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3D RayTracing Interference Analysis in V-Band

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Intellectual Property Rights

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Foreword

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

Modal verbs terminology

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

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Executive summary

The simulation results, reported in the present document, upon the Mesh network model for FWA, provide a positive feedback to deploy this outdoor application in V-Band.

It is shown that it is possible to run a network with only one frequency channel with high throughput (1,6 Gbps per link and a total 6,6 Gbps when the traffic generated from four equipment reach the fibre point of presence) and relative small delay (The performance is reached when the last link capacity is not exceeded.).

Further simulations show that high density networks can be deployed at low interference level by using steerable antenna and that on a Manhattan Grid topology the interference level experienced by using fixed beam antenna or steerable antenna is practical the same.

It has been shown that FWA links operating in V-Band can coexist well by using the same frequency channel (i.e. reuse-1) provided proper timing synchronization, assignment of TX/RX roles and working TPC.

In addition, also outdoor coexistence studies between FWA and FS applications are presented and collocated FWA links affect FS links in relatively small percent of cases (mostly below 10 %).

Exclusion zones for FS links are meaningless for street level deployments since reflections from interfering signal outside of the exclusion zone can bring interfering signal back to the receiver.

It is also confirmed that mmWV distribution network STAs do not harm indoor operation.

Finally, it is shown that LBT can guaranteed good performance in term of Average Transmit Capacity by allowing fair spectrum usage too.

Introduction

V-Band communication links are foreseen to be used for both access and transport applications.

Access applications, which are the main subject of the present document, include street level connectivity, urban/suburban fixed broadband residential access and business connectivity.

They are widely known as Fixed Wireless Access (FWA).

Transport applications include connecting devices such as Wi-Fi access-point and smart-city sensor.

These applications are compatible with V-Band equipment short range and small foot print characteristics used for FWA, which make street level installations using either P2P or P2MP topology possible.

V-Band equipment may also be used in rooftop to street connectivity, for access applications and as a feeding point for street-level chains.

The links range using beam-steering antennas is limited due to their relatively low gain to about 200 m (typical), and is additionally restricted by the availability of clear line-of-sight [i.2]. Link operation is strongly protected from interference by line-of-sight blockage (typically by structures and foliage) and by Oxygen absorption which reaches at maximum 15 dB/km in the band (around 59 GHz).

There are also secondary protection mechanisms such as the antenna spatial filtering, i.e. the low transmit power spread across wide bandwidth, leading to low spectral power density and robust modulation schemes typically being used.

NOTE: To circumvent residual interference and enhance operation reliability, sharing algorithms such as dynamic frequency selection (DFS) and listen before talk (LBT) medium access protocols may be deployed but are not object of the present document.

1 Scope

The present document presents results of an interference analysis, carried on parts of a real city scenarios, supported by a 3D ray tracing SW tool.

Also, network capacity, delay and LBT performance evaluations are provided for specific simulation cases.

A focus has been put on the new usage model called "mmWave Distribution Network", also known as "Mesh Network", as recently proposed by IEEE 802.11 [i.1] in July 2017.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

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

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

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

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

NOTE: Available at https://mentor.ieee.org/802.11/dcn/15/11-15-0625-07-00ay-ieee-802-11-tgay-usage-scenarios.pptx.

[i.2] CEPT ECC SRD/MG SRDMG(17)062 19 April 2017: "60 GHz considerations for discussion" (Huawei contribution).

[i.3] IEEE 802.11ad™-2016: "IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements-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".

[i.4] 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", International Workshop on Systems, Signal Processing and their Applications (WoSSPA) 2013 8th Algiers, pp. 521-525.

[i.5] ETSI EN 302 217-2 (V3.1.1) (05-2017): "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".

[i.6] Recommendation ITU-R F.699-7 (04-2006): "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 70 GHz".

[i.7] CEPT ECC ERC Report 173: "Fixed Service in Europe Current use and future trends post 2011" and revisions.

[i.8] ETSI GS mWT 004 (V1.1.1) (06-2016): "Millimetre Wave Transmission (mWT); V-band street level interference analysis".

[i.9] CEPT ECC ERC Recommendation 70-03 : "Relating to the use of Short Range Devices (SRD)".

[i.10] ETSI EN 302 567 (V2.1.1) (07-2017): "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".

[i.11] European Commission, Broadband strategy & policy.

NOTE: Available at https://ec.europa.eu/digital-single-market/en/broadband-strategy-policy.

[i.12] IEEE P802.11 - Task Group ay - Meeting Update.

NOTE: Available at http://www.ieee802.org/11/Reports/tgay_update.htm.

3 Abbreviations

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

A-BFT	Association Beam-Forming Training
AG	Aktiengesellschaft

NOTE: German: Stock Corporation.

AP	Access Point
ATPC	Automatic Transmission Power Control
BER	Bit Error Ratio
BF	Beam Forming
BI	Beacon Interval
BS	Base Station
BTI	Beacon Transmission Interval
BW	BandWidth
CBAP	Contention-Based Access Period
CCA	Clear Channel Assessment
CDF	Cumulative Distribution Function
CN	Client Node
DFS	Dynamic Frequency Selection
DL	Down Link
DN	Distribution Node
DOA	Direction Of Arrival
DOD	Direction Of Departure
DTI	Data Transfer Interval
eCCA	extended Clear Channel Assessment
ED	Energy Detection (threshold)
EIRP	Effective Isotropic Radiated Power
FBR	Front to Back Ratio (antenna parameter)
FCC	Federal Communication Commission
FS	Fixed Service
FWA	Fixed Wireless Access
HPBW	Half Power Beam Width
I	Interference (i.e. interference signal both single or aggregate)
IAP	Interferer Access Point
LBT	Listen Before Talk
LOS	Line Of Sight
MAC	Medium Access Control (Layer)
MCS	Modulation and Coding Scheme
MDU	Multi-Dwelling Unit
mmWV	millimetre WaVe
MP	Multi-Point
MPDU	MAC Protocol Data Unit
NF	Noise Figure
NFD	Net Filter Discrimination
NLOS	Non-Line Of Sight

P2MP	Point to Multi-Point
P2P	Point to Point
PD	Power Detection (threshold)
PEC	Perfect Electromagnetic Conductor
PHY	Physical
PMP	Point-Multi-Point
POP	Point Of Presence
PtMP	Point to Multi-Point
PtP	Point to Point
QPSK	Quadrature Phase-Shift Keying
RF	Radio Frequency
RPE	Radiation Pattern Envelope
RT	Remote Terminal
RX	Receiver
S	Signal (i.e. wanted signal)
S/I	Signal to Interference ratio
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
SP	Service Period
SRD	Short Range Device
STA	STAtion (node)
SW	Software
TD	Threshold Degradation
TDD	Time Division Duplex
TPC	Transmission Power Control
TRN-T/R	Transmit or Receive Training
TS	Time Slot
TX	Transmitter
U	Number of interference links
UL	Up Link
WiGig™	Wireless Gigabit Alliance

4 System model for 3D RayTracing simulations

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

Two kinds of nodes, provided with steerable antenna, have been defined AP (Access Point) and RT (Remote Terminal). 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 EIRP value is fixed at 40 dBm as maximum value allowed by CEPT in Europe and FCC for non-fixed P2P application in USA.

NOTE: At current moment only for indoor application and for non-fixed outdoor application.

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

Only in clause 6 a 2D geometric interference analysis has been performed.

Table 1: Main system characteristics

Parameters	Value
EIRP	40 dBm
TX power level	17,5 dBm
Noise figure	7 dB
Bandwidth	2 160 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) [i.3]
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 A.1)

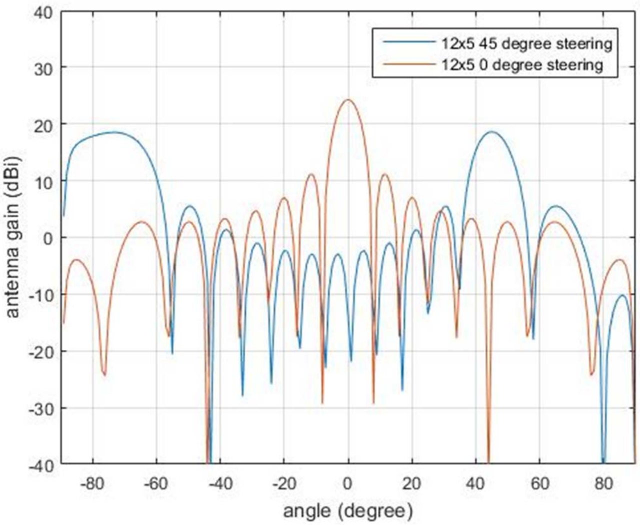


Figure 1: Antenna RPE diagram at 0° (boresight) and 45° pointing directions

5 3D RayTracing interference analysis

5.1 Washington simulation scenario

5.1.1 Simulation cases

The considered area is a portion of Washington D.C. (USA), a typical dense urban clutter (Figure 2). The green square is the actual map available for the simulation tool but, due to symmetry of the topology and buildings shielding, only the yellow sector has been analysed in detail.

Equipment with antennas are placed at height ranging from 3 m to 5 m.

Two simulation cases have been considered:

- Mesh network.
- Linear network topologies, to consider street canyoning.

Figure 2: Washington D.C. considered sector

5.1.2 Mesh network topology at street level

In Figure 3 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 out 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 present document.

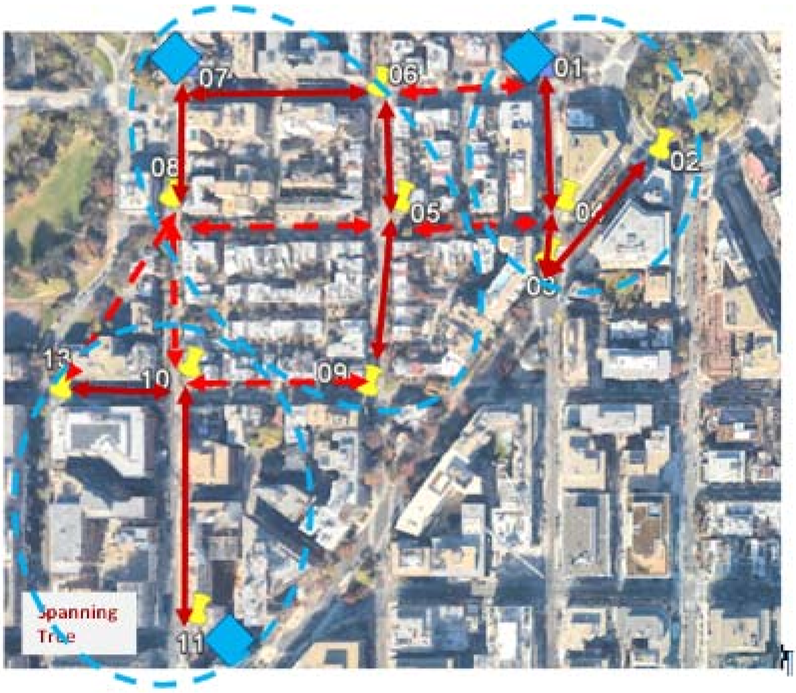


Figure 3: Specific portion analysed

5.1.3 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 2: One single channel used

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP02	AP03	140	22,6	18,4	22,6
AP10	AP11	221	4,88	9,07	9,07
AP08	AP07	118	21,5	21,6	21,6
AP09	AP05	167	13,1	10,1	14,3
AP06	AP05	105	20,1	19,6	24,3
AP06	AP07	161	8,28	12,5	12,5
AP01	AP04	120	9,94	11,7	14,1
AP03	AP04	51,6	13	14,1	18,3
AP10	AP13	117	19,1	15	19,1

Table 3: Two RF channels used

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP02	AP03	140	22,6	22,5	22,6
AP10	AP11	221	9,07	9,07	9,07
AP08	AP07	118	21,5	21,6	21,6
AP09	AP05	167	14,2	14,2	14,3
AP06	AP05	105	24,2	24,2	24,3
AP06	AP07	161	12,4	12,5	12,5
AP01	AP04	120	14,1	14,1	14,1
AP03	AP04	51,6	18,2	18,2	18,3
AP10	AP13	117	19,1	15	19,1

Table 2 and Table 3 show that the availability of a single channel in the network is enough 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.

5.1.4 Street to roof network topology

In this simulation scenario (Figure 4 and Figure 5) 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). Antenna vertical HPBW characteristic only 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 realized by a partial reflecting material (concrete) or by a perfectly reflecting one.

Figure 4: Simulation scenario

Figure 5: Antenna Vertical HPBW

Table 4 is showing 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 Line of Sight 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.

Table 4: 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 5 shows the results when perfect reflective (PEC) material is used in simulation. The figures for links, where the LOS condition is met, does not change significantly with respect to the previous case. Instead for one NLOS links reflection becomes prevalent over diffraction and the SINR improve. In this condition the link AP07-RT10 can operate.

Table 5: 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

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

5.1.5 Additional WiGig interferers

A further simulation has been done by adding three WiGig interferers (IAP 1, 2 and 3) in 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.

IAP equipment characteristics:

- TX power: 23,5 dBm
- Antenna gain: 13 dBi
- Horizontal HPBW: ~90°
- Vertical HPBW: ~10°

Table 5 shows that addition of such elements produces negligible (around 0,2 dB) or no SINR changes.

Table 6: AP/Node to/from RT, Concrete Buildings and Concrete Street, Interference AP (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

5.1.6 Long street paths

This simulation has been specifically addressed to study the behaviour of network over long straight directions (long streets). Two main cases, Mode 1 (in-phase transmission) and Mode 2 (alternate transmission) configurations (Figure 6 and Figure 7), in three specific conditions have been studied:

- Equipment (AP) located at same height (3 m) from road level and same side of street.
- Equipment (AP) at different levels (3 m and 5 m) from road floor and same side of street.
- Equipment (AP) located at same height (3 m) from road floor and geometrically alternated along both sides of street ("zigzag").

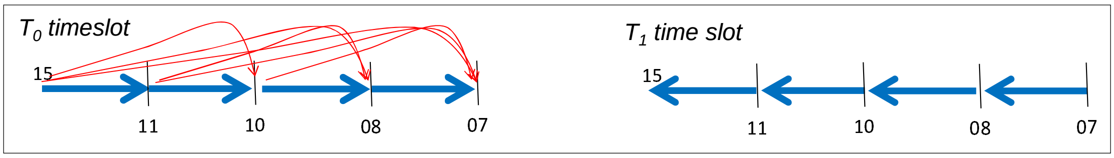


Figure 6: Mode 1 in-phase transmission configuration

Table 7: Mode 1 Simulation Results

A: Line Topology (Mode 1) (all 3 meter height) - APs at the same side

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8		4,88	13,2	17,4
AP8	AP10		5,19	7,21	19
AP10	AP11 (POP)		6,59	5,86	19,6
AP11 (POP)	AP15		12,7	3.23	16,9

B: Line Topology (Mode 1) Vertical Variation (3, 5, 3, 5 & 3) m - APs at the same side

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8		4,66	12,8	17
AP8	AP10		5,18	6,93	18,5
AP10	AP11 (POP)		6,35	5,83	19,2
AP11 (POP)	AP15		12,3	3,05	16,5

C: Line Topology (Mode 1) (all 3 meter height) geometrically alternated along both sides of the street

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8		12,9	17	21,2
AP8	AP10		9,98	10,47	17,7
AP10	AP11 (POP)		12,4	16,6	25,1
AP11 (POP)	AP15		11,6	2,98	15,8

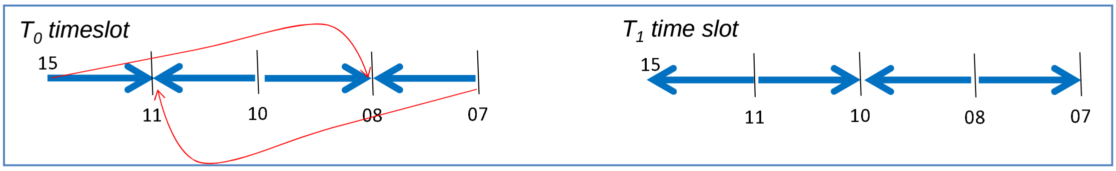


Figure 7: Mode 2 alternate transmission configuration

Table 8: Mode 2 Simulation Results

A: Line Topology (Mode 2) (all 3 meter height) - APs at the same side

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8 (POP)		10,9	17,4	17,4
AP8 (POP)	AP10		19	12,3	19
AP10	AP11 (POP)		19,6	13,1	19,6
AP11 (POP)	AP15		10,2	16,9	16,9

B: Line Topology (Mode 2) Vertical Variation (3, 5, 3, 5 & 3) m - APs at the same side

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8 (POP)		10,6	17	17
AP8 (POP)	AP10		18,5	12,2	18,5
AP10	AP11 (POP)		19,1	12,8	19,2
AP11 (POP)	AP15		9,96	16,5	16,5

C: Line Topology (Mode 2) (all 3 meter height) geometrically alternated along both sides of the street

AP	AP	Length [m]	SINR_DL [dB]	SINR_UL [dB]	SNR [dB]
AP7	AP8 (POP)		15,5	21,2	21,2
AP8 (POP)	AP10		17,7	13,8	17,7
AP10	AP11 (POP)		25,1	19,5	25,1
AP11 (POP)	AP15		11,8	15,7	15,8

Mode 2 grants from 6 and 7 dB higher SINR than Mode 1, showing that the choice of transmission system along the path can play a significant role in the overall performance. In line with this consideration, topology realized using consecutive crossing-road connections ("zigzag" topology) provides a further 3 dB increase of SINR in both modes.

Installations using nodes with equal heights from the road levels (3 m and 5 m) show negligible degradation in SNR due to the small reduction of the RX power, since no vertical steering is applied.

5.2 Shanghai, China simulation scenario

5.2.1 Roof-to-roof

In the Shanghai area (Figure 8) a simulation has been accomplished based on a roof to roof network configuration shown in Figure 9.

Figure 8: Shanghai area considered in simulations

Figure 9: Roof-to-Roof Configuration

Interference analysis assuming equipment characteristics of a real 60 GHz P2P equipment was accomplished, followed by a simulation assuming a WiGig™ based equipment.

P2P equipment characteristics:

- Duplex mode: TDD
- Frequency: 60 875 MHz
- Bandwidth: 2 000 MHz
- Polarization: Horizontal
- TX power: 5,5 dBm

- Antenna gain (TX/RX): 34,5 dBi
- HPBW: 1,9°

P2MP equipment characteristics:

- Duplex mode: TDD
- Frequency: 60 875 MHz
- Bandwidth: 2 000 MHz
- Polarization: Horizontal
- TX power: 24 dBm
- Antenna gain (TX/RX): 16 dBi
- HPBW: 15°

Table 9: Interference levels - roof to roof scenario

Victim Link(DL)	Interfering Link	RSL(dBm)	Interference (dBm)	RSL(dBm)	Interf. (dBm)	TD(dB)
		Point-to-point		Point-to-MP		
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
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

5.2.2 Nodal specific case

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

Two 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.

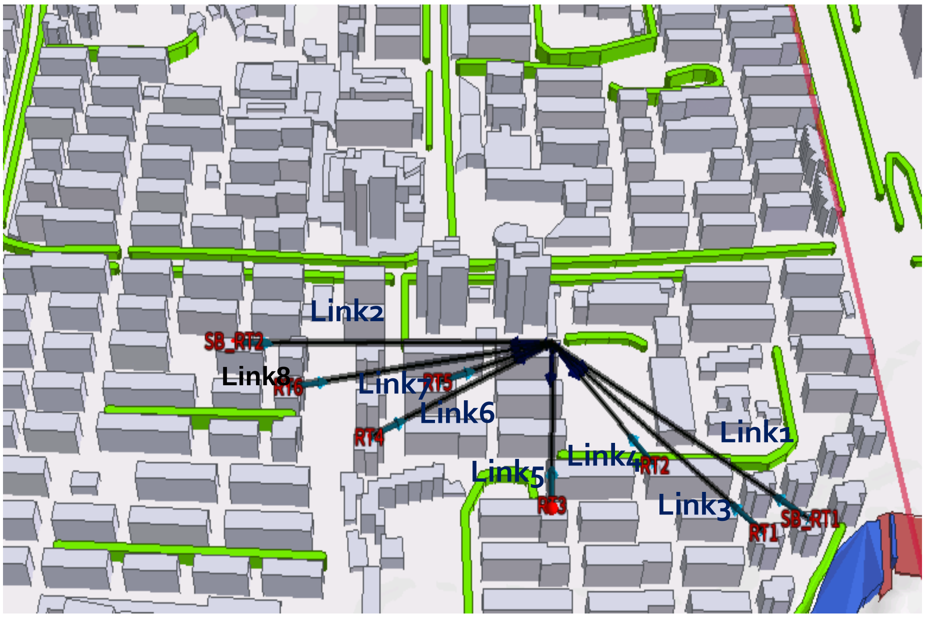


Figure 10: Nodal setup

Table 10 shows interference levels towards "self-backhaul" links during downlink and uplink and the Sensitivity threshold degradation (a single RF 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 type of antennas with negligible threshold degradation.

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

6 2D interference analysis

6.1 Rooftop deployment scenario simulation

The simulation model used in this clause is based on unplanned deployment where multiple uncoordinated sites are deployed using a license exempt spectrum management model. The deployment is based on the use of multiple P2MP beam-steering sectors, where each sector includes a single instance of P2MP beam-steering base-station (BS) with several beam-steering terminals.

NOTE: In this clause the term Base Station (BS) is used with the same meaning of Access Point (AP).

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 the link in the sector. Each interference scenario between any two links is described by angles and distances as shown in Figure 11.

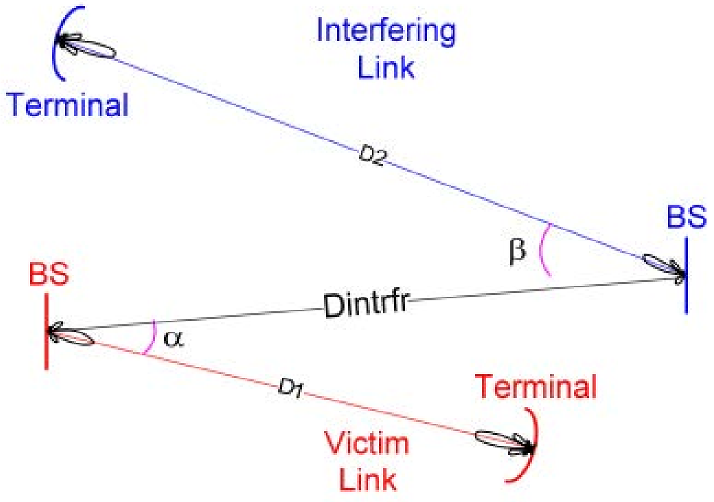


Figure 11: Interference scenario

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 it is assumed a certain terminal per base-station density, 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. 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 10 000 simulation trials. These results are visualized in a histogram with S/I bins from 0 dB to 20 dB. S/I values above ~4 dB are considered to operate with using robust modulations such as coded QPSK. An example of a simulation scenario is shown below, where the sector density is 40 base stations per square km and the area being analysed 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 and the red circles represent the terminals (i.e. RT). No coordination or ordering is used and the position of the base station is taken from a random uniform distribution over the simulation area while the position of the terminal is taken from a random uniform distribution in their respective base-station sector coverage area.

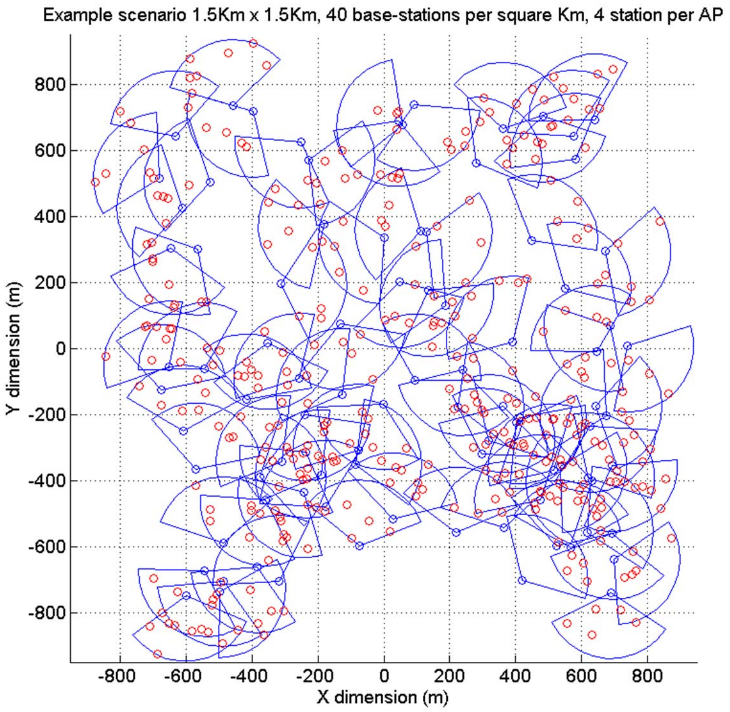


Figure 12: Scenario example

The next figures depict 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.
- The simulations include the deployment of a DFS mechanism.

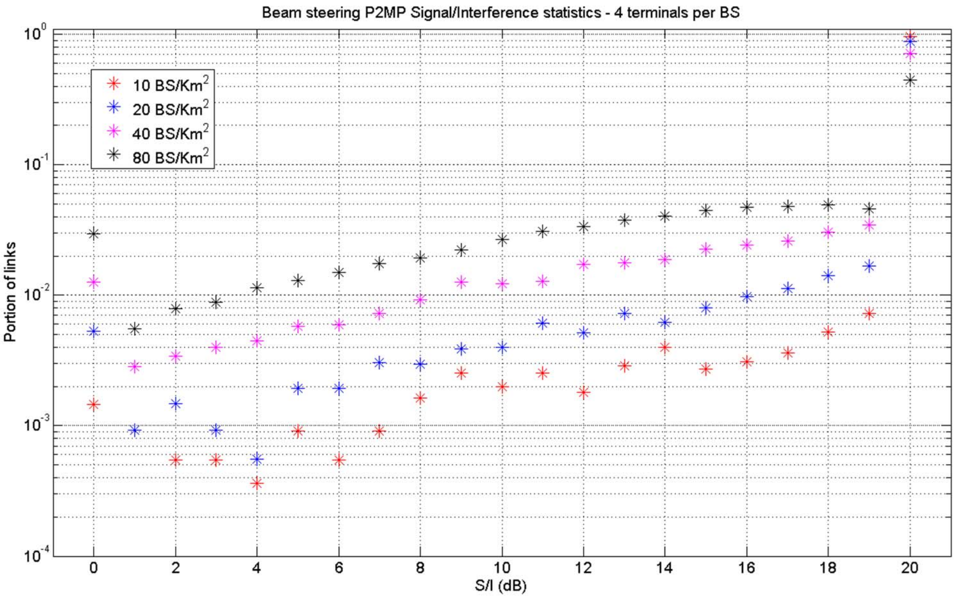


Figure 13: Fixed four terminals per base-station using two frequency channels

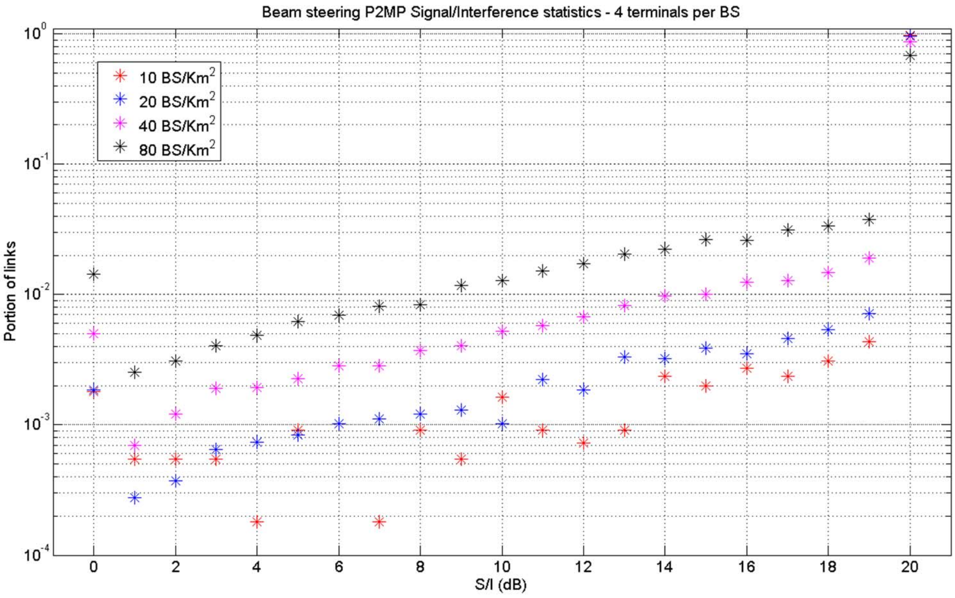


Figure 14: Fixed four terminals per base-station using four frequency channels

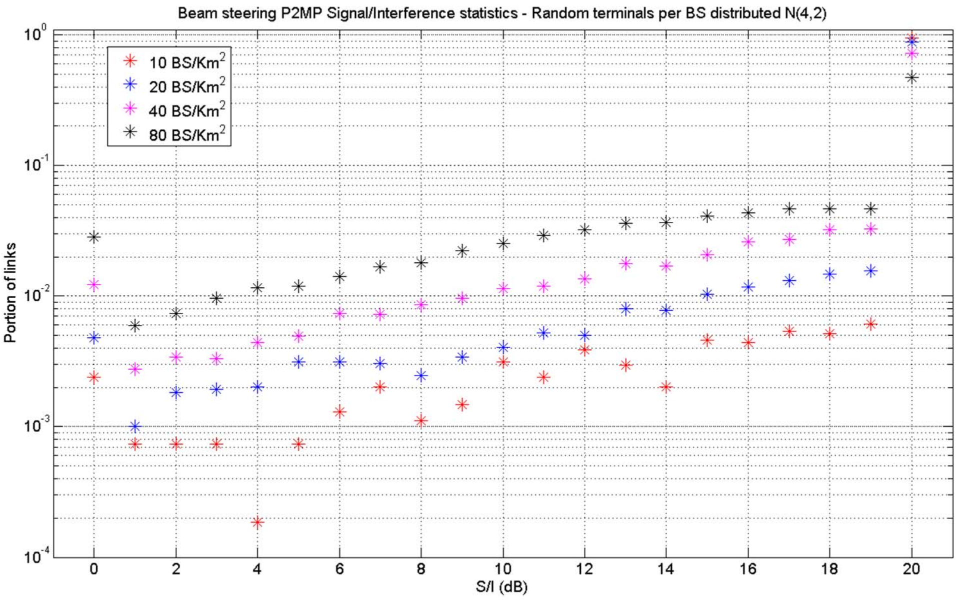


Figure 15: Random N(4,2) distributed number of terminals per base-station using two frequency channels

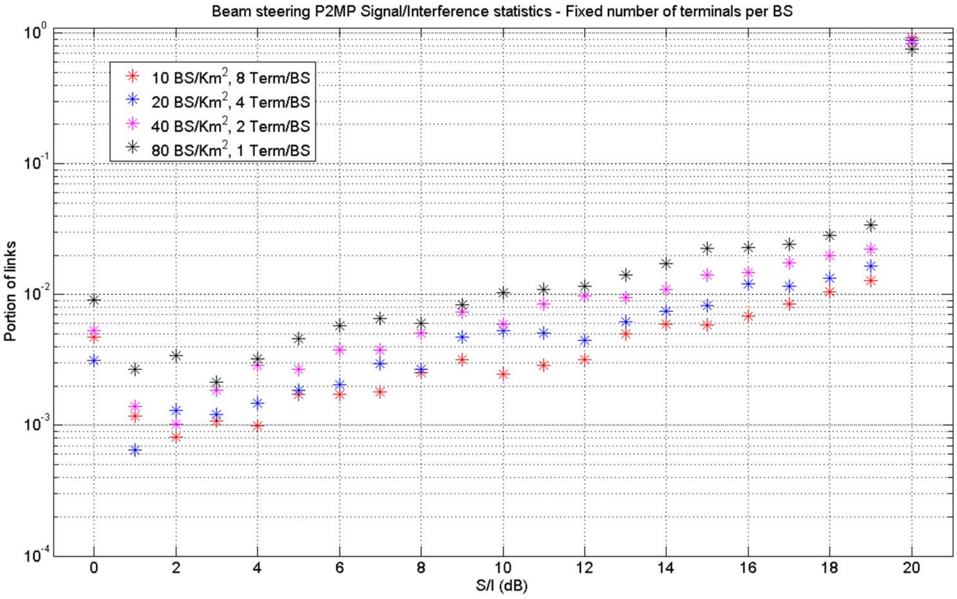


Figure 16: Fixed node density by adjusting terminal to base-station ratio using two frequency channels

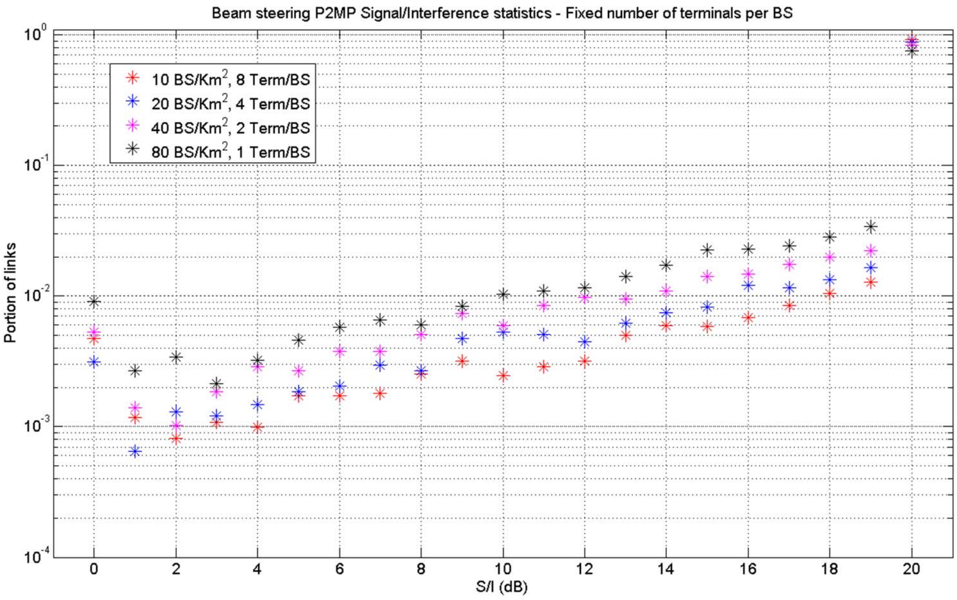


Figure 17: Fixed four terminals per base-station using two frequency channels and no TPC

The above results all demonstrate very robust performance in the view of the high densities and lack of any planning simulated. 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 expected that real life scenarios will provide even better results due factors not considered in this analysis such as obstacles to pure LOS propagation, such as rooftop height being non uniform across the deployment area and the foliage height often exceeding the rooftop height.

6.2 Street-level deployment scenario simulation

The street level deployment scenario assumes a Manhattan grid of buildings in which wireless links are deployed across the streets. In the specific scenario, the block size is 90 m and the street width is 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 m to 300 m. The distance between the interfering links to the interfered link also ranges from 20 m to 300 m. The simulation consists of generating 10 000 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 [i.5]. A graphical depiction of the simulation scenario is shown below, where the blue lines represent the victim link whereas the red lines represent the interfering link.

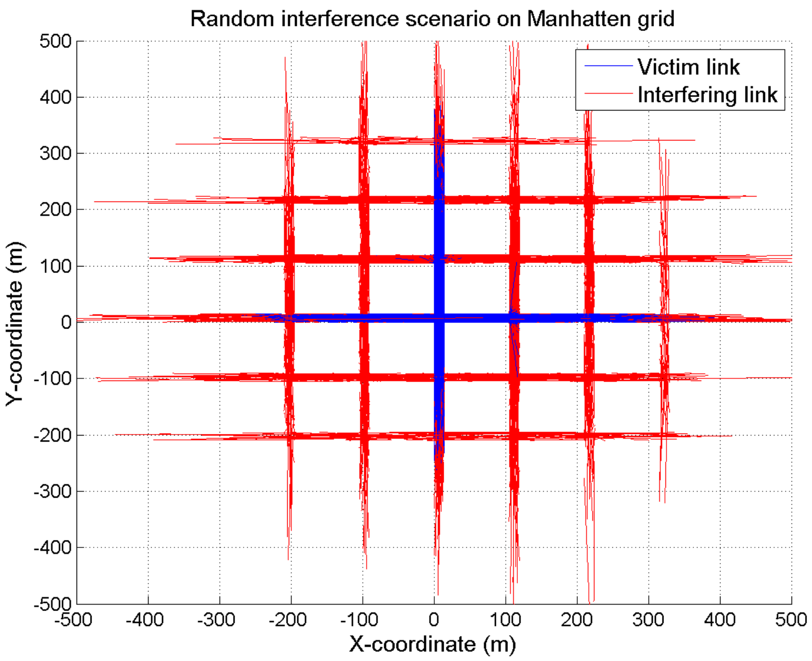


Figure 18: Street level interference scenario depiction

Figure 19 shows the simulated probability of interference shown when using a 30 dBi regular antenna with a radiation pattern envelope (RPE) conforming to Recommendation ITU-R F.699 [i.6]. No polarization discrimination is assumed. It shows that the interference probability is moderate within the same block but drops rapidly at more than one block distance.

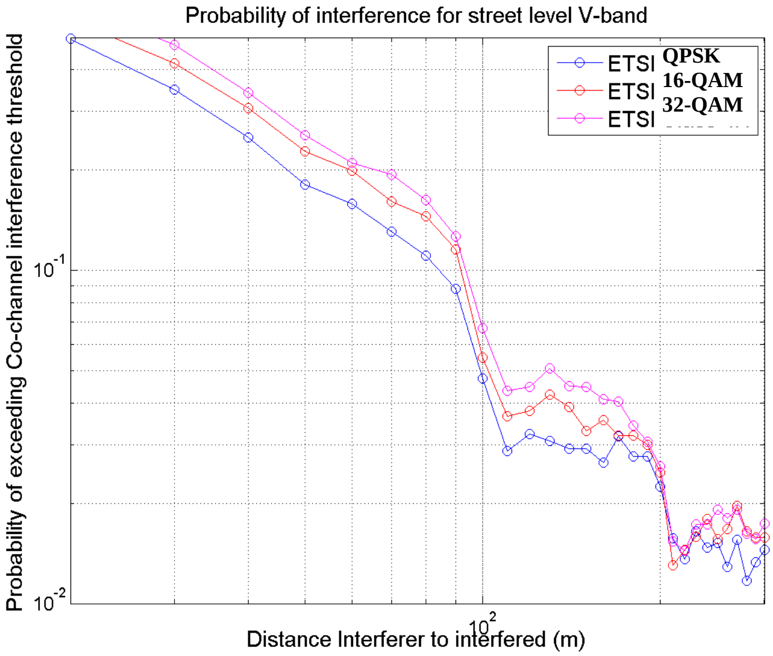


Figure 19: Regular antenna probability of interference as a function of interferer distance

The same simulation is repeated with the use of a beam-steering antenna and the result is shown in Figure 20.

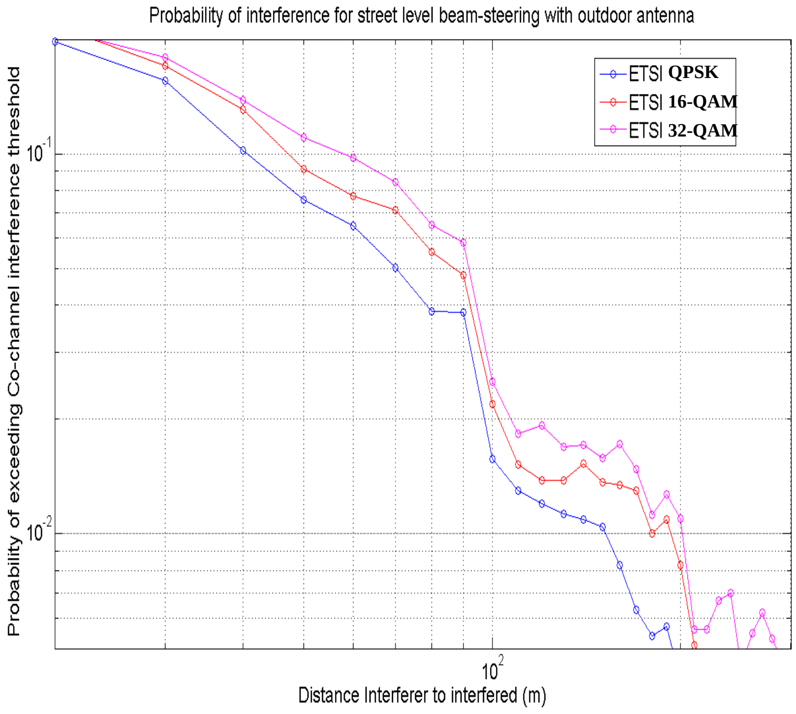


Figure 20: Beam-steering antenna probability of interference as a function of interferer distance

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. 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 3-D RayTracing Simulations of Outdoor Coexistence in V-band

7.1 Suitability of V-Band for FWA use case

7.1.1 Introduction

The Ray tracing simulation framework has also been used to study the impact of interference on FS when FWA systems are located outdoor. In this clause the topology provided by Facebook FWA prototype network deployment in San Jose USA has been used as basis for simulations.

The former simulation steps the performance of the FWA system, assuming full reuse of spectrum among all the links, has been simulated. In this way the suitability of V-band for Fixed Wireless Access use case has been checked.

In the latter simulation step the impact of FWA on performance of FS links when two systems coexist on the same channel in V-Band has been considered.

Currently according to ECC Report 173 [i.7] only three of hundred point to point Fixed Service (FS) links deployed in V-Band are counted in the whole of Europe.

7.1.2 San Jose simulation scenario

The network topology is composed by considering several multi-hops multi-point equipment deployed with several hundred nodes forming a mesh network.

In the simulation, nodes are time synchronized with a polarity assigned to determine which nodes transmit simultaneously, and to ensure that the interference to other nodes is minimized.

For the scope of the simulations a smaller subset of nodes has been simulated with respect to the whole topology of the field trial (Figure 21).

Figure 21: San Jose field trial topology

7.1.3 FWA link characteristics

The equipment antenna is based on a 36x16 array with 31dBi gain and the maximum average/peak EIRP of 40/43 dBm. PMP operation is enabled by electrically steering beams in the direction of desired receiver.

Links are mainly deployed primarily in LOS and nLOS with typical length less than 250 m.

The protocol PHY layer is based on IEEE 802.11ad [i.3] with the actual MCS 12 limited to 16QAM ¾ with max link throughput of 1,9 Gbps in uplink and 1,9 Gbps downlink by using single 2,16 GHz channel.

System performs automatic transmit power control (TPC) and MCS rate adaptation to minimize interference and compensate for variations in the propagation environment.

7.1.4 FWA C/I simulation results

To calculate the C/I results, it is assumed that the transmitter of a given link applies no TPC while all other transmitters in the system apply TPC to maximize the MCS on their links.

The probability of not meeting the MCS12 (16QAM ¾) C/I threshold of 18 dB is less than 5 % of cases.

Simulation is repeated by removing the foliage in the 3-D ray tracing propagation model which caused subset of transmitters to further reduce TX power and reduce co-channel interference.

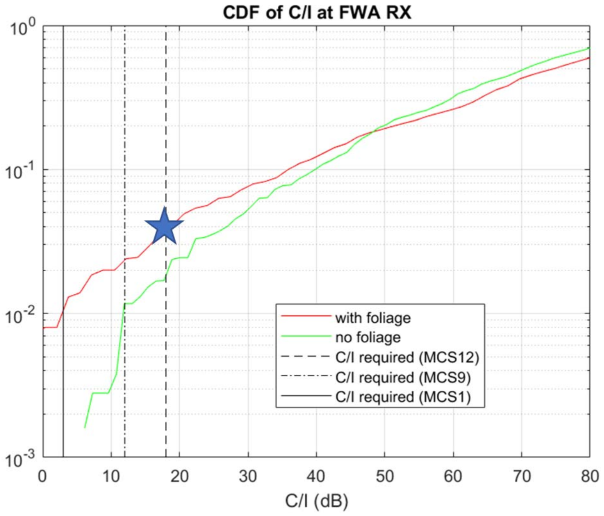


Figure 22: FWA C/I simulation results

7.2 Coexistence of FWA and Fixed Services (FS) in the V-band

7.2.1 Analysis

P2P links are based on highly directional antenna (according to [i.6] and [i.8]) and the channels occupy Nx50 MHz bandwidth (with N ranging from 1 to 40).

Typical FS links deployments are on building walls, lamp posts or roof tops with clear line of sight between the nodes.

The baseline throughput of 1 Gbps is assumed in this analysis (i.e. 64QAM over 200 MHz system configuration).

Larger throughput of up to 4 Gbps (e.g. 8PSK over 2 GHz BW) are also considered.

The target of this clause is to study the FWA impact to FS performance.

Limited bandwidth of the FS link (i.e. multiples of 50 MHz) reduces the impact of FWA for a given TX power (Table 11). However, smaller bandwidth FS link typically support higher MCS, which implies higher C/I requirements.

The C/I requirements in ETSI EN 302 217-3 [i.5] for FS link defines high C/I requirements for the FS links.

The FS links usually operate in full buffers thus this working model is assumed for both FS and FWA links in this analysis.

Table 11: Reduction in effective RX interference power at the FS for smaller bandwidths

BW [MHz]	Reduction Facto [dB]
50	-15,47
100	-12,46
200	-9,44
400	-6,43
800	-3,42
1 200	-1,66
1 600	-0,41
1 760	0,00

7.2.2 FS Exclusion zone analysis

To meet the C/I stipulated in ETSI EN 302 217-2 [i.5] for an FS link, it is possible to define an exclusion zone for placing any potential interferer (red trajectory in Figure 23).

While this guarantees interference free operation in free space propagation scenario, it is not sufficient protection in actual outdoor deployments especially in urban scenario where reflections may bring back some of interfering transmissions from outside of exclusion zone.

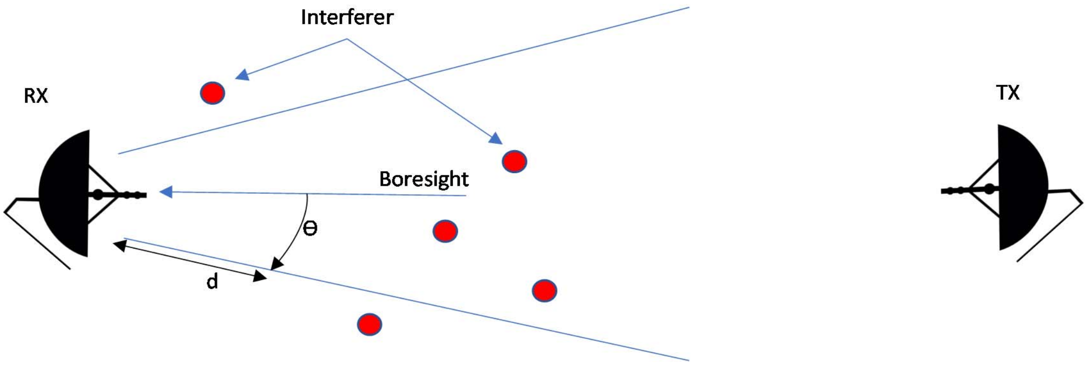


Figure 23: Exclusion zone for FS

The target degradation of existing FS links has been limited to max 3 dB of the SNR-BER performance in the presence of new FWA nodes. Assuming FS links are 200 m long, the FWA node has with EIRP of 40 dBm should be at least d distance away from the FS node, if it falls at the exclusion angle Θ (°) as shown in Figure 24.

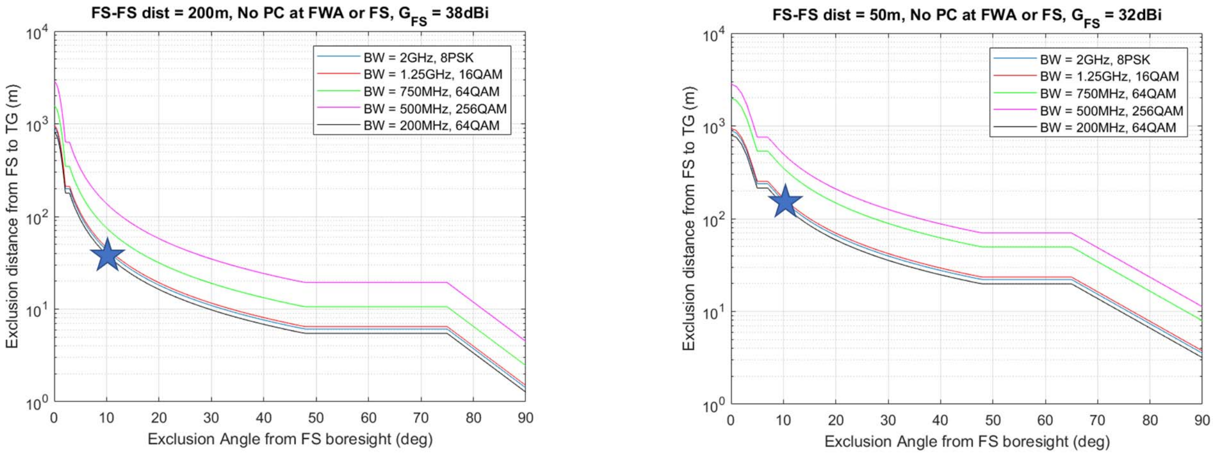


Figure 24: Exclusion angle and distance at FS

For example, for 10° exclusion angle range from boresight of FS node, the FWA nodes can be placed at a distance of 30 m and 150 m for FS antenna gain of 38 dBi and 32 dBi, respectively.

7.2.3 Statistical analysis

In this analysed scenario the FWA interferer positions have been randomized within a 200 m distance from the FS RX. The FS links distance has been fixed at 200 m, operating at max EIRP and FWA operates at max EIRP of 40 dBm.

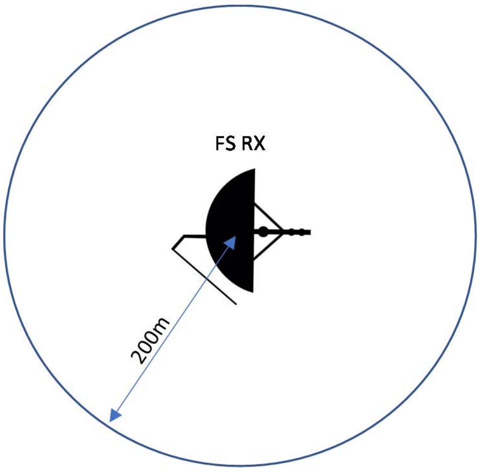


Figure 25: Statistical model scenario

FWA transmits over 2 GHz bandwidth instead the simulated FS bandwidths range with 2 GHz and 200 MHz.

FWA randomly points between ±45° from each of its antenna as it serves its own terminals.

The DOA into FS and DOD out of FWA are also randomized in the ranges [-180:180] and [-45:45], respectively.

Even in this analysis the target C/I corresponds to a 3 dB degradation and the deployment scenario is San Jose.

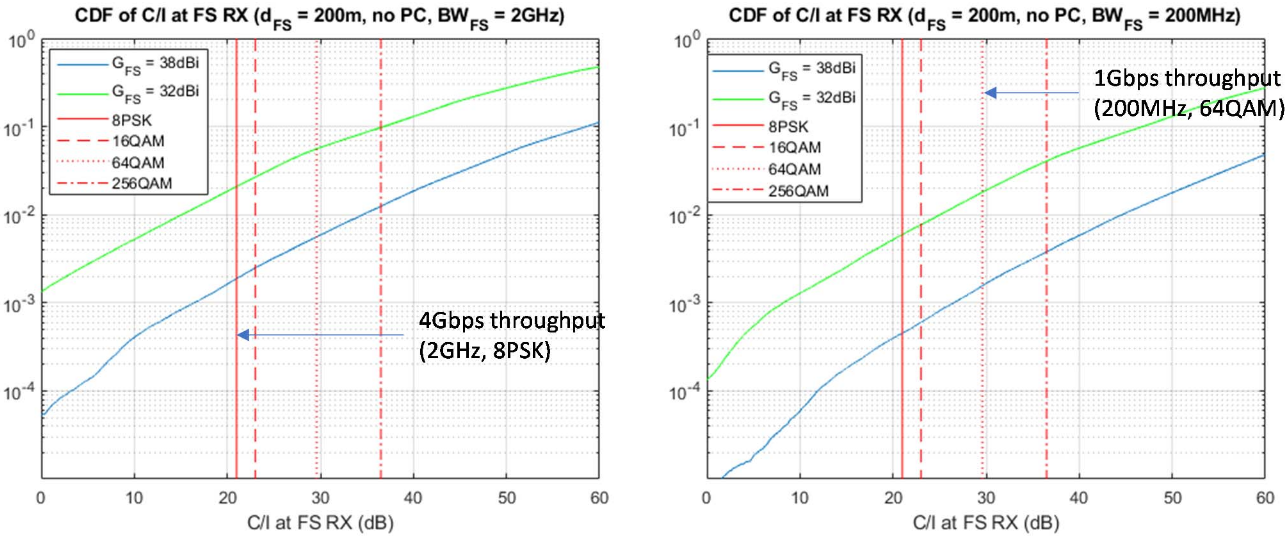


Figure 26: Statistical analysis results

C/I threshold for FS link not met in less than 10 % of cases

7.2.4 Section of San Jose deployment

7.2.4.1 Introduction

In this clause two scenarios are considered for studying FWA and FS coexistence always based on San Jose deployment.

- Scenario 1: random pointing of FWA nodes without any power control:
    - Sub scenario 1a: some FWA links have been replaced with FS links to ensure that FS and FWA nodes are not collocated on the same lamppost. Only FS links that span more than 100 m have been considered. All the other FWA nodes transmit at max EIRP and point their beams to random directions, as if there are additional CN nodes at random locations on street level, not included in the original topology. Finally, it is computed the FS C/I for each FS node pair chosen and for independent random beam-forming (BF) directions of the FWA nodes.
    - Sub scenario 1b: Short FS links, around 50 m, that span across the street are placed on building faces to study the building to building connection in the presence of FWA nodes. As in Scenario 1a, FWA randomly points beam at max EIRP.
- Scenario 2: beam pointing from FWA are directed only towards serving DN/CNs and power control is applied to meet the SNR requirement of the FWA link.

7.2.4.2 Scenario 1a

The same subsection of the San Jose deployment is taken as reference (Figure 21).

FS links are assumed to be in LOS (i.e. no foliage in its path).

FS throughput of 4 Gbps (2 GHz BW with 8PSK) can be met in 95 % and 85 % cases for 38 dBi and 32 dBi FS antenna gain, respectively.

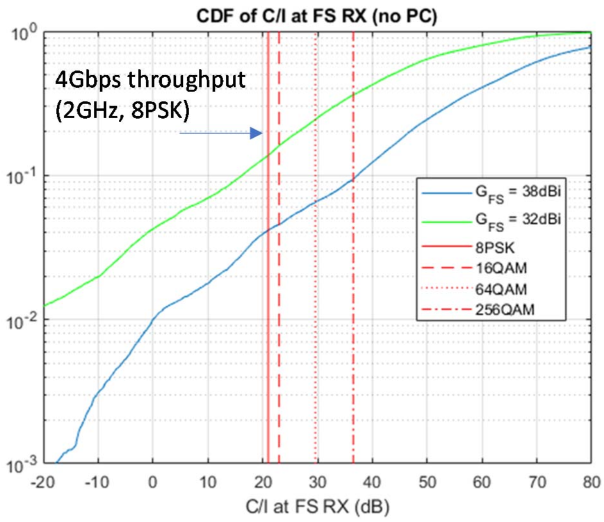


Figure 27: Scenario 1a results

7.2.4.3 Scenario 1b: FS links perpendicular to street

FS links, that are placed perpendicular to the streets, have better C/I due to the narrow beam-widths at the FS and the small distances (antenna protection).

Perpendicular links have much better coexistence properties in the presence of FWA which mostly span along the street.

Figure 28: FS link perpendicular to street

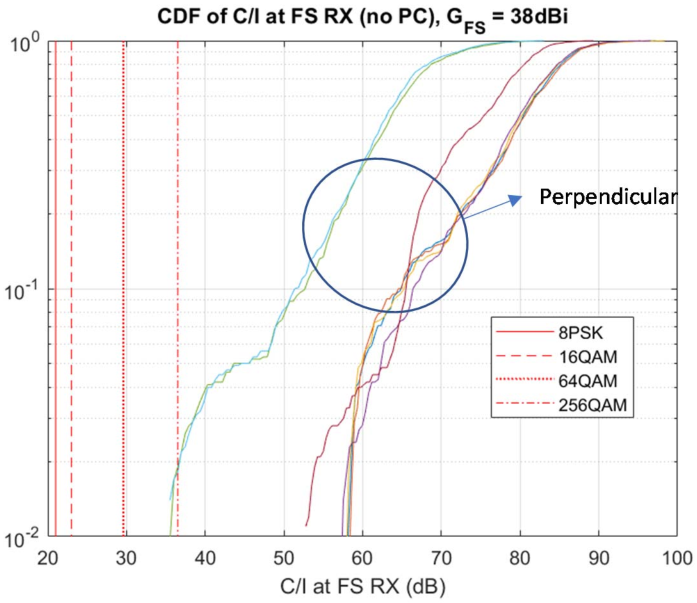


Figure 29: FS links perpendicular to street simulation results

7.2.4.4 Scenario 2: directed BF at FWA nodes

Additional client nodes (CNs) are placed on building walls every 20 m to increase node density relative to the existing topology.

Now DN beam-forming limited to serve only CNs and peer DNs has been simulated, instead of random beam-forming has evaluated in scenario 1 previously.

A TPC has been applied on FWA transmitters to meet the required SNR value.

A DN/CN polarity synchronization and TX/RX alternately have been modelled in the simulation model.

The network scheduler randomly serves DNs and CNs beams.

Various FWA antenna gain patterns are considered at both RX and TX for fixed EIRP of 40 dBm.

Table 12: FWA antenna profile VS antenna gain

Antenna Profile (#H x #V)	Antenna Gain [dBi]
36 x 16	31
18 x 8	25
10 x 4	20

Lower antenna profiles/gain have larger beam width thus TX antenna creates more interference to other links and RX antenna captures more interference from other links.

Reduced FWA RX gain also implies to use higher TPC TX power to meet the same SNR at the receiver and this causes higher interference to FS links.

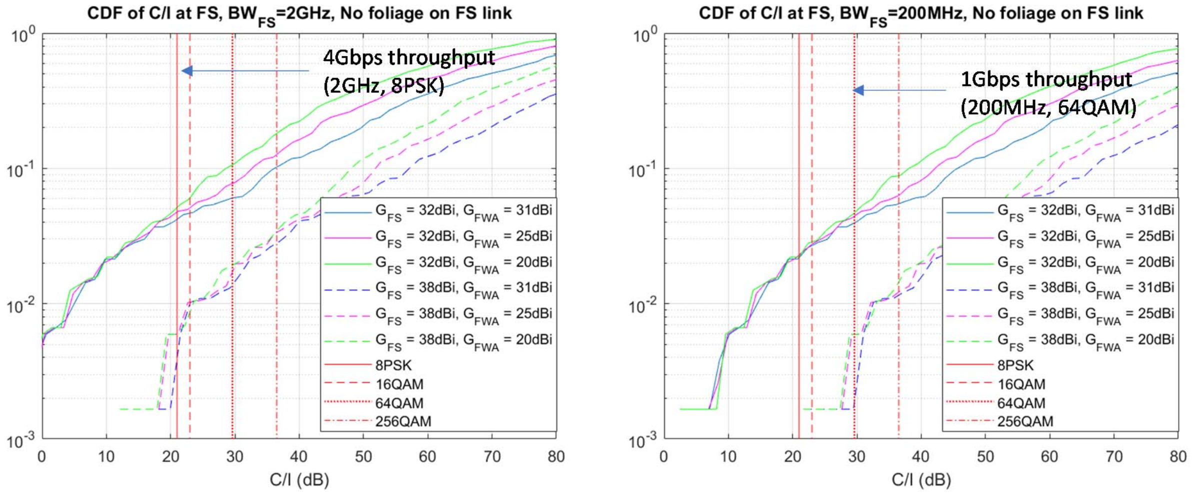


Figure 30: Directed BF at FWA nodes results

7.3 San Jose simulation conclusion

It has been demonstrated that FWA links operating in V-Band can coexist by using the same frequency channel (i.e. reuse-1) provided proper timing synchronization, assignment of TX/RX roles and working TPC.

Exclusion zones for FS links are meaningless for street level deployments since reflections from interfering signal outside of the exclusion zone can bring interfering signal back to the receiver.

Collocated FWA links affect the FS links in relatively small percent of cases (mostly bellow 10 %).

8 Distribution Networks and Short Range Devices Coexistence

8.1 Overview

In this clause the building penetration, i.e. outdoor-to-indoor, from Distribution Network to Indoor Short Range Devices (SRDs) is considered.

Two possible interference to indoor application scenarios have been simulated:

- Distribution Node (DN) to Client Node (CN) transmission.
- Client Node (CN) to Distribution Node (DN) transmission.

A typical topology of a mmWV distribution network is depicted in Figure 31.

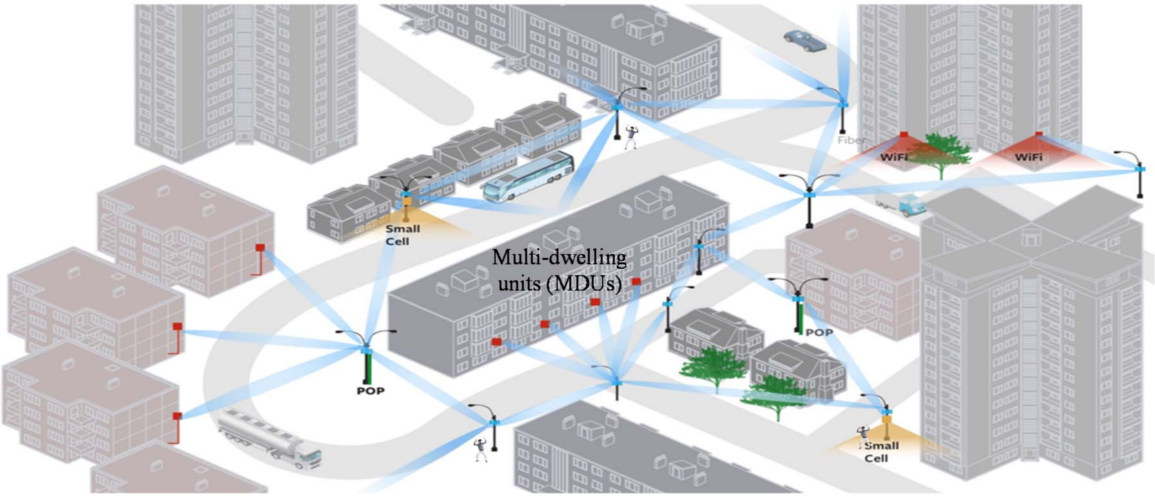


Figure 31: mmWV distribution network scenario

For the scope of the simulations the following assumptions have been taken:

- DN node typically serves from 8 to 16 CN nodes with time multiplex and no protocol limitation.
- The DN to CN link activity ranges from 6 to 12 % duty cycle.
- The target of the study is the potential interference to indoor SRDs behind the windows of a multi-dwelling unit.

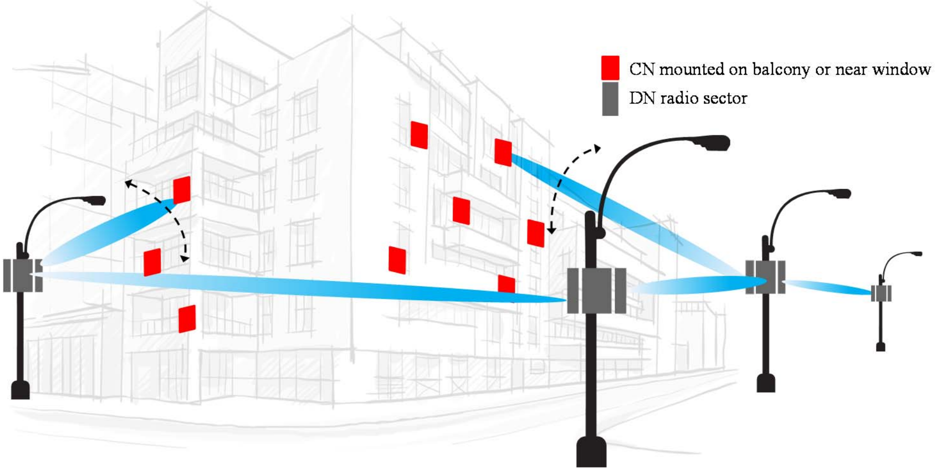


Figure 32: Multi Dwelling Unit detail

8.2 Outdoor to indoor penetration with DN to CN transmission

In the first scenario the DN node is transmitting to the CN node and it is the source of interference to an indoor SRD located in a room of a flat in a multi-dwelling unit.

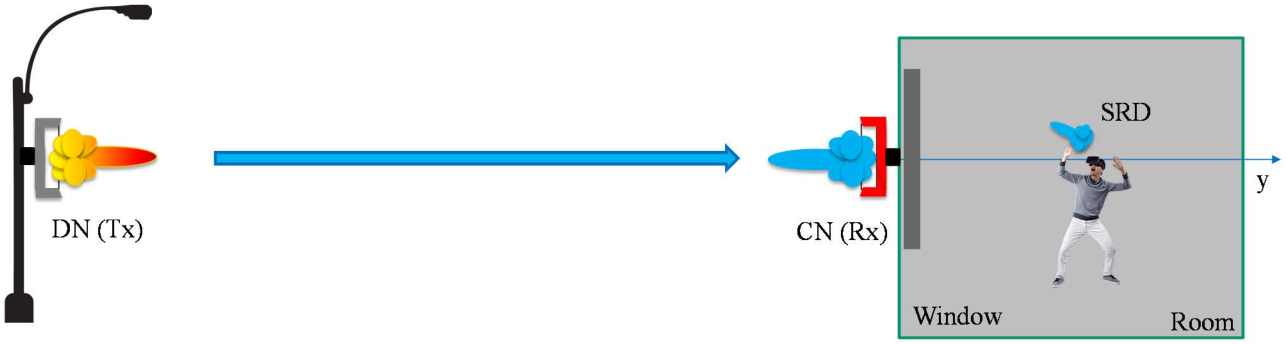


Figure 33: Distribution Node (DN) to Client Node (CN) transmission case

The reference target SNR for the CN node is 18 dB to match with the MCS 12 specified by IEEE 802.11ay (see update in [i.12]) (Annex A).

The DN transmitter applies active Transmit Power Control (TPC) to drive SNR target at CN receive.

The maximum interference level at indoor SRD is evaluated according to equation (1):

$$\max\{I\} < SNR\_targ - G\_rx + N - R + G\_srd < \mathbf{-87{,}6\ dBm} \qquad (1)$$

Where:

- G_rx: Receive array gain of CN (30 dBi).
- G_srd(α): front-to-back BF ratio plus box isolation of SRD (AP or STA), worst case none G_srd(0)= 0 dBi.
- R: In building penetration loss (worst case 3,6 dB when interferer perpendicular to single pane glass, safety glass 12 dB).
- N: thermal noise, -174 + 10 × log10 (1,76e9) + NF = -72 dBm.
- NF: Noise Figure, 10 dB has been considered.
- I: input referred interference signal level at victim SRD antenna.

The CCA threshold levels of the indoor SRD are:

- ED = -48 dBm.
- PD = -68 dBm.

Interference level below CCA thresholds has no impact to channel access for SRD devices.

The simulations results are shown in Figure 34 and Figure 35.

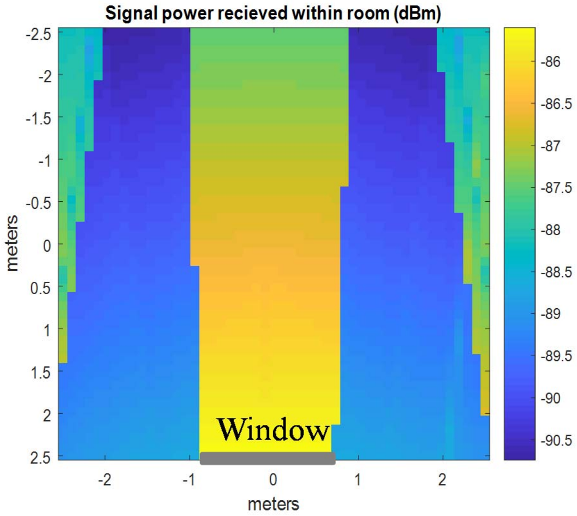


Figure 34: Interference power level within the room

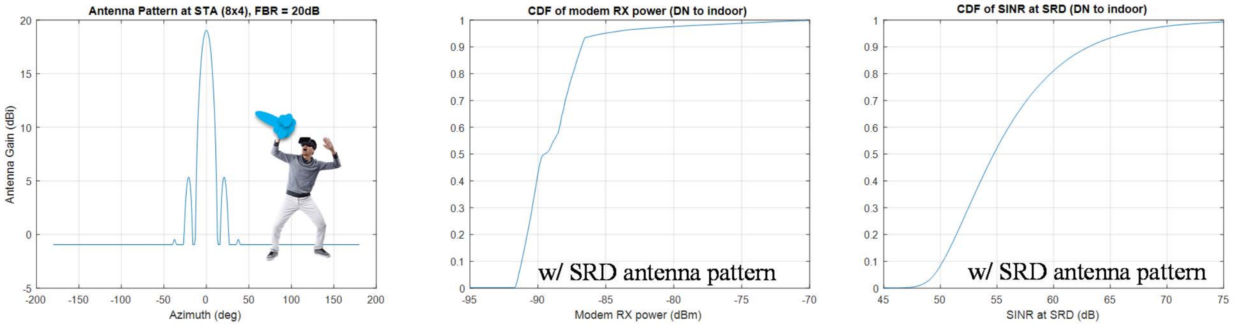


Figure 35: Antenna pattern, CDF of interference power level and CDF of the SINR of the indoor SRD

SRD CCA (i.e. -68 dBm) is not triggered anywhere within the room and thus DN transmissions does not block SRD transmission.

DN transmission could however interfere with SRDs reception, just like any other SRD device, it depends on the pointing of SRD's directional antenna (worst case directly towards window).

CDF of SINR shows healthy levels at SRD receiver, assuming its AP transmitting at EIRP = 40 dBm.

Duty cycle of DN to CN communication (6 to 12 %) would reduce the interference further.

8.3 Outdoor to indoor penetration with CN to DN

In the second scenario the CN node is transmitting to the DN node and it is the source of interference with its antenna front to back radiation to an indoor SRD located in a room of a flat in a multi-dwelling unit.

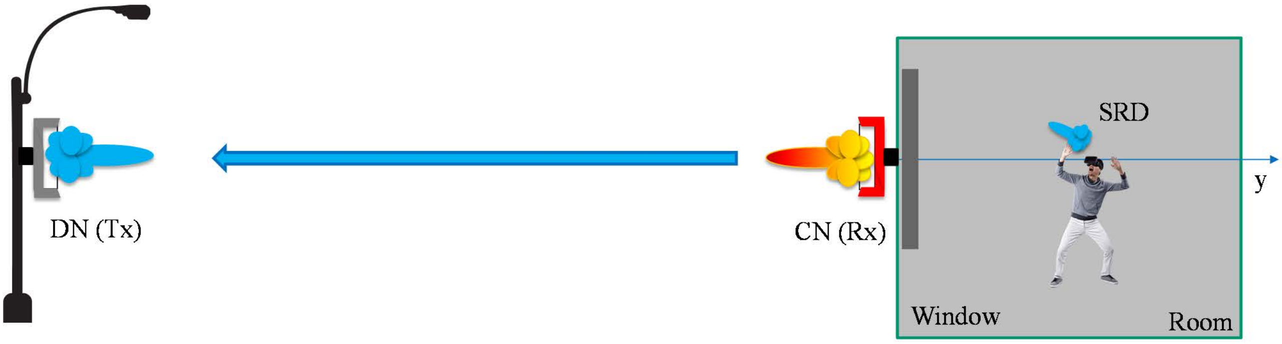


Figure 36: Client Node (CN) to Distribution Node (DN) transmission case

The maximum interference level at indoor SRD is evaluated according to equation (2):

$$\max\{I\} < EIRP - B - L(y) - R + G\_srd < \mathbf{-81{,}6\ dBm} \qquad (2)$$

Where:

- EIRP: 40 dBm.
- B: front-to-back BF ratio plus box isolation of CN, e.g. 50 dB conservative.
- G_srd(α): front-to-back BF ratio plus box isolation of SRD (AP or STA), worst case G_srd(0) = 0 dBi.
- L: Free space propagation loss (delta between CN and SRD), L(1 m) = 68 dB.
- R: In building penetration loss (worst case 3,6 dB when interferer perpendicular to single pane glass, safety glass 12 dB).
- I: input referred interference signal level at victim SRD antenna.

The CCA threshold levels of the indoor SRD are:

- ED = -48 dBm.
- PD = -68 dBm.

Interference level below CCA thresholds has no impact to channel access for SRD devices.

The simulations results are shown in Figure 37 and Figure 38.

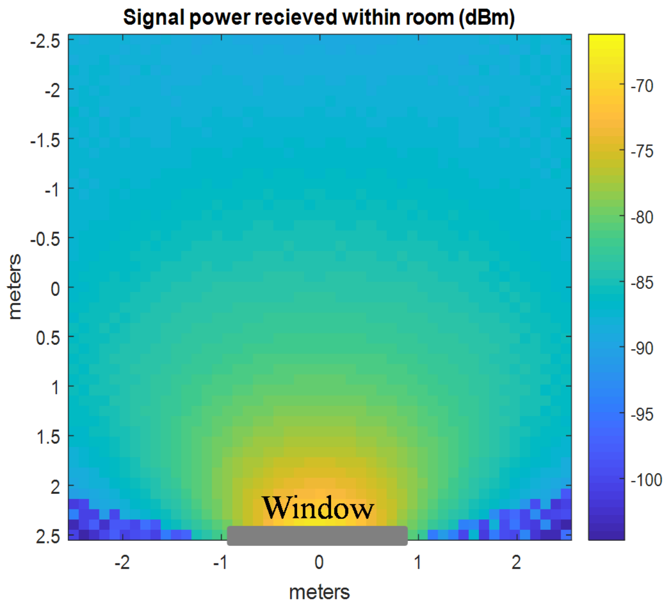


Figure 37: Interference power level within the room

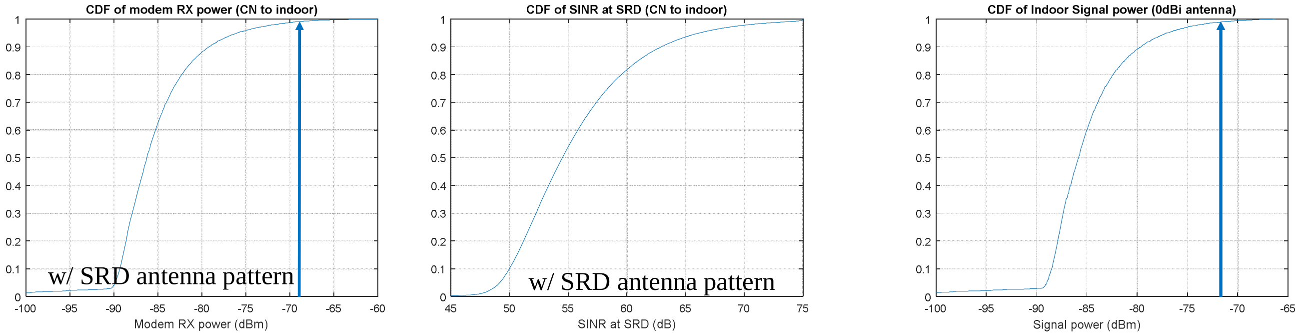


Figure 38: Antenna pattern, CDF of interference power level and CDF of the SINR of the indoor SRD

SRD CCA (-68 dBm) is not triggered except when SRD is few centimetres directly behind the CN and SRD is pointing to CN. This condition happens with Probability ($P_{RX} \geq P_{th}$) < 0,1 %.

When the SRD is pointing away from the window no CCA trigger occurs.

CDF shows healthy levels at SRD receiver, assuming its AP transmitting at EIRP = 40 dBm. This occurs even without considering the duty cycle of DN to CN communication (6 to 12 %).

8.4 Outdoor to indoor penetration with CN to DN summary

The interference on Short Range Devices (SRDs) resulting from outdoor to indoor penetration of the Distribution Network transmissions has been analysed. Simple but aggressive scenario of CN STA outside an MDU room, installed on the glass, relatively small loss through the window has been considered.

Results confirm that IEEE 802.11ay [i.1] and IEEE 802.11ad [i.3] distribution network STAs do not harm indoor operation (Table 13).

Table 13: Interference on indoor SRD results

Scenario	CCA trigger (PD @ -68 dBm)	Minimum SINR available to SRD [dB]
DN => CN transmission	Never	45
CN => DN transmission	< 0,1 % (SRD stuck to window, pointing **outside (not realistic)**)	45

9 Network Analysis

Simulations regarding network traffic capacity (i.e. aggregate Goodput, Figure 39) and End-to-End (network) delay (Figure 40) have been carried out on based on the Washington setup reported in Figure 3 and in case of use of single channel.

The 1,65 Gbps achieved by MCS 8 for a single link results in a maximum network Goodput of approximately 6,6 Gbps since there are four wireless links to the three fibre access locations.

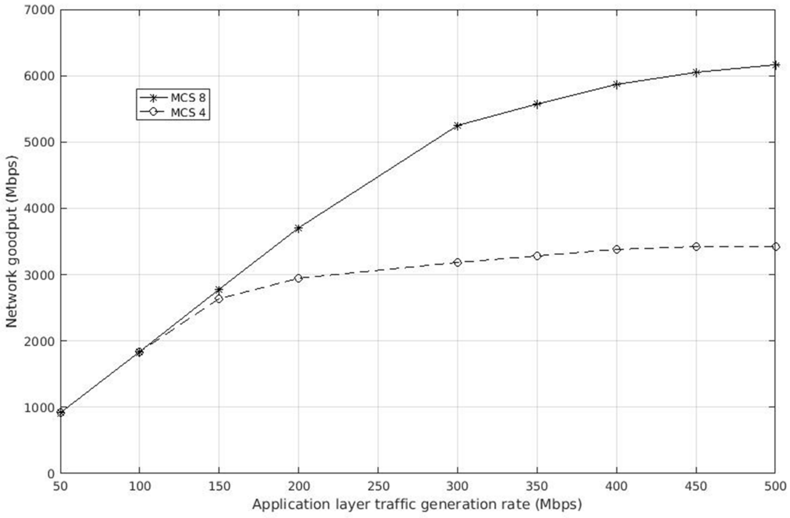


Figure 39: Overall network (aggregate) Goodput

NOTE 1: Goodput is defined as the rate of successful delivery of information [bit/s] arriving at the medium access control (MAC) layer access point (AP) of a certain station (see clause 5.1.2).

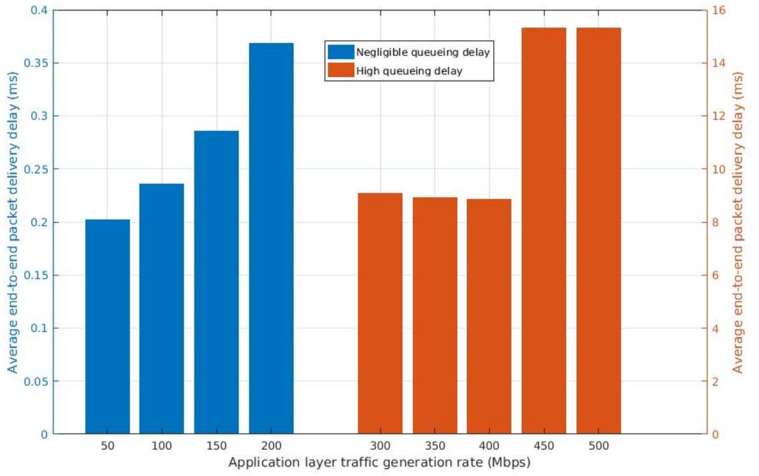


Figure 40: End-to-End Delivery Delay

NOTE 2: The blue and orange bars correspond to the left and right y axis, respectively.

The value of the traffic generation rate indicates the value of each of the uplink and downlink traffic arrival rates at the node.

For example, when the rate is set to 200 Mbps, the uplink traffic generated at each AP is 200 Mbps, and the downlink traffic generated at the fibre for each AP is also 200 Mbps.

Thus, in a three-hop set (i.e. such as in fibre point 1, connecting APs 2, 3, and 4 in Figure 3), the aggregate generated traffic results in 1,2 Gbps. When the rate/link increases to 300 Mbps, the total traffic generated is 1,8 Gbps, exceeding the maximum Goodput that can be achieved by the last-hop link (between nodes 01 and 04) to the fibre using MCS 8. Hence, the delay increases significantly when the traffic arrival rate increases from 200 Mbps to 300 Mbps.

For a low traffic arrival rate (up to 200 Mbps), the MAC layer queue of an AP is stable, resulting in a low average value of the end-to-end packet delivery delay. When the traffic arrival rate increases, the queuing delay at each AP increases accordingly, resulting in a significant increase in the average end-to-end packet delivery delay.

10 Listen Before Talk

10.1 Overview

To allow a fair access and for an efficient use of an unlicensed spectrum as V-Band, a mechanism like Listen Before Talk (LBT) is required to mitigate the interference between network stations.

NOTE: See CEPT ECC Recommendation. 70-03 [i.9], Annex 3: Adequate spectrum sharing mechanism (e.g. Listen-before-Talk, Detect-And-Avoid) and ETSI EN 302 567 [i.10], clause 4.2.5.3.

An alternative graphical formulation of the LBT algorithm is also reported in Figure 41.

The objective of the reported simulations is to check the network capacity variation in the case LBT is not used and when it is enabled by using different energy detection thresholds for a sensitivity analysis.

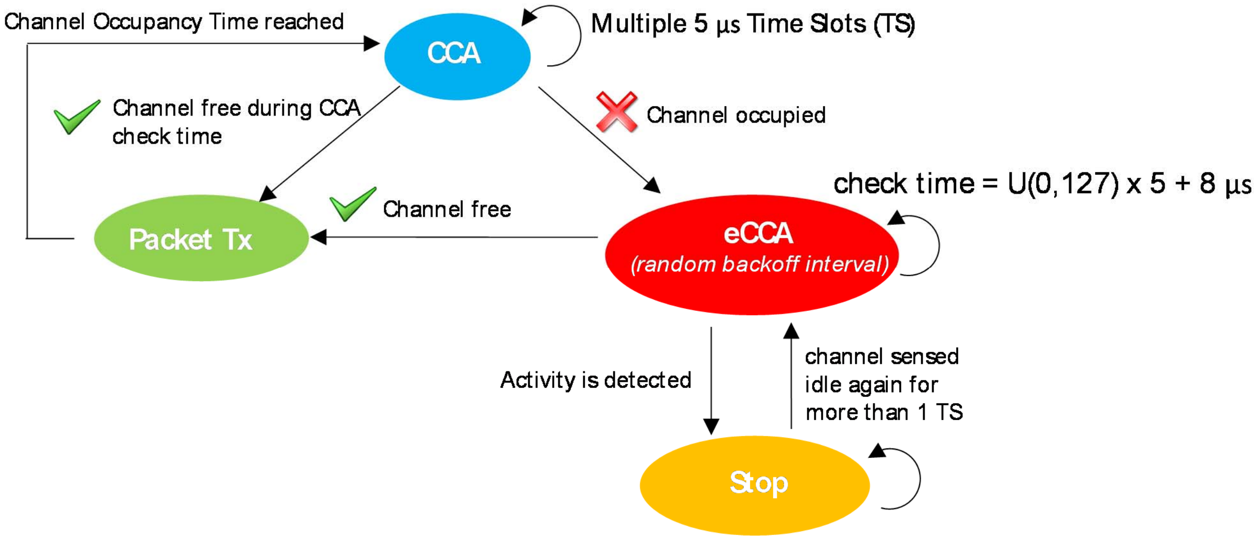


Figure 41: LBT graphical formulation

10.2 System model

The considered system model consists of an area 30 m wide and 100 m long, where for each simulation trial a wanted link is placed and variable number (U) of interferer links are also placed in a random way (U=1, 2, 4 and 8).

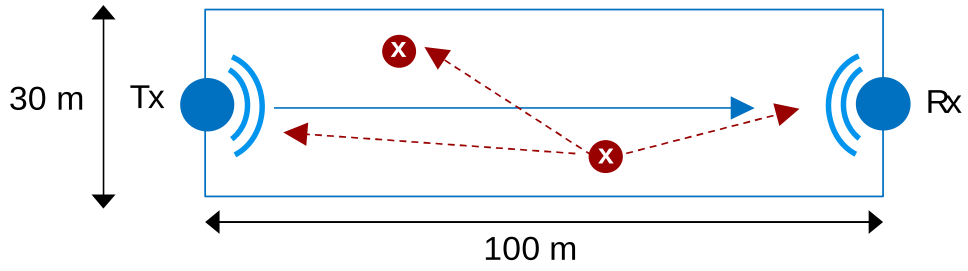


Figure 42: System model (the wanted link in blue; the interference links in red)

The wanted link is modelled as a FWA system operating with a narrow bandwidth antenna (HPBW = 3,16°). Instead the interferer link(s) is (are) modelled as wide bandwidth antenna access point(s) (HPBW = 10,2°).

All transmitters are in full buffer mode and the LBT Channel occupancy Time is 9 ms (maximum value allowed by ETSI EN 302 567 [i.10]).

The CCA and eCCA, the two types of back off interval, whose last is based on basic 5 µs time slot (TS).

The common system model parameters are reported in Table 14.

Table 14: System model common parameters

Parameters	Value
EIRP	40 dBm
Carrier frequency	60 GHz
Noise power	-76 dBm
Bandwidth	1 000 MHz. See note 1
Modulation max spectrum efficiency	7 bit/s/Hz. See note 2
Path loss model	Free space loss + Gas absorption
NOTE 1: Roughly one half of the basic IEEE 802.11ad [i.3] channel bandwidth (i.e. 2 160 MHz) was considered only to reduce the simulation computational resources and to speed up the overall simulation time. NOTE 2: 128-QAM equivalent.	

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 not enabled
- LBT enabled with energy detection threshold = -7 dBm
- LBT enabled with energy detection threshold = -27 dBm
- LBT enabled with energy detection threshold = -47 dBm
- LBT enabled with energy detection threshold = -67 dBm

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

10.3 Simulation results

The simulation results are provided as plots of the probability that the average capacity is greater or equal of the value in abscissa (i.e. Probability (Avg. Capacity $\geq$ x)) over different Monte Carlo trials including both different positions and time slots.

NOTE: The capacity is averaged in 40 ms of integration time.

The four graphs (Figure 43) below represents the probability to reach or overcome the capacity value on the x-axis in four network configurations (i.e. with 1, 2, 4 or 8 interferer links) and accordingly with the LBT algorithm configurations stated in clause 10.2.

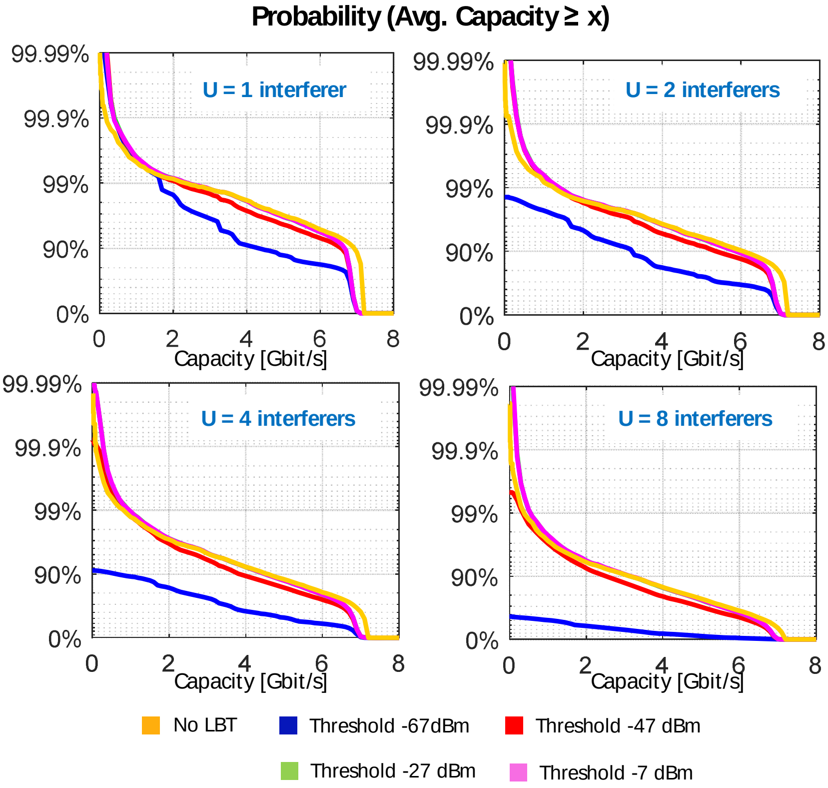


Figure 43: Simulation results

The probability slopes have more or less the same trend in the case of LBT disabled and when LBT is enabled with energy detection thresholds up to -47 dBm (i.e. the value proposed in ETSI EN 302 567 [i.10]). Thus, the average capacity is similar both with or without LBT.

Despite only when the LBT energy detection is very low, in our simulation -67 dBm has been tested, the capacity drops quickly with the increase of the number of the interferer links.

Annex A:
Network simulation parameters

A.1 Parameter definition

To perform the Network Simulations the parameters, derived from IEEE 802.11ad standard [i.3], hereafter defined were considered.

Goodput is defined as the rate of successful delivery of information [bit/s] arriving at the medium access control (MAC) layer access point (AP) of a certain station.

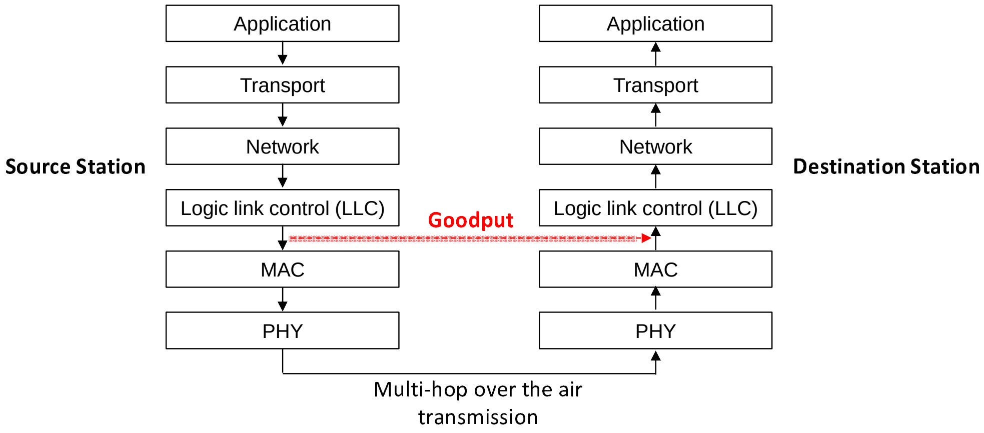


Figure A.1: Goodput application layer

End-to-End Delivery Delay is the duration from the time that a packet arrives at the MAC layer of the source station to the time that it is delivered to the MAC layer of the destination station.

A.2 Simulation assumptions

For the Goodput evaluation the following assumptions were taken:

- No transmission collision happens.
- No channel error happens.
- No re-transmission.
- No transmit or receive training field (TRN-T/R) is added to any MPDU (MAC layer protocol data unit).
- The channel idle time that may exist at the end of a DTI is neglected.
- The current simulation results are based on the scheduling scheme of the IEEE 802.11ad [i.3].

For the MAC (Media Access Control) Layer simulation the following assumptions were taken:

- IEEE 802.11ad standard based [i.3].
- Time is partitioned into beacon intervals (BI):
  - Beacon transmission interval (BTI).
  - Association beam-forming training (A-BFT).
  - Data transfer interval (DTI).

- The DTI of each AP is partitioned into equal-duration service periods (SPs) separated by guard intervals.
- A contention-based access period (CBAP) is not included in every beacon interval. In the simulations, it is included every 100 beacon intervals.
- Each SP is divided into two equal-duration periods for uplink and downlink transmissions (i.e. for transmission of data from/to an AP to/from the optical fibre access).

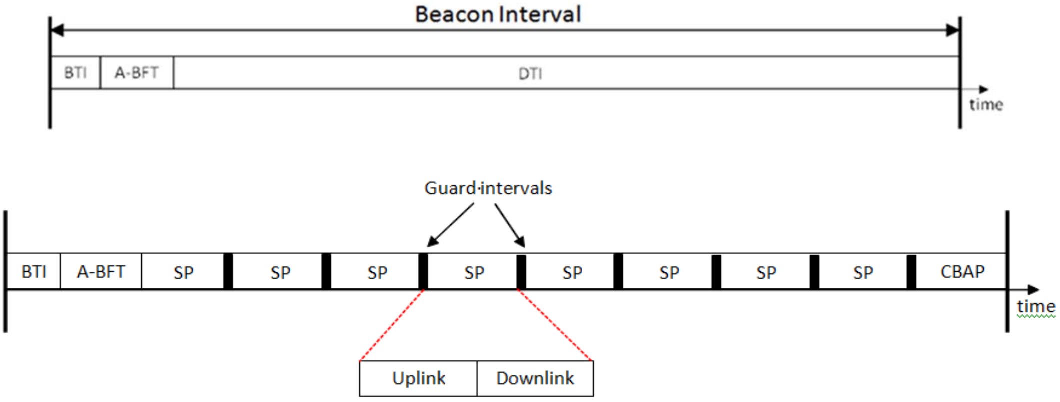
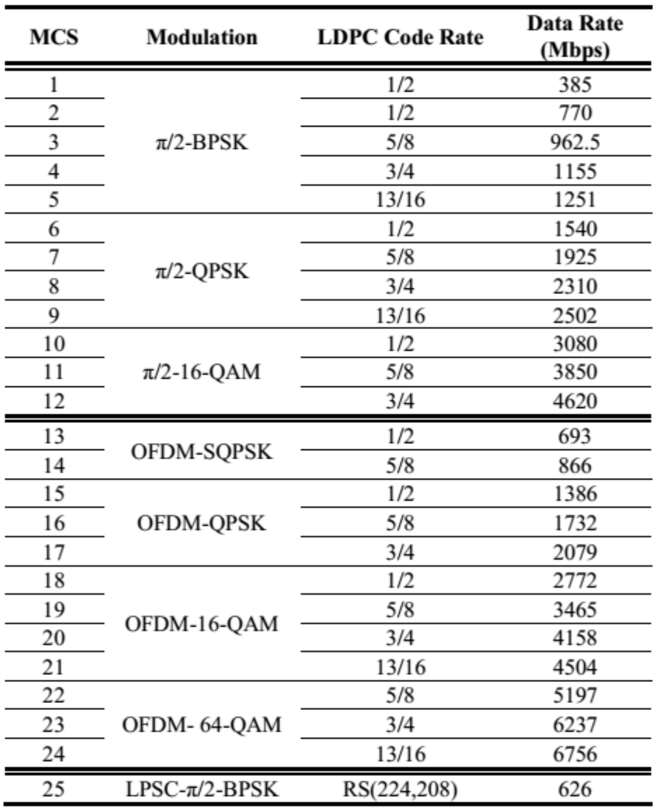


Figure A.2: Beacon interval and service period

Table A.1 and Figure A.3 show receiver sensitivity values and MCS from IEEE 802.11ad standard [i.3].

Table A.1: IEEE 802.11ad extract [i.3]

MCS	Receive sensitivity (dBm) (As per table 20-3 of IEEE 802.11-2016 [i.3])	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



MCS	Modulation	LDPC Code Rate	Data Rate (Mbps)
1	π/2-BPSK	1/2	385
2		1/2	770
3		5/8	962.5
4		3/4	1155
5		13/16	1251
6	π/2-QPSK	1/2	1540
7		5/8	1925
8		3/4	2310
9		13/16	2502
10	π/2-16-QAM	1/2	3080
11		5/8	3850
12		3/4	4620
13	OFDM-SQPSK	1/2	693
14		5/8	866
15	OFDM-QPSK	1/2	1386
16		5/8	1732
17		3/4	2079
18	OFDM-16-QAM	1/2	2772
19		5/8	3465
20		3/4	4158
21		13/16	4504
22	OFDM- 64-QAM	5/8	5197
23		3/4	6237
24		13/16	6756
25	LPSC-π/2-BPSK	RS(224,208)	626

Figure A.3: MCS, Code Rate and Data Rate [i.4]

Simulation of BER vs SINR are shown in Figure A.4.

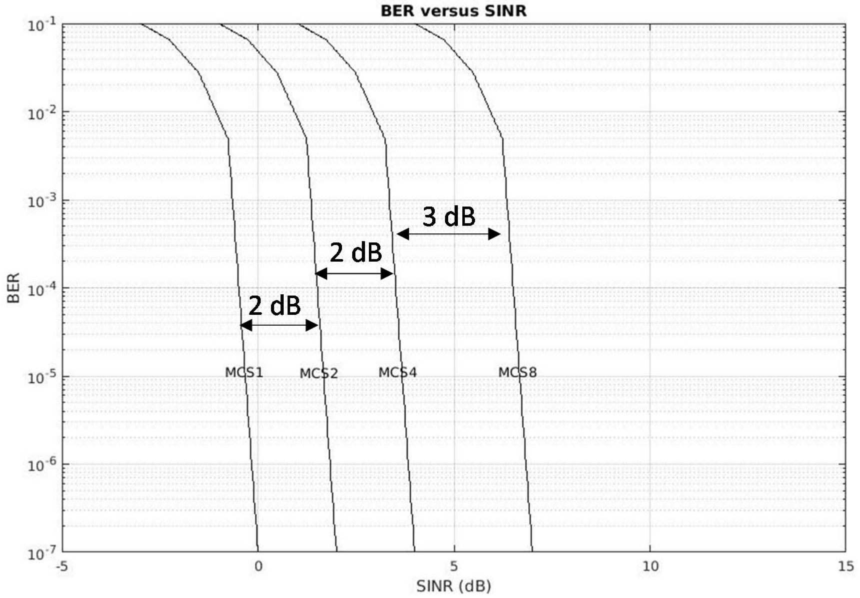


Figure A.4: BER vs SINR

Annex B: mmWV FWA

B.1 Overview

The Digital Agenda for Europe aims to facilitate the Gigabit connectivity for all the main socio-economic drivers, including access to connectivity offering at least 100 Mbps for all European households [i.11].

In this context 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 optimization (technology-assisted) and re-uses mobile and fixed infrastructure already present on rooftops and street poles.

Various scenarios are possible: Urban, Suburban and Clustered Rural. Due to the reduced achievable link lengths, V-Band seems not appropriate for rural cases.

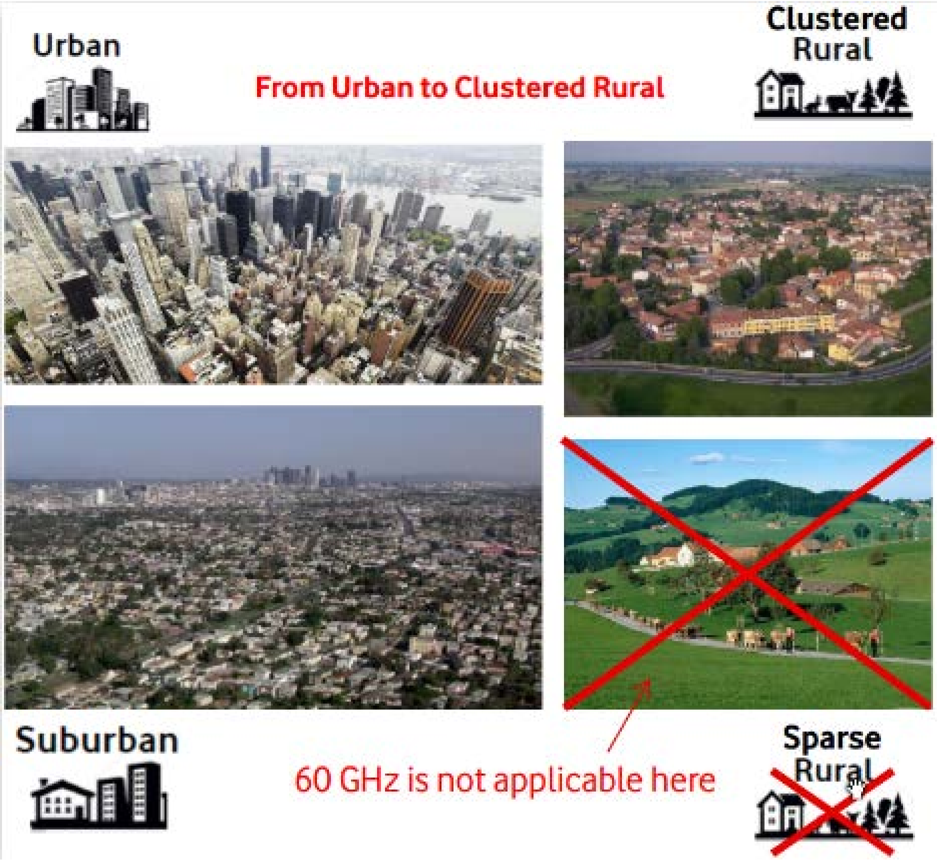


Figure B.1: Applicable scenarios

Possible deployment cases of urban and suburban scenarios are reported in Figure B.2.

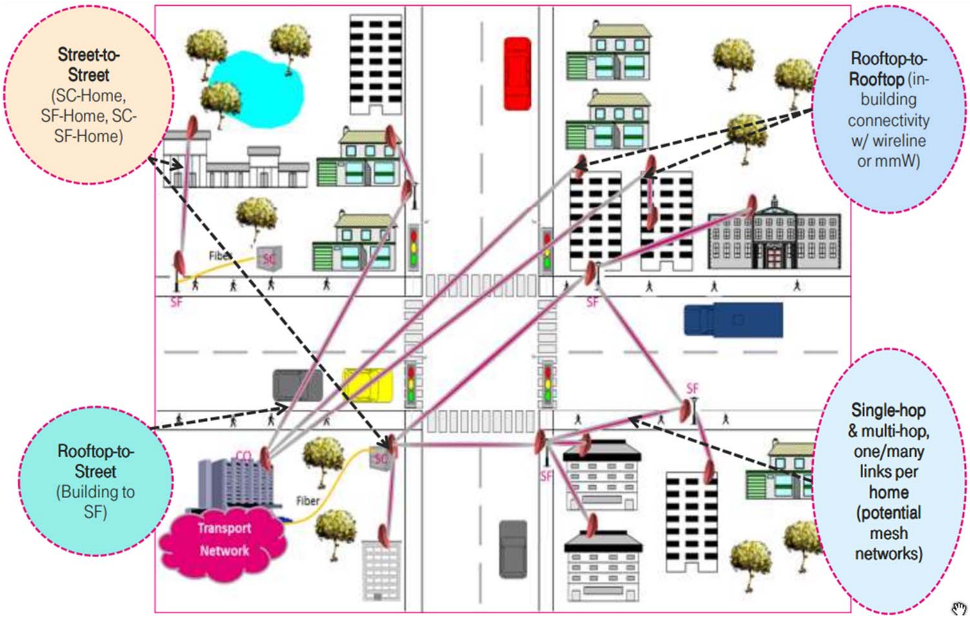


Figure B.2: FWA urban deployment

Annex C:
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