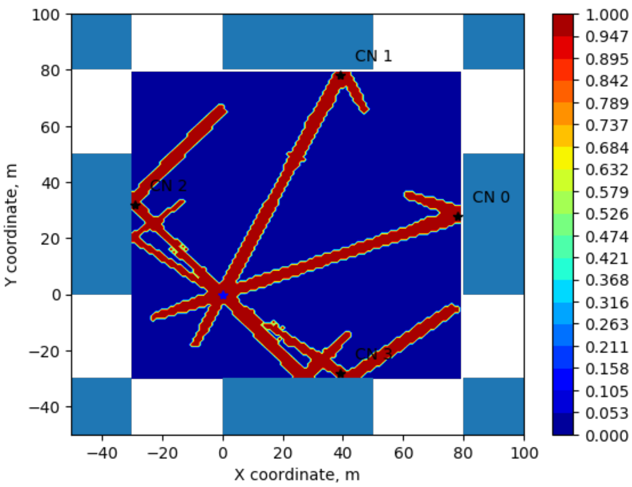


Figure 52: Probability of CCA activation – no TPC

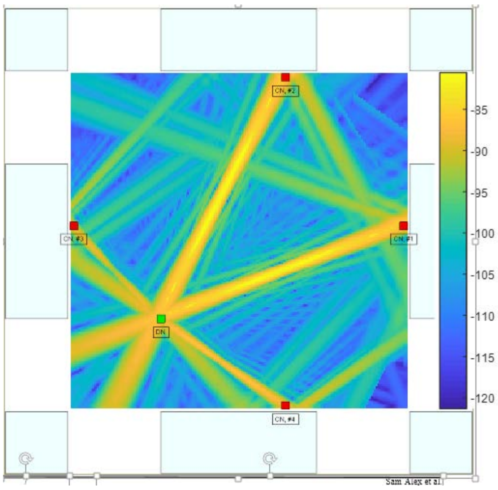


Figure 53: Interferer level– TPC (dBm)

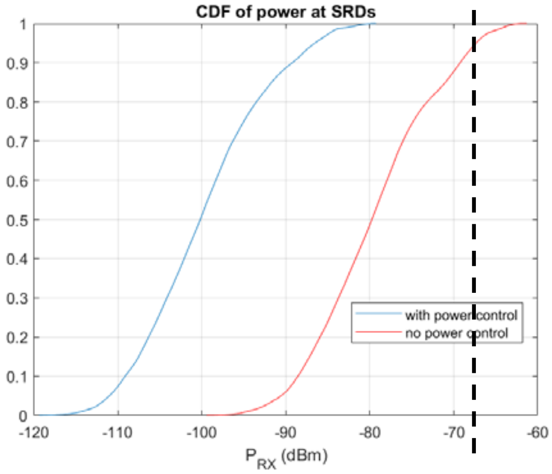


Figure 54: Probability of CCA activation

In case that power control is not used (Figure 52), regions with high probability of CCA activation can be seen in the considered area.

In the transmit power controlled scenario, DN and CN target for SNR is 18 dB (MCS12) at their respective receivers. Received power levels (Figure 54) are well below CCA thresholds (-68 dBm), i.e. no CCA triggering is activated anywhere within the assumed city square (Figure 54)

7.9.5.3 Measurements

Measurements campaign was performed at Facebook campus in Menlo Park, CA (Hacker square comparable in size to the simulated city square scenario of section 7.5):

- FWA device: 60 GHz IEEE 802.11ad based TDD/TDM prototype;
- SRD device: Intel's 60 GHz IEEE 802.11ad notebook and wireless docking station.

Two different scenarios were used; the one with FWA and SRD devices with aligned links (Figure 55) and with perpendicular links (Figure 56). In parallel links scenario, the effect of using two different channels for SRD and FWA was evaluated. In addition, interference measurements between outdoor FWA and indoor SRD were accomplished.

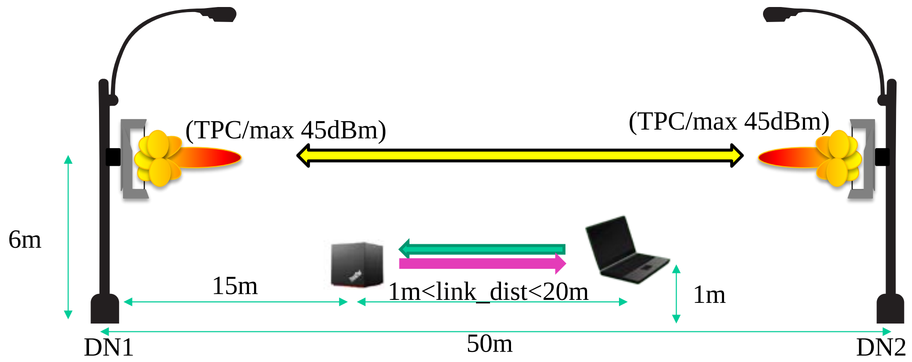


Figure 55: Parallel links

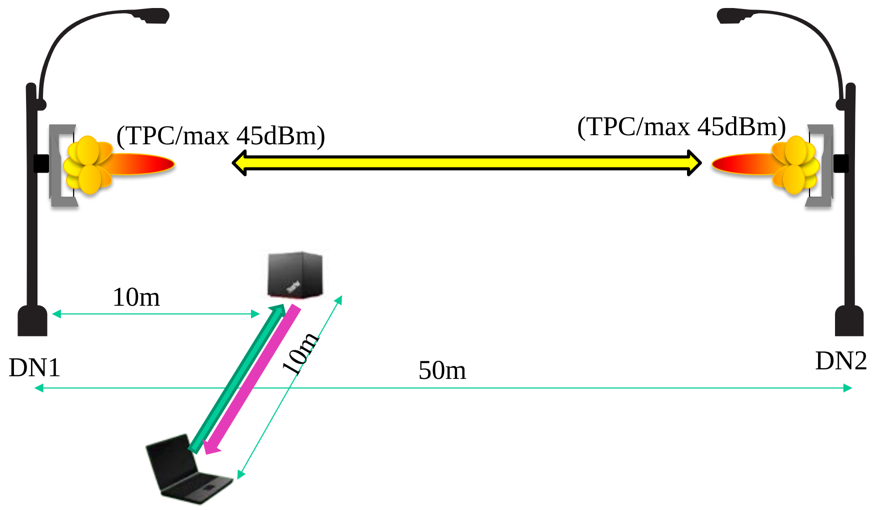


Figure 56: Perpendicular links

Results for parallel link scenario

Co channel interference (CCI) scenario: some impact on performance seen at highest FWA powers when both links operate on the same channel (channel 2).

At maximum FWA power (e.i.r.p. = 45 dBm), SRD was able to maintain a stable connection only up to 10 m link distance.

With TPC on FWA, SRD was able to have stable connection and to support the throughput at distance > 10 m.

Adjacent channel interference (ACI) scenario

When SRD link was moved to channel 1 or 3, both systems didn't impact each other´s performance even at maximum FWA e.i.r.p. of 45 dBm.

Results for perpendicular link scenario

No throughput impact (i.e. sufficient SINR for SRD) seen on SRD Rx Error vector magnitude (EVM), even with maximum FWA power.

Results for outdoor to indoor scenario

SRD placed within a room on the second floor such that the nodes are directly positioned behind a FWA node, with only a window separating the FWA from the SRD node.

No impact observed to SRD device when FWA operates at max Tx power (e.i.r.p. = 45 dBm).

Room size limitations and obstacles limited the maximum SRD link distance to 8 m.

Window loss (safety glass can be up to 12 dB loss) provides additional protection to the SRD.

Earlier simulations similarly predicted no impact to indoor SRDs from outdoor FWA systems.

7.9.5.4 Conclusions of FWA vs SRD study

- Number of outdoor and outdoor to indoor FWA vs SRD coexistence scenarios analysed via simulation and field measurements;
- No impact observed to SRD for co-channel perpendicular and adjacent channel collinear test cases, irrespective of FWA power control strategy;
- When SRD link is collinear with FWA on the same channel, transmit power control is required at FWA to mitigate impact to the SRD link;
- For outdoor to indoor scenario, no impact to SRD device observed.

8 INTER-SYSTEM MITIGATION MECHANISMS

This section describes a variety of dynamic (adaptive) interference mitigation mechanisms inherent in MGWS implementation that could be adopted to facilitate coexistence of MGWS and FS in the 60 GHz band with fair spectrum sharing.

8.1 DYNAMIC FREQUENCY SELECTION (DFS)

Modern MGWS use wideband silicon implementations comprising power amplifiers (PAs), low-noise amplifiers (LNAs) and tunable local oscillators (LOs) with bandwidths of ten to several tens of GHz. The current WiGig systems, for example, are designed to operate in all four IEEE 802.11ad channels (57-66 GHz), and the next generation of WiGig systems developed under IEEE 802.11ay are expected to support two additional channels reaching out to 71 GHz. Wideband silicon designs enable MGWS to operate in a large number of channels in the 60 GHz band, dynamically switching the channel of operation to avoid frequency overlapping with an channel occupied by applications in other services including FS.

8.2 AUTOMATIC TRANSMIT POWER CONTROL (ATPC)

Automatic Transmit Power Control (ATPC) is an important mechanism built into MGWS implementations to minimise intra-system (also known as self) interference. A transmitter adjusts its transmit power based on feedback from receiver to the minimum necessary to operate a link with desired performance. A typical MGWS using IEEE 802.11ad technology, for example, can reduce the transmit power by an average of 1 dBm for every 10-meter reduction in link distance from 200 to 50 meters. Protocol-level mechanisms to adjust transmit power through closed-loop feedback are easy to implement and work well in despite of imperfect knowledge of antenna gain and other signal transition losses and measurement imperfections.

ATPC is beneficial to MGWS operation alone, and to MGWS and FS coexistence. It should be considered as one of the most effective dynamic methods for spectrum sharing.

Power control effectiveness to reduce interference has always been shown in all studies and measurements addressed in this Report, no matter of the calculation method and the network density (even in theoretical Monte Carlo, worst cases simulations in very high density leading to high interference expected, improvement up to about 3 times could be estimated). In conjunction with DFS and in realistic cases, improvement of many times or full resolution of interference, leading to throughput increase, have been simulated or measured. As a consequence, the adoption of such mechanism(s) is deemed very effective to reduce interference scenarios in all use cases.

8.3 LISTEN BEFORE TALK

8.3.1 Overview

Operation in unlicensed spectrum has traditionally been required to include a Listen Before Talk (LBT) mechanism to allow a fair access and to promote efficient use of an unlicensed spectrum as V-Band, a mechanism like LBT is required[7] to mitigate the interference between network stations.

The effect of LBT mechanism (Figure 57) on overall system (spatial) capacity has been investigated through a simulation scenario described in this section.

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[7] Actually only in Europe the CEPT ECC Rec. 70-03 [8] mentions it in Annex 3: “Adequate spectrum sharing mechanism (e.g. Listen Before Talk, Detect And Avoid) shall be implemented by the equipment.

8.3.2 Simulation model

Figure 57 illustrates a representative LBT mechanism. At the core of LBT is a Clear Channel Assessment (CCA) mechanism regularly invoked to detect possible existing signals in the operating channel based on energy detection (ED) threshold.

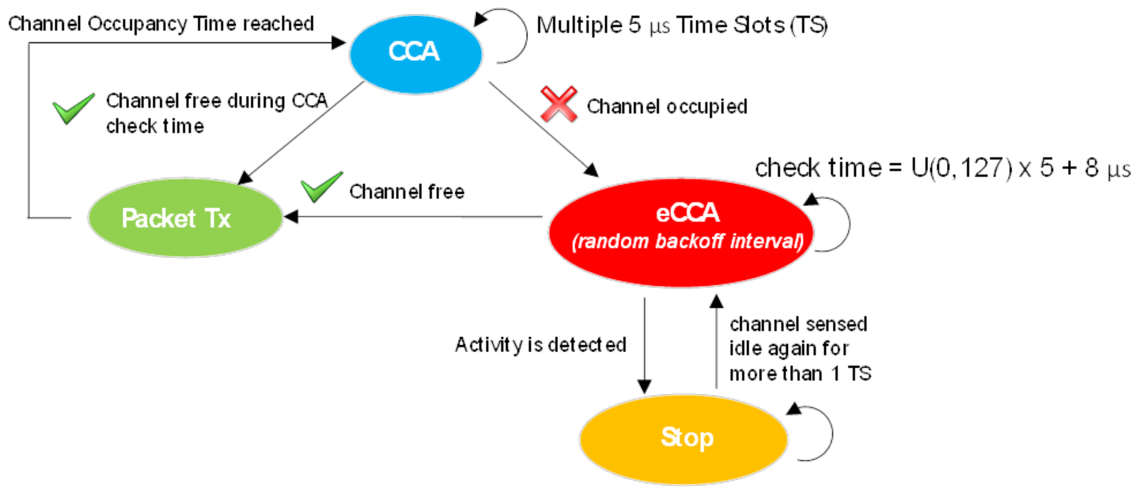

Figure 57: LBT graphical formulation

8.3.3 System model

The simulation model (Figure 59) includes a single desired link operating at 100 m distance, and area 30 m wide and 100 m long, around the desired link, populated with a variable number (U= 1,2,4,8) of interferer links randomly placed in the area.

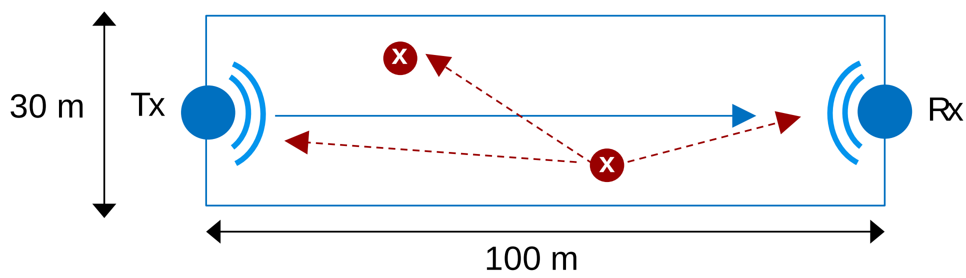

Figure 58: System model (the wanted link in blue; the interference links in red)

The wanted link is modelled as a FWA system with a narrow beamwidth antenna (HPBW=3.16°) on both ends of the link. The interferer link(s) use a wide beamwidth (HPBW=10.2°) antenna on both ends.

All transmitters are in full buffer mode, LBT Channel Occupancy Time is 9 ms (maximum value allowed by [9] and the CCA and eCCA mechanisms are based on 5 µs time slots (TS).

Common system model parameters are listed in Table 26.

Table 26: System model common parameters

Parameters	Value
e.i.r.p.	40 dBm
Carrier frequency	60 GHz
Noise power	-76 dBm
Bandwidth	1000 MHz
Modulation max spectrum efficiency	7 bit/s/Hz[8]
Path loss model	Free space loss + Gas absorption

The energy detection threshold is an important parameter in the LBT algorithm. If the detected energy level does not exceed the threshold level, the operating channel is considered clear or free and the equipment may transmit immediately on the operating channel for a channel occupancy time.

The following LBT algorithm configurations have been considered:

- LBT disabled;
- LBT enabled with energy detection (ED) threshold of -7 dBm, -27 dBm, -47 dBm and -67 dBm.

The analysis is based on the Monte Carlo methods with tens of thousands trials each lasting 4 s.

Channel bandwidth of about one half of the basic 2160 MHz IEEE 802.11ad channel was used to speed up the overall simulation time.

8.3.4 Simulation results

The simulation results are provided as plots of the probability that the average[9] capacity is greater than or equal to the value in abscissa (i.e. Probability of average Capacity ≥ x)) over Monte Carlo trials including both different positions and time slots.

Figure 59 shows the system capacity distribution for 1, 2, 4 and 8 interferer links and each of the five LBT configurations described above.

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[8] 128-QAM equivalent

[9] The capacity is averaged in 40 ms of integration time

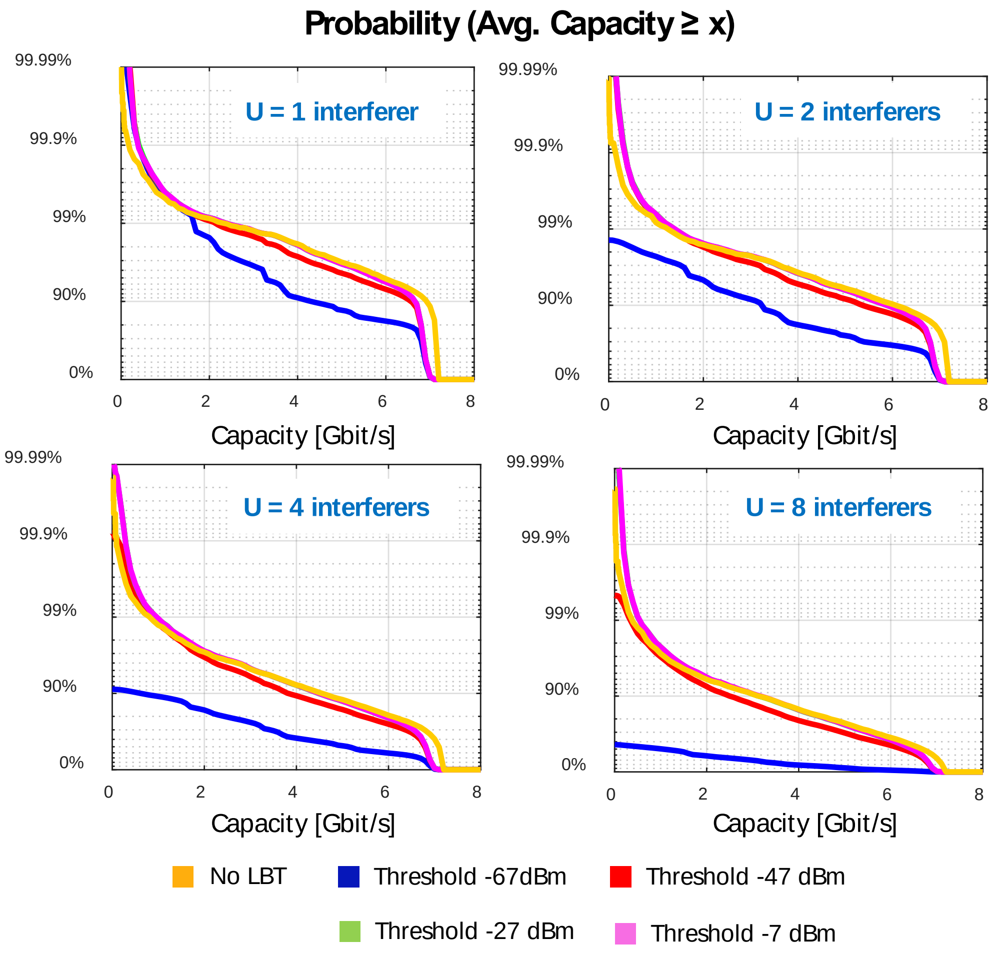

Figure 59: Simulation results

The probability slopes have more or less the same trend in the case of LBT disabled and when LBT is enabled with energy detection (ED) thresholds up to -47 dBm (i.e. the value proposed in ETSI EN 302 567 [9]). Thus, the average capacity is similar with or without LBT.

8.3.5 LBT conclusion

As expected, capacity drops faster with the increase of the number of the interferer links. Maximum capacity is reached without LBT, with a slight capacity decrease when LBT is enabled with energy detection (ED) threshold of -47 dBm or higher. LBT with a detection threshold of -67 dBm has an adverse effect on capacity.

No substantial capacity reduction is therefore expected in case the implementation of LBT is required, with ED values properly selected.

8.4 SYNCHRONISATION AND MODE OF OPERATION

FWA networks can achieve a high level of time synchronisation by using a global time reference such as GPS at every node, running a time synchronisation protocol such as IEEE 1588 or IEEE 802.1AS between network nodes or a combination of both methods. Even for simple FWA implementations that do not run these protocols, both ends of a given link can achieve time synchronisation to within ±1 µs as long as one of them has access to a global reference clock such as GPS.

A common time base enables coordinated transmissions across an FWA network. In particular, transmission schedule for each FWA network node can be designed to eliminate or reduce (self) interference on different sectors of the node itself, interference on neighbouring FWA links, and as an added benefit, interference on neighbouring FS links.

For example, one network[10] employs a transmit polarity (alternate transmission) concept, enforcing a transmission schedule that results in no two adjacent nodes transmitting at the same time. Note that with this arrangement, interfering transmitters are moved to 3 hops away from each receiver, reducing the overall interference on each FWA network node, .As mentioned, this has a benefit on each neighbouring FS link.

To see the interference improvement resulting from alternate transmission, a linear network topology with 5 network nodes (representative of a long street) has been studied. Two modes of operation are addressed: Mode 1 (in-phase transmission) and Mode 2 (alternate transmission).

The two modes of operation are shown in Figure 60 and Figure 61. For each model, three different equipment placements have been considered:

- Equipment (APs) placed at same height (3 m) from road level, and on same side of the street;
- Equipment (APs) placed at different heights (3m and 5 m) from road level and on same side of the street;
- Equipment (APs) located at same height (3 m) from road level and alternated along both sides of street ("zigzag").

Interference results for Mode 1 and Mode 2 are shown in Table 27 and Table 28, respectively.

Figure 60: Mode 1 in-phase transmission configuration

Table 27: Mode 1 simulation results

		APs at same side, all 3 m height			APs at same side , vertical variation (3, 5, 3, 5 & 3) m			APs alternated along both sides of street, all 3 m height		
AP	AP	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)
AP7	AP8	4.88	13.2	17.4	4.66	12.8	17	12.9	17	21.2
AP8	AP10	5.19	7.21	19	5.18	6.93	18.5	9.98	10.47	17.7
AP10	AP11 (POP)	6.59	5.86	19.6	6.35	5.83	19.2	12.4	16.6	25.1
AP11 (POP)	AP15	12.7	3.23	16.9	12.3	3.05	16.5	11.6	2.98	15.8

[10] Facebook Terragraph

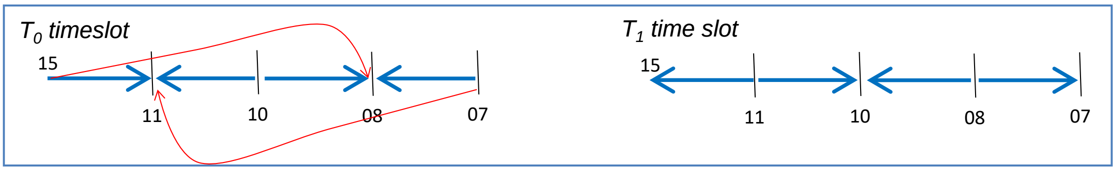

Figure 61: Mode 2 alternate transmission configuration

Table 28: Mode 2 simulation results

		APs at same side, all 3 m height			APs at same side , vertical variation (3, 5, 3, 5 & 3) m			APs alternated along both sides of street, all 3m height		
AP	AP	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)	SINR_DL (dB)	SINR_UL (dB)	SNR (dB)
AP7	AP8	10.9	17.4	17.4	10.6	17	17	15.5	21.2	21.2
AP8	AP10	19	12.3	19	18.5	12.2	18.5	17.7	13.8	17.7
AP10	AP11 (POP)	19.6	13.1	19.6	19.1	12.8	19.2	25.1	19.5	25.1
AP11 (POP)	AP15	10.2	16.9	16.9	9.96	16.5	16.5	11.8	15.7	15.8

As the tables show, Mode 2 provides 6 and 7 dB higher SINR than Mode 1, demonstrating that the choice of transmission system along the path can play a significant role in overall performance. In line with this observation, the zig-zag topology improves SINR by 3 dB in both modes.

Installations using nodes not at different heights from road levels (3 and 5 m) show negligible degradation in SNR due to the small reduction of the Rx power, since no vertical steering is applied.

9 ANTENNAS

9.1 E.I.R.P. AND ANTENNA GAIN RELATIONSHIP

Considering the results of studies undertaken in this Report, based on current regulations for indoor and outdoor, Figure 62 shows the relationship between e.i.r.p. and antenna gain (Gant) which is appropriate for correct operation of equipment in this band under general authorisation regime.

Figure 62 shows the relationship between e.i.r.p. and antenna gain. It takes into account max e.i.r.p. of 40 dBm (indoor) (see Annex 3 of ERC Recommendation 70-03[8]) and 55 dBm combined with a minimum antenna gain of 30 dBi (outdoor) (see ECC Recommendation (09)01and ETSI EN 302 217-2 Annex H [4]).

Furthermore the current MGWS technology provides equipment operating with minimum antenna gain of 13 dBi.

Moreover, potential use of antennas with gain less than 13 dBi implies a corresponding decrease in e.i.r.p. which would reduce the potential interference area around the equipment noting that EMF limits need to be met for protection of people but is considered to be out of the scope of the present ECC Report.

Regarding the first part of the figure until 30 dBi antenna gain, the e.i.r.p. of 40 dBm can be achieved with a minimum antenna gain of 13 dBi and a maximum output power of 27 dBm or an antenna with higher gain combined with reduced output power.

To get e.i.r.p. of 55 dBm, a slope of 2 dB EIRP increase for each dB of antenna gain is used, starting from 30 dBi. This slope of 2 dB/dBi is to maintain the potential interference area confined within the main beam angle of the antenna (See ANNEX 3: for background).This slope results in the 37.5 dBi to reach 55 dBm e.i.r.p. It is noted that the FCC requires a slope of 2 dB/dBi from 30 dBi (see FCC cfr 47 part 15 (§15.255)).

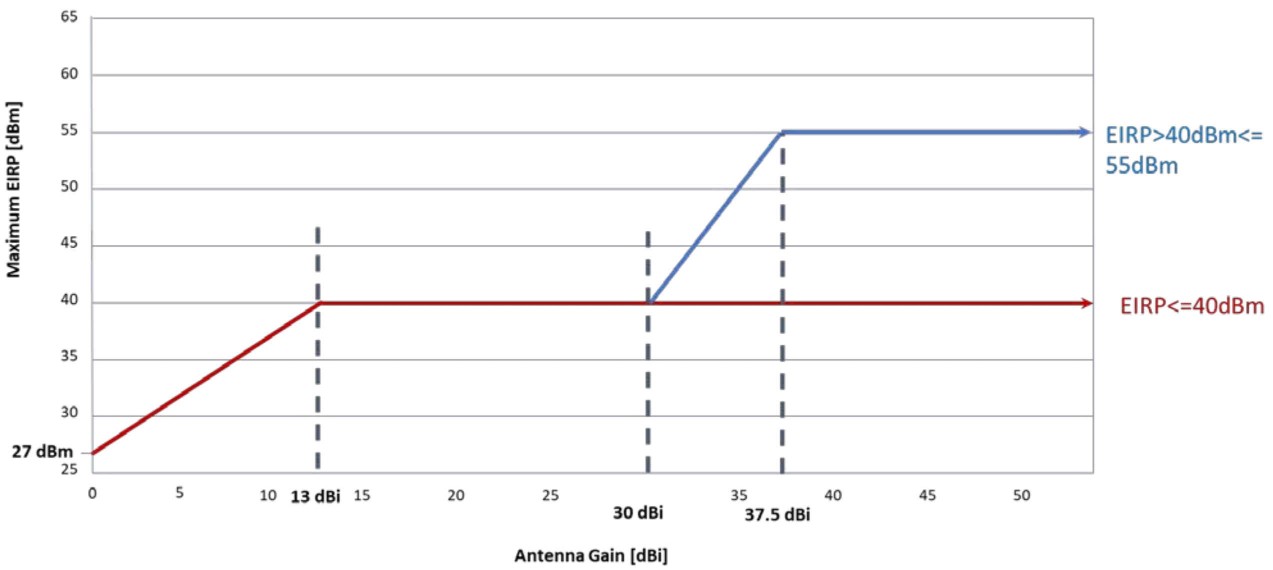

Figure 62: Maximum e.i.r.p. and Gant relationship

This could be implemented as:

For operation at e.i.r.p. ≤ 40 dBm:

- Maximum transmit power delivered to the antenna port or ports of 27 dBm and
- Maximum e.i.r.p.:
  - e.i.r.p.(max) = min (40, 40-(13-Gant)) dBm.

For operation at e.i.r.p. > 40 dBm:

- Maximum e.i.r.p.: 55 dBm
- The maximum e.i.r.p. shall be reduced by 2 dB for every 1 dB that the antenna gain is less than 37.5 dBi. This can be represented as:
  - e.i.r.p.(max) = 40 + 2*(Gant-30) dBm

In this way, the e.i.r.p. is increased gradually with the antenna directivity.

9.2 BEAMFORMING (FOCUSED TRANSMISSION AND RECEPTION OF ENERGY)

PMP systems with point and shoot beamforming (using phased arrays) radiate energy almost exclusively where it is needed; this is unlike sectored PMP systems with a radiation pattern that spans the entire sector at all times and reduces spatial reuse of spectrum. For PMP systems with phased array, increasing the number of antenna elements in the array moves stronger side lobes closer to the main lobe and improves the energy focus toward the intended user.

For FWA and SRD coexistence, FWA vertical radiation pattern is of more significance, and for FWA and FS coexistence FWA horizontal radiation pattern plays a greater role. For the same e.i.r.p., the coexistence improves as antenna beamwidths are reduced. This suggests that appropriate antennas with sufficiently narrow beamwidths can improve coexistence in difficult topologies and environments.

Side lobes can also be improved by adjusting the elemental amplitude gains of the phased array. For example, applying gain taper can reduce interference caused by side lobes.

Proper orientation and positioning of nodes along with beamforming can greatly improve coexistence with FS nodes when their locations are known. After identifying an FS link orientation, FWA nodes can be placed such that the FWA links are orthogonal (or as close to orthogonal as possible) to the FS links, which avoids or minimises beamforming in the direction of the FS link. The highly directional beams from FWA could provide additional decoupling to achieve better coexistence with FS links.

9.3 BEAM NULLING

For PMP systems using phase array antennas, it is possible in some cases to reduce or even eliminate the energy received from (and radiated towards) an FS node. Nulling the beam pointing to an FS node is not always possible (nulled beam needs to be sufficiently away from the main lobe), but it is highly effective where applicable. Again, knowledge of the location and orientation of FS links during FWA equipment installation can increase beam nulling opportunities. The effective potentiality of this technique still requires further evaluation.

10 USE OF THE BAND

10.1 ECC REPORT 173

The 2018 version of ECC Report 173 [27] contains information on the use of FS band in Europe, collected by means of a specific Questionnaire.

The following situation describes the band addressed by this Report.

10.1.1 57-64 GHz band

The channel plan for this band follows ECC Recommendation/(09)01 [12] which combines the whole 57-64 GHz range specifically for PP application with Multi Gigabit Wireless Systems (MGWS) following ERC Recommendation 70-03 [8] and ETSI EN 302 567 [9].

27 administrations indicated that the band is available; several licensing regimes were declared: link by link basis (18 answers), block licence (4 answers), light licence (3 administrations).

11 administrations declared the band, or part of it, as unlicensed.

A total of about 350 links were declared in operation by 6 countries (about 330 are used by 2 countries only).

It should be noted that evaluation of effective used links is not possible due to the unknown number of unlicensed links. Nevertheless, the effective use appears quite limited, compared to most bands traditionally used by FS (where several tens of thousands of links are in service).

10.1.2 64-66 GHz band

Band is open in 27 countries, but no active link is reported in this band.

A general trend for a link by link authorisation regime was indicated (14 answers) for high capacity PP links.

The frequency band is used according to the ECC Recommendation (05)02 [22].

10.1.3 Evaluation of possible victim links

For each use case studied in this Report, the application of results (% of interfered links) to the number of declared/estimated links in operation according to the ECC Report 173 provides an estimate of possible number of FS links currently in operation which could be subject to performance degradation caused by interference.

11 CONCLUSION

Analyses of interference potentially affecting FS applications in the 57-66 GHz band, derived from MGWS systems, have been accomplished.

Due to unknown location of interfering devices, consequence of unlicensed regime, traditional interference analyses for the protection of FS is in general not possible. However, proper mitigation mechanisms have shown to be effective in this band in reducing the probability of interference to a few percent of FS links.

A variety of methods and design practices are available to modern MGWS that would reduce interference to FS. Ranking these methods and practices in terms of effectiveness (i.e. maintaining performance of both MGWS and FS), complexity, and cost is generally case dependent.

Among dynamic mechanisms, ATPC and DFS are the most effective and cost-efficient mechanisms. ATPC is particularly important as MGWS equipment are naturally motivated to implement ATPC to control self-interference. Coordinated transmission based on a common (synchronised) time base is highly effective in minimising interference and helps with intra-system interference, especially if it is coupled with topology planning.

High propagation loss for signals in 60 GHz band due to oxygen absorption (up to 15 dB/km) naturally improves interference immunity for both MGWS and FS. Results in Section 7 indicate that combination of ATPC and adaptive antenna beamforming on MGWS can be used to further improve coexistence between MGWS and FS.

Evaluation of possible real cases of licensed links in service affected by interference (links with possible threshold degradation) could be estimated by applying the calculated percentages of interference to the number of known active links

Regarding ITS, conclusions derived from ECC Report 113 are still considered valid.

The utilization of MGWS outdoor is compatible, in the majority of cases, with current use of FS in this band, provided that common technical conditions as follows are adopted:

- The establishment of a common set of technical conditions under which fixed service applications and other outdoor envisaged uses/applications may coexist within the 57-66 GHz range in the same uncoordinated deployment is considered feasible;
- Therefore, the technical conditions described in section 9.1 are considered appropriate to manage the coexistence amongst any MGWS and FS applications intended to be used in this band;
- In addition, the adoption of interference mitigation technique such as ATPC/DFS is also highly beneficial.

ANNEX 1: IEEE RELATED PARAMETERS

Table 29 and Table 30 show receiver sensitivity values and MCS from IEEE 802.11ad standard.

Table 29: IEEE 802.11ad extract [2]

MCS	Receive sensitivity (dBm) (As per Table 20-3 IEEE802.11-2016)	SNR required (dB)
0	-78	-7
1	-68	3
2	-66	5
3	-65	6
4	-64	7
5	-62	9
6	-63	8
7	-62	9
8	-61	10
9	-59	12
10	-55	16
11	-54	17
12	-53	18

Table 30: MCS, Code Rate and Data Rate [3]

MCS	Modulation	LDPC Code Rate	Data Rate (Mbps)
1		1/2	385
2		1/2	770
3	π/2-BPSK	5/8	962,5
4		3/4	1155
5		13/16	1251
6		1/2	1540
7	π/2-QPSK	5/8	1925
8		3/4	2310
9		13/16	2502
10		1/2	3080
11	π/2-16-QAM	5/8	3850
12		3/4	4620
13	OFDM-SQPSK	1/2	693

MCS	Modulation	LDPC Code Rate	Data Rate (Mbps)
14		5/8	866
15			1386
16	OFDM-QPSK	5/8	1732
17		3/4	2079
18			2772
19		5/8	3465
20	OFDM-16-QAM	3/4	4158
21		13/16	4504
22		5/8	5197
23	OFDM -64-QAM	3/4	6237
24		13/16	6756
25	LPSC-π/2-BPSK	RS(224,208)	626

Simulation of BER vs SINR are shown in Figure 63

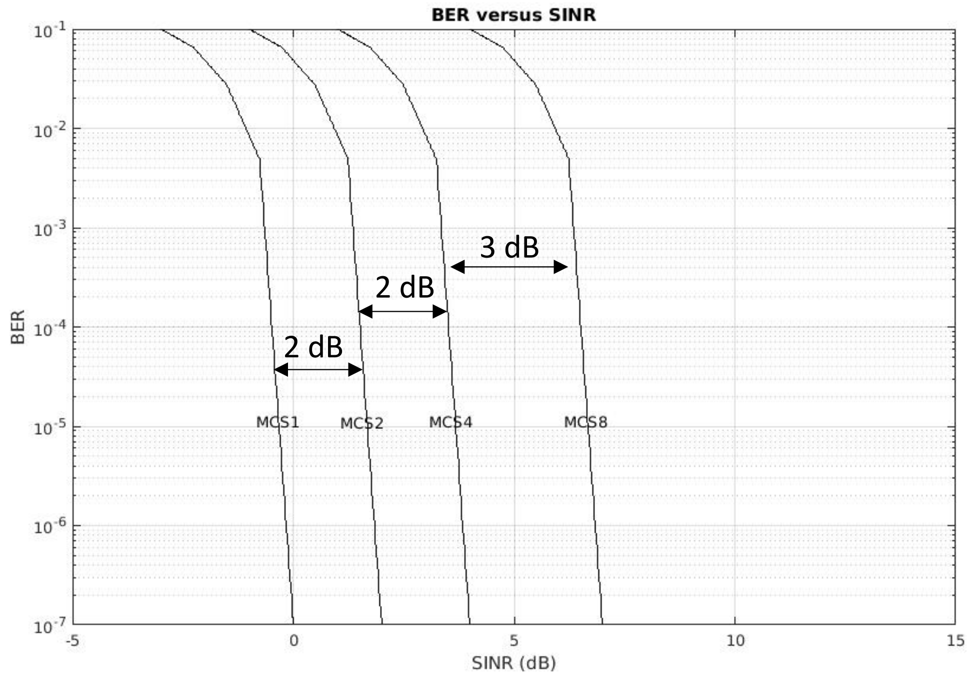

Figure 63: BER vs SINR

ANNEX 2: MGWS IN EU DIGITAL AGENDA

The Digital Agenda for Europe aims to facilitate the Gigabit connectivity for all main of socio-economic drivers, including access to connectivity offering at least 100 Mbps for all European households [10].

In this contest, mmWV FWA may play an important role by delivering Gigabit services at reduced time to market and on lower cost with respect to fibre access network.

mmWV can leverage on real-time performance assurance and optimisation (technology-assisted) and re-uses mobile and fixed infrastructure already present on building's rooftops and street poles.

Various setup scenarios are possible: urban, sub-urban and clustered rural. Instead, due to reduced achievable link lengths, V-Band looks not applicable for rural case.

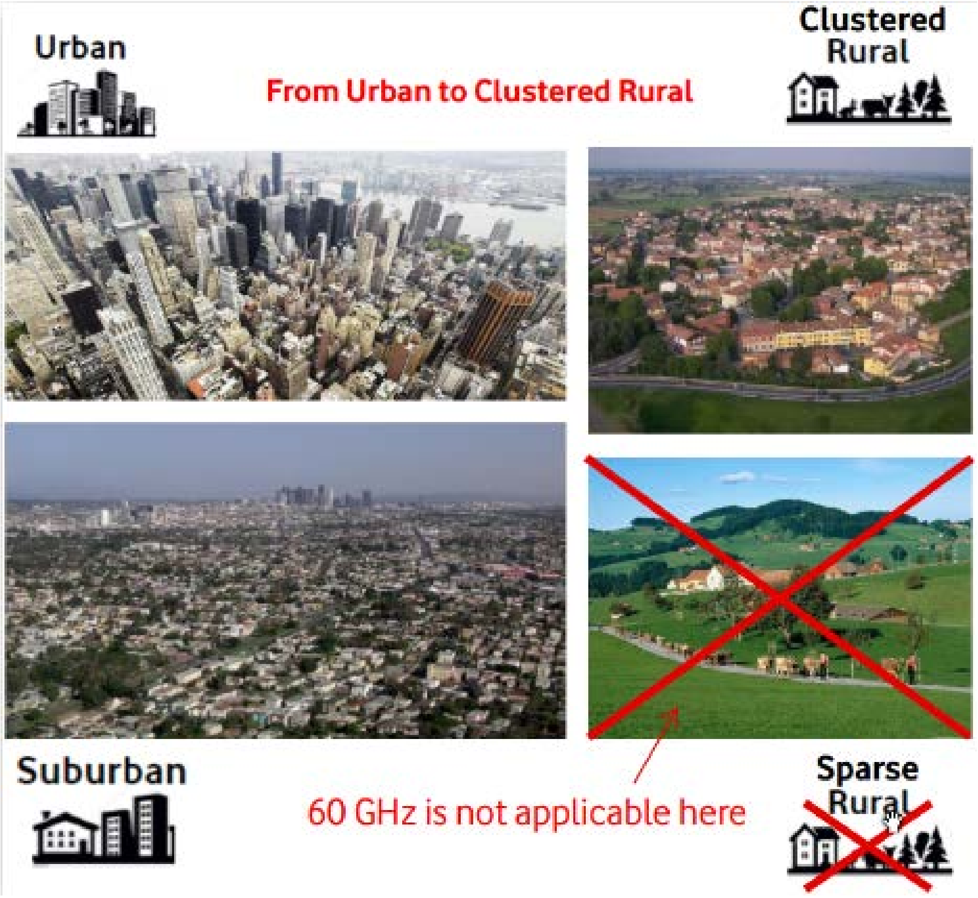

Figure 64: Applicable scenarios

Regarding the possible deployment cases an example for the urban and sub-urban scenarios is reported in Figure 65.

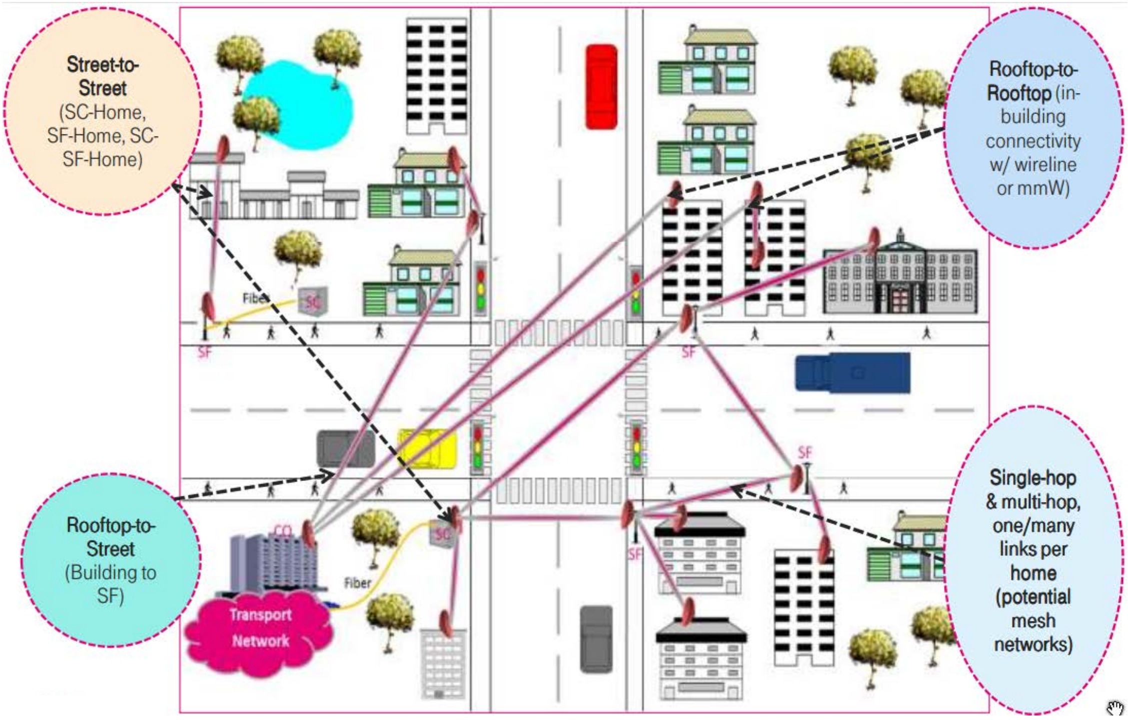

Figure 65: FWA urban and sub-urban deployment

ANNEX 3: CONSTANT PFD AREA EVALUATION UNDER DIFFERENT E.I.R.P. LIMITATION APPROACHES

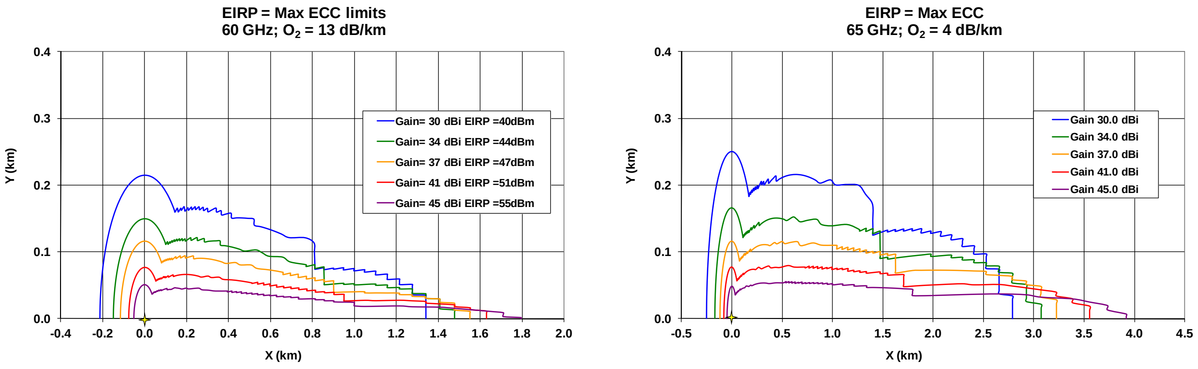

Figure 66: Constant target PFD area contour (ECC Rec (09) 01 only i.e. 55 dBm e.i.r.p.)

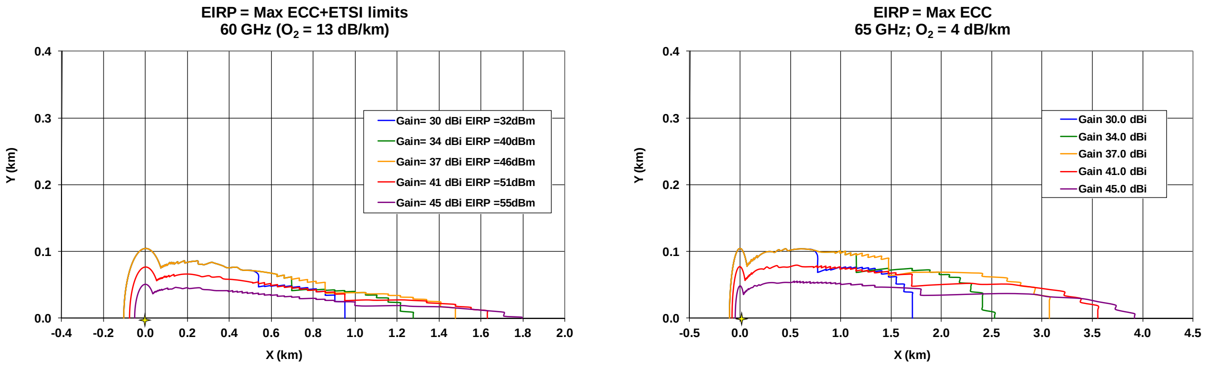

Figure 67: Constant target PFD area contour (ECC (09) 01 + slope of 2dB/dBi e.i.r.p.limitations)

In the above comparison, antenna radiation pattern given in Recommendation ITU-R F.699 was used.

ANNEX 4: LIST OF REFERENCES

[1] IEEE 802.11 -2015/0625r5 July 2017: "IEEE 802.11 TGay Use Cases"

[2] IEEE 802.11ad 2016: “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band”.Reference one (style: reference)

[3] International Workshop on Systems, Signal Processing and their Applications (WoSSPA) 2013 8th, Algiers, 2013, pp. 521-525: M. Zaaimia, R. Touhami, A. Hamza and M. C. E. Yagoub, "Design and performance evaluation of 802.11ad phys in 60 GHz multipath fading channel".

[4] ETSI Harmonised Standard EN 302 217-2 V3.1.1 (2017-05): “Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2: Digital systems operating in frequency bands from 1 GHz to 86 GHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”.

[5] Recommendation ITU-R F.699: “Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 86 GHz”

[6] ECC Report 173: “Fixed Service in Europe Current use and future trends post 2011”

[7] ETSI ISG mWT GS mWT 004 V1.1.1 (2016-06): “Millimetre Wave Transmission (mWT); V-band street level interference analysis”

[8] ERC Recommendation 70-03: “Relating to the use of Short Range Devices (SRD)”, 19 May 2017

[9] ETSI Harmonised Standard EN 302 567 V2.1.1 (2017-07): “Multiple-Gigabit/s radio equipment operating in the 60 GHz band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”

[10] European Commission, Broadband strategy & policy, https://ec.europa.eu/digital-single-market/en/broadband-strategy-policy

[11] G. Hattab, E. Visotsky, M. Cudak and A. Ghosh, "Coexistence of 5G mmWave Users with Incumbent Fixed Stations over 70 and 80 GHz," 2017 IEEE Globecom Workshops (GC Wkshps), Singapore, 2017, pp. 1-5.

[12] ECC Recommendation (09)01: “Use of the 57-64 GHz Frequency Band for Point-To-Point Fixed Wireless Systems”, January 2009

[13] 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)”, May 2009

[14] ETSI Harmonised Standard 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", July 2009

[15] Rohde & Schwarz, “802.11ad – WLAN at 60 GHz. A technology introduction white paper”, November 2017

[16] ETSI Harmonised Standard EN 302 217-4-2 (V2.0.3): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-2: Antennas; Harmonised EN covering the essential requirements of article 3.2 of the R&TTE Directive", June 2016.

[17] 3GPP Technical Report 38.901: “Study on channel model for frequencies from 0.5 to 100 GHz (Release 14),” May 2017.

[18] ECC Report 176: “The impact of non-specific SRDs on radio services in the band 57–66 GHz”

[19] TR 102 555: “Technical characteristics of multiple gigabit wireless systems in the 60 GHz range System Reference Document”

[20] ECC Report 113: “Compatibility studies around 63 GHz between Intelligent Transport Systems (ITS) and other systems”

[21] 2013/752/EU: “Commission Implementing Decision of 11 December 2013 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2005/928/EC”

[22] ECC Recommendation (05)02: “Use of the 64-66 GHz frequency band for Fixed Service”

[23] CEPT Roadmap for 5G https://cept.org/ecc/topics/spectrum-for-wireless-broadband-5g

[24] Recommendation ITU-R P.452-12, " Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz"

[25] IST-4-027756 WINNER II D1.1.2 V1.2WINNER WINNER II Channel Models

[26] ITU-R Recommendation F.1497-2, Radio-frequency channel arrangements for fixed wireless systems operating in the band 55.78-66 GHz

[27] ECC Report 173: “Fixed Service in Europe Current use and future trends post 2016”